Basic Facts Report on Design for Plastic Packaging Recyclability

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Contents

1. Introduction by GPN

While a circular economy with high recycling rates is an important goal, the environmental performance of packaging solutions always depends on the entire value chain. The most important function of packaging is to secure that the product reaches its intended use. The efforts to reduce food waste show how the product gives packaging leverage on the overall environmental performance.

At the same time, sustainability and EU's strategies demand transitions towards circular material flows. Product and packaging development should follow a two-step, iterative process. First, the sustainability of the entire packaging solution must be investigated using life cycle thinking. Second, the recyclability and circularity of the packaging must be investigated, and possible improvements identified. Then back to step one to evaluate if the packaging can be made more recyclable without weakening its primary function.

FTI AB and Grønt Punkt Norge AS (GPN) are the leading producer responsible organisations (PROs) in Sweden and Norway. We work to support and develop circular value chains. The EU proposed very ambitious goals for recycling of packaging in December 2015, and the revised framework directive on waste and the packaging directive is expected to be finalised during first half year of 2018. With higher recycling goals, addressing the low recyclability of plastics is key to finding efficient solutions to the task at hand. Design for recyclability is therefore a good investment for industry and the environment, a win-win. In many cases, small adjustments can have a big impact on sorting and recycling.

With this on design for plastic packaging recyclability, we hope to offer knowledge and inspiration to everyone involved in plastic packaging design. The report aims to bring knowledge about the sorting and recycling industry into the design process. The content will be condensed into design for recyclability guides, and companies will be invited to join project groups that take on specific challenges and possibilities related to plastic packaging recyclability.

Mepex Consult has written this baseline document as an objective analysis based on the best available knowledge today from many different sources.

Good luck!

2. Scope and Rationale

2.1 Introduction

Green Dot Norway and Förpacknings- och Tidningsinnsamlingen (FTI) in Sweden have in cooperation developed a set of guidelines that present recommendations and solutions to produce plastic packaging that is ultimately based on achieving increased material recycling. There is a great need to better understand what happens to plastic packaging after collection when it is sorted and recycled. This kind of knowledge is vital when designing plastic packaging to be sortable and recyclable in practice.

There are many functional requirements for plastic packaging that can be conflicting when attempting to increase recyclability. These requirements must be fully understood and evaluated up against one another. Such requirements include for instance that plastic packaging shall protect the product, and maintain its quality and life time. Packaging can in this way contribute to preventing and reducing food waste. Furthermore, the packaging shall provide information to the consumer, contribute to effective logistics, have a low weight, and thus contribute to an efficient use of resources.

An objective analysis on factual data from each step in the value chain has been emphasized in these guidelines. Clear recommendations are given where it has been possible, and in areas where there is more than one correct solution, options have been given.

The guidelines are based on existing sorting and recycling technologies for Norwegian and Swedish plastic packaging products. It is important to highlight that the existing market and technology is dynamic. It is therefore crucial that this guide be regularly updated.

2.2 Building on International Knowledge

Existing international guidelines on the design of plastic packaging have been a useful basis for the development of these guidelines. Different guidelines can give varying recommendations so it has been necessary to thoroughly review the underlying assumptions for each recommendation. Specific Norwegian and Swedish circumstances in terms of packaging usage and waste solutions have been emphasized in this process.

2.3 Plastic materials in packaging products

These guidelines include plastic packaging products. But what is plastic? Plastics are mainly synthetic polymer materials; a large material family with many usage areas. Roughly 330 million tons of plastic were produced in total worldwide in 2016, and the production continues to grow. In Europe, plastic packaging constitutes ca. 40 % of all plastic production, ca. 63 % of all plastic waste, and ca. 83 % of all plastic that is recycled. Roughly 50 % of the plastic material in Europe that is recycled, is recycled in the far East.

Plastic consists of molecular chains with different molecular weights. Biological resources are used in the production of plastic material, however, oil and the gas are the most common resources. Biobased and biodegradable plastics are discussed in section 0

In comparison, the production capacity for biobased and biodegradable plastics is expected to be ca. 6 million tons, where biobased plastics constitute 5 million tons.

The most important types of plastics used for packaging products are LDPE, HDPE, PP, PET and PS (see list of types of plastics in Chapter 7.1. These plastics are called thermoplastics and can be recycled, i.e. they can be melted and moulded into different shapes.

Plastics contain various additives to give the material desired properties. Additives can for instance give the plastic an oxygen barrier which protects the content of the packaging product. Different types of plastics can be mixed, and fillers can also be added to the material. Multimaterial packaging products are however not ideal in terms of material recycling, and monomaterials should be promoted. Additives and barrier materials are further explained in Chapter 4.

There are strict EU regulations on plastic materials used for food contact.[1] This also applies to plastics that are recycled from waste to new products.

2.4 Packaging products for Consumer products

These guidelines include plastic packaging used for consumer products common for Norwegian and Swedish households. The main product area is groceries including foods, but shall also be universal for other industries that often have less complicated demands for their packaging. Packaging used for transportation has been disregarded.

2.5 Guidelines for Film and Rigid Plastic Packaging.

There is a great deal of knowledge about the building blocks of plastic packaging materials in Norway and Sweden and their recyclability:

- Roughly 50 % of plastic packaging waste from households is plastic film, mainly in the form of polyethylene film (LDPE), well suited for material recycling. A large part of the film consists however of several barrier layers; laminated plastics.
- The other half consists of rigid plastic packaging made of various polymers, chiefly PP, PET, HDPE and PS. Rigid plastics that consist of these materials are normally suited for recycling. Different types of trays and cups, e.g. PET, are included as rigid packaging (albeit these products being thermoformed film).

2.6 Recycling and Sorting Technology

In the Nordic countries plastic packaging waste is collected from households, either separately in its own container/bag or as in some places in Norway together with the general waste. This collected plastic packaging waste is dependent on automatic sorting technology to sort the plastic into its different fractions, achieving high quality material recycling and reducing significant loss of usage areas. Plastics packaging is primarily sorted at large facilities in Germany and Sweden. In some places, material recovery facilities (MRFs) for municipal waste have been established. These facilities can separate plastics from municipal waste. Several municipal companies are planning such plants in Norway.

An understanding of the options and limitations in the MRFs and their associated technology is crucial when conveying knowledge of plastic packaging in the value chain. In areas where recyclable materials are separated from the general waste stream at the start, the recyclable materials are sent to material recovery facilities (MRFs).

2.7 A Market for Recycling

The recycling industry for plastic packaging in Europe is still in its early stages. The market has thus far consisted of small and medium sized sorting facilities. Many of these facilities were built for collected plastic waste of high quality, e.g. LDPE film and PET bottles, with simple washing and separation processes. Technical improvements in this industry are crucial for handling plastic waste of varying quality and complexity, and for producing high quality raw plastic material. There are various types of qualities of the recycled raw plastic material where some are more valuable than others. Over time it is natural that this will change. Better packaging design is part of this solution.

[1] https://ec.europa.eu/food/safety/chemical_safety/food_contact_materials/legislation_en

2.8 Steps of Recyclability

The recommendations given in these guidelines are based on the principle that plastic materials should for all purposes be recycled into the same materials for the same purpose, or for other applications and/or products. This way the quality of the material is maintained, as is its market value and usage areas. The plastic material can therefore be recycled multiple times. This will contribute to higher value recycling in the future.

Recycling of plastic packaging that contains several different plastic materials, colour pigments and/or barrier materials represents a down-grade of the material, and thus normally also the value which will limit the usage areas. Plastics of high quality are rewarded with higher prices on the market and are easier to distribute.

3 User Guide

3.1 Definitions

A list of the most important types of plastics, relevant definitions and an explanation of abbreviations used in the guidelines, can be found in the appendix.

3.2 Structure and Usage

Recommendations and universal information for all types of plastics have been gathered in a separate section, Chapter 4, while specific information tailored to different plastic materials are gathered in other subchapters; Chapter 5 for packaging film and Chapter 6 for rigid and thermoformed packaging

In this report green text boxes are presented at the start of each subchapter to summarise the take-home messages of that chapter. The rationale for each of these messages is further explained in the same chapter or in the appendix with references listed accordingly.

3.3 Relevance

The recommendations in these guidelines are based on a range of external sources that have been analysed and evaluated against one another. Independent evaluations were made based on the collected material from external sources and were consulted with experts within plastic recycling.

The guidelines were sent to external review with a range of experts in the field of plastic packaging production and plastic recycling.

FTI (Sweden) and Green Dot Norway are planning to develop popular version of this report to present and deliver to their members. These guidelines will require regular updates as the market and technology develops and new knowledge is readily available.

The guidelines comprise several aspects related to different types of materials. It is important to underline that there is no one best solution or packaging material for all kinds of needs. Each material has its strengths and weaknesses. The chart below illustrates the different properties for some of the common polymers.[2]

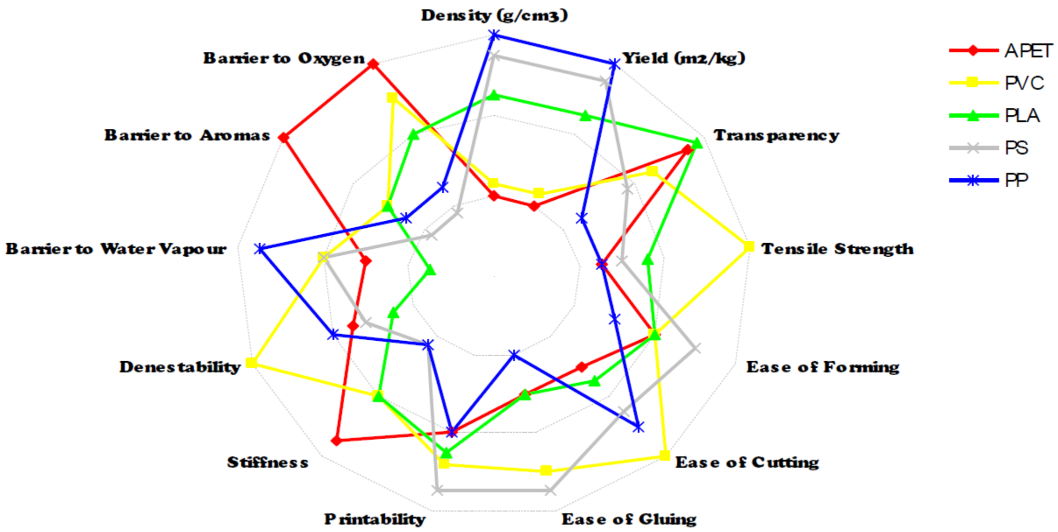

Figure 1 – Technical considerations for polymer selection (RECOUP).

[2] Recoup presentation by Stuart Foster on "Future trends in plastic packaging, Cape Town 2013

4. General Guidelines

4.1 Additives

SUMMARY – ADDITIVES
Additives are used in packaging products to achieve various desired properties. The primary function of packaging is to contain, protect and identify the product. However, the choices made at the design stage will influence what happens in the sorting and recycling processes and the quality of the new raw material. It is thus important that a thorough evaluation of available alternative solutions to additives should be considered for different types of plastic packaging. Such evaluations must be based on thorough knowledge, including understanding of relevant sorting and recycling technologies used. Calcium carbonate is a common additive in many types of plastic. This heavy material will quickly alter the density of the packaging and thus influence the separation process. Material with such fillers can therefore be sorted out by the washing and not recycled. Alternatively, when not sorted out, these fillers can harm recycling and the properties of the recycled material.

Additives are substances that are added to plastic products by polymerization or modification processes to obtain specific the product properties. These processes alter the plastic compound by giving it specific characteristics. Additives are also useful for lowering the transition temperature of a polymer, or by making a product cheaper with the use of fillers. The table below shows a brief list of examples of additives.

Additives	Function
Anti-Counterfeiting	Combating counterfeiting. Optical brighteners are an example of this type of additive.
Antimicrobials/Biostabilisers	Help prevent deterioration of plastic materials.
Antioxidants	Help prevent 'oxidation' (a reaction between the polymer and oxygen)
Antistatic Agents	Help prevent build-up of static electric charge
External Lubricants	Help prevent damage to plastics or the mould during processing
Fillers/Extenders	Natural substance used to improve strength and lower cost of the material. Usually mineral-based
Fragrances	Fragrances and deodorants used in a variety of applications
Heat stabilisers	To prevent decomposition of the polymer during processing.
Impact Modifiers	Enables plastic products to absorb shocks and resist impact without cracking.
Internal Lubricants	Used to improve processability of plastics by increasing the flowability
Light Stabilisers	Used to inhibit the reactions in plastics, which cause undesirable chemical degradation from exposure to UV light.
Pigments	Tiny particles used to create a particular colour
Plasticisers	Used to make plastics softer and more flexible
Process Aids	Used to improve processability of plastics by increasing the flowability.
Reinforcements	Used to reinforce or improve tensile strength, flexural strength and stiffness of the material. Often fibre-based.

Table 1 – List of additives and their functions.[3]

[3] http://www.bpf.co.uk/plastipedia/additives/default.aspx

The EU Commission states[4]:

There are hundreds of additives in the EU market, and their presence in the plastics can vary largely, from a few percentages and up to 50-60 %. Some of them are sought after in recycling, as they are much needed in the recycled product (e.g. stabilizers, hardeners, plasticizers, structural fillers). Some of them may have no function in the recycled product (UV absorbers, flame-retardants) or need correction measures (odor, color).

The homogeneity of the packaging product is most important when it comes to recycling; however, additives provide extra protection for the product inside the packaging, giving it protection and, if a barrier material is added, a longer shelf life.[5] Compatibilizers are relevant additives in order to enhance recycling of different polymer blends.[6]

Plastic products and plastic waste contains different additives to obtain the wanted properties of the products. The EU Commissions elaborates in brief on the issue of additives and hazardous substances in plastic waste[7]:

Most additives of the original waste plastic, except e.g. lubricants or catalysts, are <u>not</u> consumed, altered or degraded during the melting process of mechanical recycling (much unlike glass or metal recycling), so these are kept and found in the pellets. The recycling of additives is well identified. Currently, only very few problem substances used in/as additives have been identified as bearing environmental and/or health risk, notably:

- *Bisphenol A (curing agent in polycarbonate and epoxy resins)*
- *Low molecular weight phthalates (plasticizers): DEHP, BBP, DBD, DIBP, but not high molecular weight ones such as DINP and DIDP.*
- *Halogenated flame retardants*
- *Toxic heavy metals (colorants and stabilizers): Cadmium, Chromium6, Lead and Mercury.*

Some of these substances have been voluntarily phased out by the industry, and they are present as legacy but are not being re-introduced in the plastic cycles through virgin plastics. The presence of these substances in waste is currently handled via specific legislation, essentially WEEE and ROHS, and to a certain extent REACH (e.g. Annex XVII on restriction of uses of recycled material). The presence of these substances in plastic products is handled by REACH (and CLP for labeling), the POPs Regulation, and specific food contact legislation for this type of use. Should these substances be present, REACH is to ensure the provision of environment and health information through the supply chain.

4.1.1 Calcium Carbonate ($CaCO_3$) and other fillers

Fillers are often used in conjunction with plastic packaging products to reduce the amount of plastics in a product, thereby reducing costs and partly to improve the properties of the plastic. Calcium carbonate is used as a functional filler, and is one of the most important fillers that is used today.[8]

Calcium carbonate will not influence the melting point of the plastic packaging product; however, it will heavily influence the density – an important property for the sorting process. This can cause problems in when materials that should float, end up sinking because their density has changed.[9] There are PS, PP and HDPE products on the market that have a content of $CaCO_3$ of up to 50 %. The density of $CaCO_3$ is 2.71

[4] European Commission, DG Joint Research Centre, mail correspondence to all EoW stakeholders by A. Villanueva, 11.05.11
[5] Comment from participant at workshop
[6] http://www.dupont.com/products-and-services/additives-modifiers/polymer-additives/articles/polymer-compatibilizer-for-recycling.html
[7] European Commission, DG Joint Research Centre, mail correspondence to all EoW stakeholders by A. Villanueva, 11.05.11
[8] Martina Lehmann, MAKSC
[9] Martina Lehmann, MAKSC, Antonio Furfari

g/ccm, which means that small amounts can change the packaging's density substantially. To split these fractions from the plastic stream, they require a density of less than 0,995 g/ccm or 1,07 g/ccm.[10] If the density is above this level, it will be lost in the sorting process to the residual waste fraction.[11] High levels of $CaCO_3$ can also alter the viscosity of the plastic, in addition to its transparency and crystallisation properties.[12]

It is possible to identify $CaCO_3$ with the NIR detector and it is possible to separate plastic packaging products with different amounts of $CaCO_3$ in them.[13] However, when multiple types of products that contain $CaCO_3$ are mixed together it is impossible to know the fraction of $CaCO_3$ in this fraction, even though the plastic material is the same. This makes it difficult to recycle because there could be changes in viscosity because of the $CaCO_3$ content.

Nanofillers such as nanoclays, hydroalcite and montmorillonite are the fastest growing market of plastic fillers and their use is expected to increase in the future.[14]

In summary, the use of additives/fillers such as calcium carbonate, talc, etc. in concentrations that alter the density such that they cause for example the HDPE plastic to sink in water or alter the properties of the regrind are undesirable and should be avoided.[15]

4.2. Barrier Materials

SUMMARY – BARRIERS
Barrier materials are used in packaging products to achieve various desired barrier properties. The primary function of packaging is to contain, protect and identify the product. However, the choices made at the design stage will influence what happens in the sorting and recycling processes and the quality of the new raw material. It is thus important that a thorough evaluation of available alternative solutions to barrier materials should be considered for different types of plastic packaging. Such evaluations must be based on thorough knowledge, including understanding of relevant sorting and recycling technologies used. Variations of the barrier materials polyamide (PA) and PVdC should be avoided as they can drastically reduce the quality of the recycled plastic material and can create problems in the recycling process. NIR technology can, to a certain degree, identify multilayer materials that cannot be recycled and reduce the fraction that enters this product stream. EVOH is an effective barrier material against oxygen, but it also creates some challenges in the recycling process. Additives that will make EVOH more compatible in the recycling process of LDPE and PP-film are under development. PET has, in some cases, good barrier properties. By using this material for packaging products, the use of other less ideal barrier alternatives, can be reduced. The downside to the use of PET trays is that very few of these are recycled today as there are technical and marketing challenges tied to the recycling of all types of PET, except for PET bottles. By better design, the intention is to make PET packaging more recyclable. In parallel, of course, better sorting and recycling technologies can contribute positively too.

[10] Thomas Etien, Danone
[11] Oliver Lambertz, Tomra, Paul East RECOUP
[12] Comment from participant at workshop
[13] Oliver Lambertz, Tomra
[14] http://www.marketsandmarkets.com/PressReleases/plastic-filler.asp
[15] RECOUP Recyclability by design

Barrier materials give the plastic specific barrier properties. This includes for instance barriers against UV radiation, oxygen and other gases. The most common barrier materials are EVOH (Ethylene vinyl alcohol), SiO_x coatings (silicon oxide), carbon-plasma coating, polyamide (PA), PTN alloys, UV stabilisers, AA blockers, optical brighteners and oxygen barriers. Various layers are added to give the product specific qualities - five layers are not uncommon in many packaging products.[16] It is difficult to reduce the amount of layers in some laminated trays and films if the barrier qualities are to be maintained.[17] The table below illustrates different barrier materials according to their permeation rates for water and oxygens.[18]

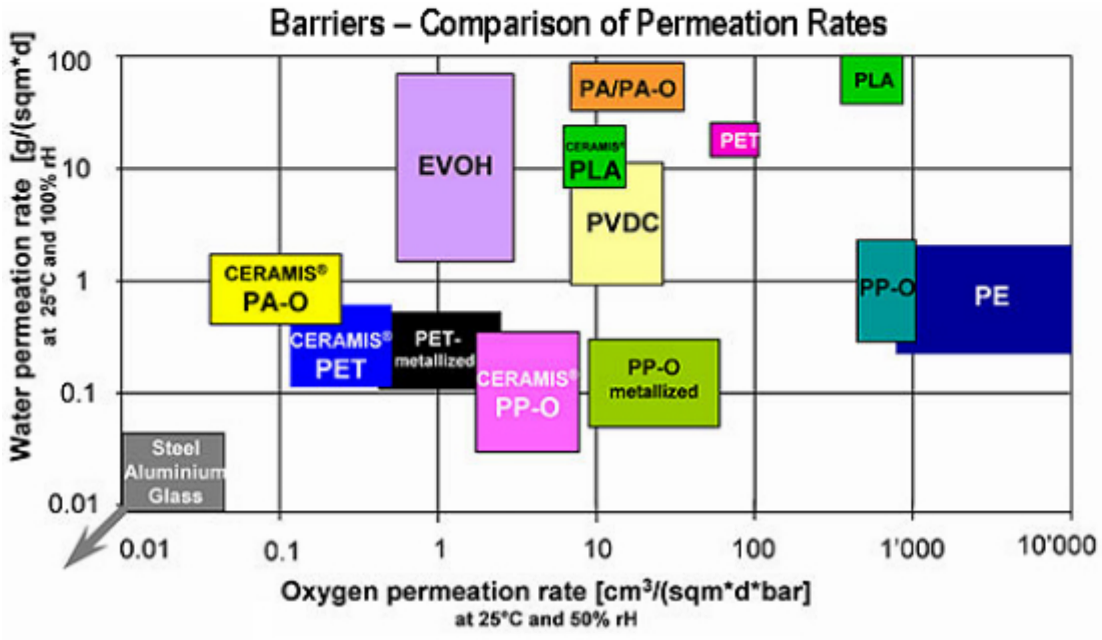

Figure 2 – Comparison of permeations rates for various barrier materials.

PVOH, EVOH, PVdC, silicone oxide and PETg are coatings that have been tested MRFs and were shown to have a negative impact on the recyclate. They were either dispersed into the recyclate or removed during the extrusion process as gases.[19] PVdC was shown to have a detrimental effect on the quality of the recycled material due to its thermal degradation below the temperatures required to melt the conventional polymer.[20] PVdC is therefore a highly discouraged additive to use in polymers.

Crisp packets present a difficult point of discussion because there are no right solutions for recycling. To maintain the lifetime of the content, an aluminium layer is required on the inside of as crisp packet. Aluminium will contaminate the recyclate if it is not separated from the waste stream. After separation, it will be incinerated. It is therefore recommended that the use of aluminium be minimised. However, it has to be acknowledged that today there are no other materials that provide a sufficient barrier that can be used for crisp packets and other similar types of packaging. However, new technologies, microwave induced pyrolysis,[21] might reduce or solve these problems in the future, e.g. remove the aluminium and recycle it.

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[16] Comment from participant at workshop
[17] Comment from participant at workshop
[18] Fraunhofer- Institut
[19] McKinlay, R. and Morrish, L. (2016). REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project. Axion Consulting.
[20] McKinlay, R. and Morrish, L. (2016). REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project. Axion Consulting.
[21] ENVAL technologies described in RECOUP Recyclability by design, page 64

4.2.1 EVOH

EVOH is a copolymer and is the dominating additive used in plastics packaging today, especially when it comes to barrier properties.[22] It gives good compatibility and is often used in combination with other additives.[23] It is used as a thin layer, normally 1-2 % of the total material, and gives a good oxygen barrier.[24] Although total quantities of EVOH used are small, it is used in a wide range of products. If PE were to have the same barrier qualities as a typical EVOH layer, the PE layer would have to be 6m thick.[25]

EVOH has a melting temperature of 165-185°C, but the temperature varies for different additives. This can cause problems in the recycling process if different materials melt at different temperatures.[26] If EVOH is the only additive in the packaging material, the recycling process is easier.[27] EVOH is very widespread in plastic packaging; however, there is evidence of a change towards the use of PET film to provide food protection.[28]

For PET bottles, EVOH is not recommended by EPBP as EVOH, above 500ppm, deteriorate the mechanical properties of the recycled material.

4.3.2 Polyamide/ Nylon (PA)

Many types of PA are used as barrier materials in plastic packaging products today.[29] PA itself is not a barrier material, but PA-O, orientated PA, is a good barrier.[30] The production of orientated PA happens by stretching the plastic in both directions giving it a crystalline structure.[31]

PA laminates have been tested in the recycling facility and found to be problematic. PA is a tough material that becomes fluffy when shredded. It also has a high melting temperature, 220°C, which means it will often create lumps in the recyclate if the melting temperature of other materials is lower.[32] These qualities make it difficult to extrude at levels with more than 5 % PA.[33] PA should particularly be avoided in combination with EVOH and LDPE because of the different melting temperatures.[34]

4.2.3 Sorting and recycling materials with barriers

Those barriers that cause the least harm to the recycled fraction are those that have a low melting point.[35] The material will then be sure to melt in the recycling process. There are many types of laminated film with different barrier qualities and many of these have a high recycling potential. However, the challenge today is that the individual amount of each type of laminated film is too small to be sorted and the recovery rate is negligible.[36]

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[22] Comment from participant at workshop
[23] Martina Lehmann, MAKSC
[24] Comment from participant at workshop
[25] Comment from participant at workshop
[26] Martina Lehmann, MAKSC, Antonino Furfari
[27] Comment from participant at workshop
[28] Comment from participant at workshop
[29] Martina Lehmann, MAKSC
[30] Comment from participant at workshop
[31] Comment from participant at workshop
[32] Comment from participant at workshop
[33] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.
[34] Martina Lehmann, MAKSC
[35] Oliver Lambertz, Tomra
[36] Oliver Lambertz, Tomra

PET/PE laminates produce an inhomogeneous mix in the recycling facility, resulting in a weaker strength and a more brittle structure than PP/PE. PET/PE laminates should therefore not enter the PE/PP mechanical recycling stream.[37]

Studies have shown that the presence of aluminium on a polyolefin (PO) recyclate causes a degree of weakening of the material, making it more brittle. This suggests that it is not suitable for mechanical recycling.[38]

4.3 Colours

SUMMARY – COLOURS
Plastic packaging can be transparent or all kinds of colours. Generally, packaging that is transparent is preferred because it has more potential to be recycled to a wide variety of applications, so the value of the recyclate is higher. The NIR detector can also sometimes have difficulties identifying products that are dark in colour. Coloured packaging with solid, dark colours will have fewer possible applications after it has been recycled. For PET in particular, there is a limited market for dark coloured recycled material. For polyolefins, colourants can in some cases have a negative impact on the recycling process and the granulates. Use of the pigment carbon black is problematic because the NIR technology cannot identify the material. Other available technology is currently evaluated as not relevant for this purpose. There is a clear recommendation that the pigment carbon black should be phased out as far as possible.

4.3.1 Colourful plastic packaging

The colour of a product is important because it is used to market the product. Various colours appeal to the consumer in different ways. However, the colour of a plastic packaging product will in many cases also determine whether a product can be recycled or not. Colour interferes with the mechanical recycling process of a product in various ways. Gasses from the dyes can for instance exhaust from the product in the recycling facility. In order to handle this, a proper degassing system is needed.[39]

The colour will also determine the end market for a product. Strongly coloured plastic material has a much lower economic value than transparent, non-pigmented plastics. Many packaging products today are transparent, or they have light, translucent colours. Unpigmented containers are preferred to pigmented for packaging products as it makes it easier for the consumer to identify the product they are purchasing.

In the recycling market, unpigmented packaging material is preferred and the amount of colour in packaging products should be minimised.[40] However, this depends on the material of the packaging product. The end markets differ between products, depending on the quality of the product, its colour, and the applications. Translucent PET, for instance, has a much higher value in the product chain than

[37] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.
[38] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.
[39] Oliver Lambertz, Tomra
[40] K-online (2016). *Plenty of Potential for Recycling.* Press Release. Available at: http://www.k-online.com/cgi-bin/md_k/lib/all/lob/return_download.cgi/FA02_Recycling_long_version_Logo_en.pdf?ticket=g_u_e_s_t&bid=3186&no_mime_type=0

coloured PET, whilst coloured PP has a similar value to that of translucent PP. This is further explained in Chapter 0 on PP and Chapter 1 on PET:

In many cases, products with solid, opaque colours are problematic because they have fewer possibilities in the end market.[41] If a producer chooses an opaque colour, it is preferred that they minimise the use of other colours in the product to keep the recycled stream as untainted as possible. Mixing colours will lower the value of the recyclate and reduce the applications it can be used for.

COLOURS				
	No colouring	Light, translucent colours	Strong, solid colours	Carbon black
HDPE	Ideal	Yes	Not ideal	No
PET	Ideal	Yes	No	No
PP	Ideal	Yes	Not ideal	No
PS	Ideal	Yes	Not ideal	No
LDPE	Ideal	Yes	Not ideal	No

Table 2 – Compatible colours for plastic packaging of different material types. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

Certain machines can, when specified, read colours. Such machines are often used for identifying different coloured PET bottles.[42] However, in many MRFs, heavily coloured plastic can interfere with the automated sorting machinery. Heavily coloured plastics are strongly light absorbing and the NIR detector could have difficulty identifying the nature of the plastic.[43] Heavy colours, metallic colours, and carbon black are therefore listed as unfit colours for packaging products for all materials and categories of packaging.

Some producers and recyclers have discussed the use of a coating on the outside of a packaging product, instead of dying the material itself. If this coating can be removed, then the value of the uncoloured plastic product will remain high. These products would then have to undergo a washing process prior to sorting, something that would require reconstructions in the recycling facilities.[44] Tests are underway; however, there is uncertainty as to whether the NIR scanner can see through this coating as it may be too thick.

4.3.2 Carbon Black

Carbon black is the name of the pigment that gives plastic packaging its black colour. Manufacturers have been using carbon black because it is an attractive packaging colour. It creates a contrast between the packaging and its contents, which makes the food more appealing to the consumer. Carbon black has excellent UV barrier properties and is also the least costly way of giving plastics their black colour.[45]

The pigment carbon black is problematic because the NIR detectors cannot identify the polymer in the MRF. This fraction is therefore not sorted out to the plastic stream but goes into an unidentifiable fraction that consists of municipal solid waste where the material is incinerated.

Many retailers, such as Walmart, have announced that they will remove carbon black from their packaging because these products end up in the municipal solid waste fraction.[46] Many organisations, industries and brand owners suggest a move away from the use of carbon black altogether because existing technology does not allow it to be sorted.

[41] Oliver Lambertz, Tomra
[42] Oliver Lambertz, Tomra
[43] RECOUP (2016). *Plastic Packaging. Recyclability by Design. The Essential Guide for all those Involved in the Development and Design of Plastic Packaging*. http://www.recoup.org/p/130/recyclability-by-design
[44] Comment from participant at workshop
[45] Plastic Zero (2012). *Carbon Black Plastic – Challenges and Ideas for Environmentally Friendly Alternatives.* Available at: http://www.plastic-zero.com/media/58691/sort_plast_brochure_final_en.pdf
[46] Walmart (2016). *Sustainability Packaging Playbook. A guidebook for suppliers to improve packaging sustainability*. Presentation.

There have been experiments to see whether there are alternatives to solve the challenge with carbon black for packaging products. These projects focus on changing the technology in the MRF, or altering the properties of the plastic making it visible in the NIR detector. However, there are debates as to whether the focus should be on changing the production of the product, or the sorting technology.

There are alternative pigments available to create black plastic, instead of carbon black. These alternative pigments can be viewed by NIR detectors and the material can be sorted into its correct fraction. These alternative pigments are however not fully developed, and they are often 4-5 times more expensive than carbon black. However, it is unclear how this price difference influences the price of the final product and whether this price makes it uneconomical for use by product manufacturers, retailers and packaging manufacturers.[47] Novel NIR detectable black colourants have been shown to work with PET, PP, HDPE, PS and PVC in large-scale trials at recycling facilities.[48] The study resolved that the detectable black colourants need to be matched with the polymer.[49] The trials concluded that alternative colourant techniques would allow for sorting of black packaging with existing NIR technology.[50]

The question is whether to choose a different pigment altogether, or to add a marker to the product. The marker could make the plastic, coloured by carbon black, visible to the NIR detector. This way existing technology could still be used, with just minor modifications.[51]

A third option is to improve the sorting technologies, even though this is the more expensive option. Many options for carbon black do not work with existing NIR technology.[52] New separation technologies, MIR scanners, use a different spectrum to identify the plastic - the medium infrared spectrum. Carbon black can in theory be identified and separated by these scanners; however, the technology is still very new and costs 5-6 times the price of regular NIR.[53] Plastic Zero (2012) states that this technology will not be commonly adopted at recycling facilities for at least another 5 years.[54]

There are two technological alternatives to sorting carbon black plastic:

1. Black scan: a laser scans the conveyor belt and sorts out dark coloured and black plastic, regardless of material type, whether it's textiles, metal or carbon black plastic. The laser cannot differentiate between material types.
2. Black eye: black eye technology is based on NIR and can differentiate between materials. However, this technology is more used for plastic granules. This technology is not extensive in the industry because granules do not tend to be black. It also does not sort the material types properly and is dependent on having a conventional density separation process to further divide the plastic materials.[55]

These new technologies require a substantial amount of energy and are associated with a higher risk of fire. Existing facilities also need to be reconstructed.[56]

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47 Plastic Zero (2012). *Carbon Black Plastic – Challenges and Ideas for Environmentally Friendly Alternatives.* Available at: http://www.plastic-zero.com/media/58691/sort_plast_brochure_final_en.pdf

48 Wrap (2011). Development of NIR Detectable Black Plastic Packaging. Dvorak, R.; Kosior, E. and Moody, L. of Nextek Limited. Oxon.

49 Wrap (2011). Development of NIR Detectable Black Plastic Packaging. Dvorak, R.; Kosior, E. and Moody, L. of Nextek Limited. Oxon.

50 Wrap (2011). Development of NIR Detectable Black Plastic Packaging. Dvorak, R.; Kosior, E. and Moody, L. of Nextek Limited. Oxon.

51 Oliver Lambertz, Tomra

52 Oliver Lambertz, Tomra

53 Plastic Zero (2012). *Carbon Black Plastic – Challenges and Ideas for Environmentally Friendly Alternatives.* Available at: http://www.plastic-zero.com/media/58691/sort_plast_brochure_final_en.pdf

54 Plastic Zero (2012). *Carbon Black Plastic – Challenges and Ideas for Environmentally Friendly Alternatives.* Available at: http://www.plastic-zero.com/media/58691/sort_plast_brochure_final_en.pdf

55 Oliver Lambertz, Tomra

56 Oliver Lambertz, Tomra

It is easier to change the production of the product, using alternative pigments to carbon black. This way the costs of new technology and the danger these technologies bring with them is avoided.[57] However, conversations with packaging producers indicate that alternative pigments are not readily available either on the market, or cost several times the price of carbon black.[58] Avoiding the use of the colour black in plastic packaging products, if it is not required for its physical properties, is the best way forward until alternatives are easily obtainable. The less colour that is used, the lighter the colours, and the better it is for the recycling process.

4.4 Aluminium

Aluminium can be separated from the waste stream in many material recovery facilities (MRF) however, not all facilities have such equipment. It is especially difficult if there are small amounts of aluminium present that can remain together with the plastics and cause problems. Small aluminium particles in the recyclate can alter with the properties of the recycled material. Aluminium closure systems should therefore be avoided in plastic packaging. All kind of multi-material packaging with aluminium should also be avoided.

4.5 Paper

Paper is the most common material for packaging labels. Paper has been recommended as a good label material; however, paper can be detrimental in the recycling process if not separated from the packaging material. The washing process will not remove all paper particles from the plastics waste stream, so remaining particles will cause a contamination. Paper can alternate the properties of the plastic recyclate, and can also give the recyclate a malodour, reducing the recyclates usage areas.[59]

4.6 PVC

PVC is a material with outstanding mechanical properties, making it indispensable in many sectors. PVC is widespread and is the third most used plastic after PP and PE.[60] PVC used to be heavily used for packaging food products, but has been phased out.

Small amounts of PVC mixed with other polymers can harm recycling. The acceptable level of PVC in PET for instance is only 0.25 %.[61]PVC should thus be avoided as a packaging material, or at least make it easily separated if used.[62]

4.7 Adhesives

SUMMARY – ADHESIVES
Adhesives are used on plastic packaging to attach labels and other packaging components. They are also used for closure systems. It is important that adhesives can be removed in normal washing processes to avoid a reduction in the quality of the recycled material. There should also be focus on choosing adhesives that do not leave glue residues on the attached label or component after the washing process. It is recommended to choose adhesives that are water soluble at 60°C.

[57] Oliver Lambertz, Tomra
[58] Comment from participant at workshop
[59] Martina Lehmann, MAKSC
[60] K-online (2016). *Plenty of Potential for Recycling.* Press Release. Available at: http://www.k-online.com/cgi-bin/md_k/lib/all/lob/return_download.cgi/FA02_Recycling_long_version_Logo_en.pdf?ticket=g_u_e_s_t&bid=3186&no_mime_type=0
[61] Petcore Europe (2014). *Recycled Products*. Available at: http://www.petcore-europe.org/recycled-products
[62] Walmart (2016). *Sustainability Packaging Playbook. A guidebook for suppliers to improve packaging sustainability*. Presentation.

The use of adhesives in plastic packaging has been widely used over the years in varying concentrations and amounts. There is agreement among many sources that the use of adhesives should be reduced to a minimum in order to prevent contamination of the recyclate. Physical contamination at a microscopic level from adhesives is difficult to remove. Such impurities create weak spots and lead to problems in the reprocessing of materials.[63]

Glue used to be difficult to remove and were often hazardous. Some glues had melting temperatures of 170°C and caused trouble in the recycling facilities because they could not be washed off.[64] The process for removing adhesives today is less complicated as there are several restrictions on which adhesives that are acceptable for use. Depending on the temperatures used, adhesives can be dissolved by using chemical filtration or particle filters – processes that are not further elaborated in depth in this guide. The treatment process heavily influences the recycling process and the quality of the end product.[65]

There is agreement amongst experts that adhesives should be water or alkali soluble at less than 80°C, however, several sources state that the maximum temperature necessary should be limited to 60°C to reduce energy use. Other sources state that water-soluble adhesives are the only option and alkali-soluble ones should be reduced.[66] There is agreement that adhesives that are not soluble in water or alkali conditions above 80°C should be avoided.

ADHESIVES				
	Non-adhesive	Water/alkali soluble <60°C	Water/alkali soluble 60-80°C	Non water/alkali soluble >80°C
HDPE	Yes	Yes	Not ideal	No
PET	Yes	Yes	Not ideal	No
PP	Yes	Yes	Not ideal	No
LDPE	Yes	Yes	Not ideal	No
PS	Yes	Yes	Not ideal	No

Table 3 – Compatible adhesives for plastic packaging of different material types. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

4.8 Inks and Printing

SUMMARY – INKS AND PRINTING
Printing information, using ink, directly on to the surface of the packaging product should generally be avoided. This will contribute negatively in the recycling process and for the quality of the recyclate. 'Best before-dates' can be printed on the packaging product, however, preferably it should be printed onto the label or sleeve. Laser printing is an acceptable solution for PET, HDPE, and rigid PP packaging products.

Most existing guidelines recommend the minimum printing requirements that follow existing European regulations and industry standards.[67] They recommend that the date of production and/or expiry is the only thing that should be printed on a packaging product. The reason for this is that inks cause a big

[63] Petcore Europe (2014). *Recycled Products*. Available at: http://www.petcore-europe.org/recycled-products
[64] Martina Lehmann, MAKSC
[65] Martina Lehmann, MAKSC
[66] Walmart (2016). *Sustainability Packaging Playbook. A guidebook for suppliers to improve packaging sustainability*. Presentation.
[67] European Printing Ink Association (EUPiA)

problem for the water treatment.[68] Inks that bleed in the recovery stream wash water can contaminate the water and the recyclate.

Water-based primers are the easiest to remove using printing or ink removal technology. Alkaline solutions can be used to remove inks.[69] It is technically feasible to remove inks from some types of flexible packaging; however, it has not been economically viable for post-consumer household films.[70] The costs involved in the removal of inks, exceed the financial benefit of producing colourless or light coloured recycled material.[71]

In many recycling processes, the ink is not removed and the final recycled polymer has a greyish-green colour. The colours do not influence the physical properties of the material but it can limit the applications the recycled plastic can be used for in the end market.

Laser marked printing is acceptable for rigid PP products, but not PP-film. Minimal printing of the date of production/expiry on PET packaging is acceptable, however laser marked printing is a better option.

PRINTING			
	Laser marked	Minimal printing (date of production/expiry)	Any other direct printing
HDPE	Yes	Yes	No
PET	Yes	Conditional	No
PP	Conditional	Yes	No
LDPE		Yes	No
PS		Yes	No

Table 4 - Compatible printing options for plastic packaging of different material types. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

4.9 Sleeves and labels

SUMMARY – SLEEVES AND LABELS
It is important to choose the right label and sleeve material based on how it will affect the sorting and recycling process. Sleeves and labels, not removed by consumers, are in most cases not recycled. Thus, it is more important to choose a solution that can easily be separated from the packaging product in the recycling process. Separation happens in a water stage where PE and PP can be separated from packaging products that have a density of more than 1 g/ccm. Film can be separated from thick, rigid packaging by using a hydrocyclone/sentrifuge before the drying process. A general rule is that sleeves and labels should not cover more than 60 % of the packaging surface that is scanned by the NIR detector. This is essential to securely identify the product and ensure a high hit-rate. If the same material is chosen for the sleeve/label and the packaging product, one can deviate from this rule.

[68] Martina Lehmann, MAKSC, 11, Walmart
[69] Comment from participant at workshop
[70] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.
[71] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.

Based on several recommendations, the sleeve and label should not cover more than 60 % of the surface of a packaging product. If the label covers too much of the surface, the NIR detector in the MRF will have trouble identifying the packaging material and may not be able to sort the product into its correct material fraction.[72] The label area should be minimised to avoid issues with the NIR technology and to avoid rejection from the high value recycle stream.[73] If it is possible to avoid the use of a sleeve or label, then that is ideal, however this depends on the alternative. There are most likely variations in NIR technology, and what resolution the machine uses to read the material.

Labels and sleeves are removed in two types of processes, depending on the recycling facility and which process they want to use either a wet cleaning process using chemicals, or a dry process using friction (or both).[74] Making the label or sleeve easy to remove is also an important factor for making them separable from the product body.[75] The sleeve or label should ideally separate from the packaging body in the washing process.[76] Sleeves and labels that are not removed by friction washing are removed at a later stage where the materials are separated in a conventional density separation process or by the use of a wind turbine. For this reason, sleeves and labels that have a density of more than 1 g/ccm are deemed unsuitable; because it is more difficult to remove them. However, this depends on the material of the sleeve and the product.[77] Full sleeve labels are relatively heavy and can affect bale yields or the material sent to recycling.[78] It should be possible to separate sleeves/labels from plastic packaging products through a float/sink system.[79]

It is vital that the sleeve is constructed and configured so that the automatic sorting by the NIR detector can correctly identify the material of the packaging product.[80] Depending on the thickness of the sleeve or label, the NIR detector will read more or less information from the label material. It can be difficult to know whether the machine will read the packaging material or the sleeve/label.[81] It is therefore impossible to give a recommendation on sleeve and label thickness.

There is uncertainty as to whether the colour of a sleeve or label will affect the detection of the plastic packaging material in the NIR detector and ultimately affect whether the product is sorted into the correct fraction or not. There is agreement amongst sources that as long as the sleeve or label does not cover more than 60 % of the surface of the product, the colour should not affect the process significantly.

There are many different recommendations given as to what material the sleeve or label on a product should have. This will mostly depend on the material of the main packaging body. In the sorting process, it is easier if the product has the same material as the sleeve or label, as it is more likely to be sorted into the right material fraction. However, in the washing process it is easier to separate the two from each other if they are made from different materials.[82]

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[72] Association of Postconsumer Plastic Recyclers (2016). *Selecting Shrink Sleeve Labels for PET Packaging – an APR Design Guide Bulletin.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/Technical-Bulletins/APR_PET_Sleeves_Tech_Bulletin.pdf

[73] Association of Postconsumer Plastic Recyclers (2016). *Selecting Shrink Sleeve Labels for PET Packaging – an APR Design Guide Bulletin.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/Technical-Bulletins/APR_PET_Sleeves_Tech_Bulletin.pdf

[74] Martina Lehmann, MAKSC, Karen, Kidv

[75] Thomas Etien, Danone

[76] Association of Postconsumer Plastic Recyclers (2012). Principles for Sleeve Labels on PET Bottles. Available at: http://www.plasticsrecycling.org/images/pdf/PET-Resins/PET-Bottles/principles_for_sleeve_labels_on_pet_bottles.pdf

[77] K-online (2016). *Plenty of Potential for Recycling.* Press Release. Available at: http://www.k-online.com/cgi-bin/md_k/lib/all/lob/return_download.cgi/FA02_Recycling_long_version_Logo_en.pdf?ticket=g_u_e_s_t&bid=3186&no_mime_type=0

[78] Association of Postconsumer Plastic Recyclers (2016). *Selecting Shrink Sleeve Labels for PET Packaging – an APR Design Guide Bulletin.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/Technical-Bulletins/APR_PET_Sleeves_Tech_Bulletin.pdf

[79] Antonio Furfari, Plastics Recyclers

[80] Association of Postconsumer Plastic Recyclers (2012). Principles for Sleeve Labels on PET Bottles. Available at: http://www.plasticsrecycling.org/images/pdf/PET-Resins/PET-Bottles/principles_for_sleeve_labels_on_pet_bottles.pdf

[81] Oliver Lambertz, Tomra

[82] Oliver Lambertz, Tomra

4.10 Residues

It is normal to find product residuals on the plastic packaging after use. It is not unusual to find 15 - 20g of product left in every bottle – a large amount.[83] The packaging must be easy to empty for the consumer.

If a pack has product in, it may not pass through the sorting systems correctly, due to excess weight. If it passes, it is important to stress that the washing process will not remove all the residues, so any dangerous chemicals remaining in the packaging could be disastrous if they enter the waste stream. Chemical contamination is not uncommon and occurs by the adsorption of flavourings, essential oils, etc. that the packaging contains, or due to a container being re-used for purposes other than the original one.[84] If the packaging contains residues, it shall be treated as (dangerous) waste.

Residues in the waste stream can ultimately give the recycled material an odour. If there are problems with odour in the recyclate, the recycled plastic is less sought after. Complete removal of residues in the washing process requires "desorption", a slow, time-consuming process, decreasing productivity.[85] The packaging must therefore be easy to empty, whether it is a tray, bottle, cup or other form of packaging.

4.11 Biobased, Oxo-Degradable, and Biodegradable Plastic

SUMMARY – BIOBASED, OXO-DEGRADABLE, AND BIODEGRADABLE PLASTIC
Biobased, renewable plastics are plastics produced from renewable material that have a similar polymer structure and physical properties to those plastics produced from fossil fuels. Biobased plastics are not biodegradable, but they are compatible in the recycling process. Green PE is an example of a biobased plastic, and has been found to have the same recyclability as fossil-PE and can generally be recommended in terms of its ability to be recycled. Biobased plastics constitute ca. 80 % (5 million tons) of the world's total production capacity for biobased plastics and biodegradable plastics in 2017. The amount of the estimated production capacity that is used is unknown. Biodegradable plastics constitutes compostable, biodegradable, and oxo-degradable plastics where there is a range of varieties that are both biobased and fossil based. These materials are generally incompatible with non-biodegradable polymer materials in the production of new raw materials. This type of plastic is not suitable for recycling and can potentially reduce the potentials for high value recycling of fossil-based plastics if they are added to the conventional plastics recycling stream. Even a small influx of these can damage the recycling of conventional plastics. Biodegradable plastics will not necessarily be identified by the NIR detector in the MRF, and will therefore largely end up in the general waste fraction or the mixed plastics fraction. However, a small amount of contaminants in the different plastic fractions is unavoidable, and some of this could be biodegradable fractions. The challenge in the MRF is exceptionally large for biodegradable plastics that are based on normal polymers and are identified as such by the NIR detectors. Oxo-degradable PE is an example of this. Biodegradable plastics will then contaminate the product stream. In the subsequent washing and separation processes, biodegradable plastics can be removed if they have a different density than the fossil product stream (over 1 g/ccm for PO or under 1 g/ccm for other types). This is however not the case for oxo-degradable PE.

[83] Comment from participant at workshop
[84] Petcore Europe (2014). *Recycled Products*. Available at: http://www.petcore-europe.org/recycled-products
[85] Petcore Europe (2014). *Recycled Products*. Available at: http://www.petcore-europe.org/recycled-products

Either way, it is impossible to avoid a small influx of contaminants in the recyclate. Biodegradable plastics represent a contaminant in the sorting and recycling process of conventional plastics. The use of biodegradable plastics is therefore not recommended. Biodegradable plastics are difficult to remove from the conventional plastics stream and will have a negative impact even in small amounts. Especially biodegradable plastics that are often identified as polyethylene (PE) or other plastics that are sorted out, will create problems. These contaminants will impact the properties of the recyclate and its application areas in a negative direction. Increasing use of biodegradable plastics is therefore a threat to the recycling of conventional plastics.

Biodegradable plastics can also create challenges in the collection and recycling of food waste. Biodegradable plastics and all other plastics are not wanted in biogas plants.

Full text for biobased and degradable plastic is in attachment 7.4.

5. Packaging Film

SUMMARY – FILM
Sweden and Norway have a high consumption rate of LDPE film used for consumer packaging that is suitable for recycling. PP film is also widely used but this material type does not have the same recycling potential because a market for this type of recyclate has not yet been developed. There is a significant share of film products that are composed of various materials to create different barriers, such as for oxygen or water. LDPE laminated plastics can be difficult to separate from pure LDPE film in the NIR detector and this is therefore a challenge for recyclers. By adjusting the NIR equipment the share of laminated plastics in the pure fraction can be reduced, however the dividend of pure LDPE will also decrease. A process for making barrier materials more acceptable in the recycling process is underway, especially for EVOH. Variations of PE/PA and PE/PET is not recommended. It is normal to find a small amount of PP film in the LDPE recyclate. A fraction of 3 % can be accepted. Biodegradable film that is not separated in the sorting process is not wanted. It is especially difficult to separate oxo-degradable PE from the other fractions.

5.1 Film applications

Film is used for a vast number of applications requiring a variety of properties, including film for meat packaging, different pouches for snacks etc., shopping bags and as transport packaging.

Based on the needed properties, film can be monolayer LDPE, multilayer LDPE, multilayer with barrier materials or monolayer PP or other materials. LDPE is by far, still the most common material.

For recycling, LDPE is the only targeted material. All other materials, like PP, biodegradable film, laminates etc. are regarded as a contamination. However, household waste collection may comprise of all types of plastic packaging. This means that the MRFs must sort out a clean LDPE fraction for recycling, while all other films are sorted out for incineration. In practice, about 85 % of all these other films are sorted out, while 15 % end up in the LDPE fraction as contamination. Some of these contaminations can be removed during the washing processes. The given percentages can vary based on adjustments of sorting machines; The LDPE fraction can thus be even cleaner; however, such adjustments result in increased losses also of LDPE in the process.

LDPE film that is separated from other household packaging will be a mix of colours, thicknesses and qualities. High-grade recycling of film-products from households involves creating new film-products. There are also other products with somewhat lower quality requirements.

The end market for recycled LDPE film varies depending on the material and its quality. Measures to improve the recycling process include packaging design, for example making good choices when using laminated LDPE packaging for a product.

5.2 Labels

Labels that are made of the same material as the packaging body, or a compatible material, is the preferred option, as this will not contaminate the recycled film. LDPE and PP labels are therefore preferred.

PET labels can be separated from LDPE and PP film in a sink/float process; however, it can be detrimental if a large fraction remains in the recyclate. It is therefore better to avoid the use of this material.

Paper labels cause trouble in the recycling process if they are not separated by separation systems in washing processes. They cause contamination of the recyclate and can lead to malodour of the recycled material.

If the paper labels are satisfactory removed from the packaging by using a wind shift, then the potential hazard paper has is heavily minimised.[86]

IDEAL	GOOD	NOT IDEAL	BAD
None	LDPE PP/OPP	PET Paper	Metal PVC

Table 5 - Compatible material types for labels on film packaging products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

5.3Additives and Barriers

LDPE-film and PP-film offer limited, to no barrier properties on their own and therefore often contain additives to give the film its necessary properties. When the packaging film consists of several layers, it is called a laminated plastic. Laminated plastics can be created in two separate ways, either by gluing separate layers that do not have compatible melting temperatures together, or by co-extruding them in one single process.

LDPE-film and PP-film that contain barrier materials are challenging to both sort and recycle. A fraction of these will not be able to be sorted out by the NIR detector, and will remain together with the film-fraction to the recycling facility. Coatings and layers are not removed in the film recycling process, but are either melted or blended together with the material. The effect that these coatings and layers have on the recyclate is uncertain and therefore requires further testing. A reduction in the amount of layers in LDPE film is advised – fewer layers will lead to less contamination in the recyclate material streams.[87] Non-PE layers in film could harm the recyclate, so their content should be minimised.[88]

EVOH is the most common barrier material for LDPE. EVOH is easier to combine with polyolefins, LDPE and PP, than PA. PA should not be combined with EVOH and LDPE.[89] If the product has a shelf life, it requires the best possible combination of materials. There is more and more evidence that PA is reducing in use.[90]

Caution should be executed when combining fillers with film as this could alter the overall density. As density is a critical separation tool, the film should float, rather than sink.[91]

IDEAL	GOOD	NOT IDEAL	BAD
None	EVOH (< 2 % of total weight)	PET PA (<1 % of total pack weight) EVOH (<10 % of total pack weight) PET	Aluminium Metallized PA (>1 % of total pack weight) EVOH (>10 % of total pack weight)

86 Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines for LDPE, LLDPE, HDPE Film.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/PE_Film_APR_Design_Guide.pdf
87 Comment from participant at workshop
88 Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines for LDPE, LLDPE, HDPE Film.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/PE_Film_APR_Design_Guide.pdf
89 Martina Lehmann, MAKSC
90 Comment from participant at workshop
91 Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines for LDPE, LLDPE, HDPE Film.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/PE_Film_APR_Design_Guide.pdf

			PVC, PVdC

Table 6 - Compatible additives and barrier materials for film packaging products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

5.4 Sorting and Recycling

There is generally a lot of contamination in the film-fraction at a recycling facility. Film is difficult to recycle because there are so many different types with various melting point, barriers and additives, depending on the properties required of the material. Although the market for recycled film is minor, it is important to secure large volumes of this, and that this fraction is kept at a high quality.

5.4.1 PP-film

PP-film can be recycled in principle, but based on its limited use, demand for high quality, and the non-developed market for recycled PP film, recycling of this material is still not economically viable. The collected volume of PP film is very small and there are therefore few who recycle it today.[92]

During the sorting process, PP film can in theory, be separated. However, PP film and all other non- LDPE films are in practice sorted out for incineration. As an alternative, some PP-film are accepted in a mixed PO fraction for recycling.

If PP- film shall be sorted out as a single stream, the challenge is to prevent rigid PP from being sorted into the PP film fraction. Some rigid PP products are often identified as two-dimensional, lids are common, and are sorted together with the film fraction.[93]

B-OPP or OPP are monomaterials with additional barrier functions arising from the production of the material where the molecule structure has been changed by physical stretching.[94] It is unsure whether this property poses an added challenge in the recycling facility for PP-film recycling. Some PP material, incl. B-OPP, is recyclable, for example as part of a mixed PO. However, it loses its orientation-quality in the process. They will be downgraded and used for other purposes.[95] Certain B-OPP or OPP products are very delicate where a long lifetime and the ability to tolerate high pressures must be guaranteed. Recycled material can therefore not be used in these products.

PP-film can to a certain extent be recycled as a part of the HDPE/PP fraction.[96] PP film contaminates the LDPE fraction if it is mixed. The PP fraction can be heavily contaminated if PET is mixed into it.

Current PP films require a very high quality that is difficult to achieve with current recycling systems. It is possible to recycle PP and reach a similar quality, but this is pioneer work.

5.4.2 LDPE film

70-80 % of the material that comes out of a large MRF in Norway is LDPE. It is a huge fraction. Monolayer films are sorted today, but not much else.[97] LDPE offers no other barrier other than a humidity barrier. For this reason, LDPE film often has additives. The barrier layers in PE films are what causes problems with

[92] Oliver Lambertz, Tomra, Comment from participant at workshop
[93] Oliver Lambertz, Tomra
[94] Karen van de Stadt, Kidv
[95] Antonino Furfari, Plastics Recycling
[96] MTM, some film accepted as part of PO fraction
[97] Thomas Etien, Danone

recycling. However, if the barriers are removed, then protection of the product is gone. If these layers can be reduced without, compromising the quality, then that would be ideal.[98]

LDPE is recycled in combination with PA. There have been attempts to separate LDPE from PA in the recycling process, but there is no concrete evidence that this is possible. The division process may have to include several steps. LDPE with PA is difficult to recycle because the materials have different melting points. LDPE and PA are not so compatible so adhesives are required to bind the materials together.[99]

PET in the LDPE fraction is a problem for recycling. A 3 % fraction of PP in the LDPE recyclate is acceptable.[100] If there is more than 2 % biodegradable material in the LDPE fraction, it will cause problems.[101]

There are movements to replace PP film with PE film because recycling systems exist for LDPE, and not for PP. Nevertheless, in order to provide the same functionality and product protection, PE films may need to be thicker, and are hence less resource efficient.[102]

[98] Comment from participant at workshop
[99] Comment from participant at workshop, Martina Lehmann, MAKSC
[100] Martina Lehmann, MAKSC
[101] Martina Lehmann, MAKSC
[102] Nina Ackermans, Borealis

6 Rigid and Thermoformed Packaging

6.1 Polypropylene (PP) products

SUMMARY – PP
PP is used for a wide range of applications, amongst them bottles, trays, boxes, cups, lids etc. There is an end market for different types of recycled PP in various colours that works well. However, this market can be further developed to ensure a higher quality recyclate gives a wider range of applications. It is recommended that lids, caps, sleeves and labels on PP products be made from the same material, that includes OPP. HDPE or LDPE are also acceptable materials on PP packaging, as they will not heavily affect the quality of the recycled end product in most cases. Combinations of PP/PET should be avoided, even though the materials can in some places be separated. There are no good solutions for the use of barrier materials in PP products. If good barrier properties are required, other packaging materials are likely to be better. PP packaging can ideally be sorted by colour as dark colours are generally less welcome and have a lower value on the end market. Use of the pigment carbon black is not recommended.

6.1.1. PP applications

The range of PP applications is very large, giving recycled PP a high-end market value.[103] PP is typically found in yoghurt containers, ketchup bottles, syrup bottles and medicine bottles.[104] It is a good material for storing acids, bases and other solvents. It is a strong material with a high melting point.

The outlets of recycled PP are often crates, bottles, and other essential 'low value' products such as brooms, auto battery cases, bins, pallets, signal lights, ice scrapers and bicycle racks.[105] These are often white or coloured and are usually thick-walled.[106]

6.1.2. Colours

There are many compatible colours for PP packaging products. All colours, except for carbon black, have the potential to be recycled; however, there is not always a market for it.[107] Recycled PP has a high value as the quality is good, and can be used for many different applications; from dish brushes and other kitchen utensils to park benches and crates.

Although most types of PP in various colours can be recycled, the quality of the recycled product will vary depending on the amount of different colours in a product. The packaging product will have a lesser value if there are many colours mixed in the packaging. The packaging should ideally consist of as few colours as possible.

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[103] Martina Lehmann, MAKSC

[104] Natural Society (201). *The Numbers on Plastic Bottles: What do the Recycling Symbols Mean?* Website. Available at: http://naturalsociety.com/recycling-symbols-numbers-plastic-bottles-meaning/

[105] Natural Society (201). *The Numbers on Plastic Bottles: What do the Recycling Symbols Mean?* Website. Available at: http://naturalsociety.com/recycling-symbols-numbers-plastic-bottles-meaning/

[106] Karen van de Stadt, Kidv

[107] Oliver Lambertz, Tomra

The mixing of colours in PP packaging products should under ideal condition be avoided in order to produce distinct streams of different colours of recycled PP, increasing the amount of applications it can be available for on the end market.

Carbon black is not an ideal colour for PP packaging, as the NIR detector cannot be detected in the MRF. There is a new PP product under development that does not contain carbon black, black PP trays. This tray has been tested in Norway and could be detected by the NIR detector at the RoAf MRF.[108]

6.1.3. Closure Systems

When using closure systems on PP packaging, it is an advantage that they are the same colour as the bottle. This is not essential; however, it helps reduce colour contamination in the recycled product, giving it better quality and a higher value on the end market.

PP caps, or OPP, are ideal for PP bottles as they can be recycled together and do not require separation. OPP is a monomaterial with additional barrier functions due to a physical stretching of the molecular structure. This will not create problems in the recycling process.[109] Caps made out of HDPE are also good for PP packaging products. HDPE and PP are both polyolefins and therefore have many of the same properties. HDPE has a lower melting point than PP (ca. 130°C vs. 170°C), and a small amount of HDPE in the PP fraction will not have detrimental consequences.[110]

If PET is mixed up into the recycled stream of PP, it can cause contamination of the recycled product. PET is therefore not an ideal material to combine with PP. Even if the product goes through a MRF to separate the two materials from one another, there will always be a small fraction that will not be sorted out. If a less ideal material is chosen, it is important that the density is above 1.0 g/ccm so it can easily be separated from the packaging in conventional density separation processes.

Aluminium is a common material used for creating a seal under plastic lids in products like butter tubs. Aluminium is generally not acceptable unless it can, and will, be completely removed by the consumer and will not end up in the plastics fraction.

IDEAL	GOOD	NOT IDEAL	BAD
PP, OPP	HDPE LDPE LLDPE	PET	PS PVC Thermoset plastics Silicone Metals

Table 7 - Compatible closure systems for PP products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.1.4. Sleeves and labels

As for the closure system, it is an advantage in the PP fraction that the sleeves and labels are of similar colours to the main packaging body. As much of the PP can be recycled, main colour PP streams are desired to reach the highest quality of the recycled product.

PE and PP are good materials for sleeves or labels on a PP packaging product.[111] PE and PP have very similar densities and it is therefore difficult to separate them. However, as mentioned above, PE and PP

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[108] Oliver Lambertz, Tomra
[109] Karen van de Stadt, Kidv
[110] RECOUP (2016). *Plastic Packaging. Recyclability by Design. The Essential Guide for all those Involved in the Development and Design of Plastic Packaging*. http://www.recoup.org/p/130/recyclability-by-design
[111] Martina Lehmann, MAKSC

are both polyolefins and PE causes therefore little harm in the recycled fraction. PE has a lower melting temperature than PP and can therefore be processed together into other high-grade products.[112] Small fractions of PE can hence be accepted in the PP fraction.

PET is not an ideal material for a sleeve or label on a PP product because PET can highly contaminate the recycled PP fraction. However, a PET sleeve on a PP bottle is possible because the densities are different so they can be separated in a MRF. Nevertheless, because the MRF can never sort out 100 % of the sleeves and labels, PET is likely to be mixed into the recycled PP. PET is therefore acceptable in small quantities; however, it should preferably be avoided. PS has a similar story where it is only acceptable in small quantities as it can contaminate the recycled PP.

When comparing labels and sleeves on a PP bottle, to printing on PP, sleeves and labels are better for giving PP a high value at the end market. Inks are difficult to remove and end up contaminating the recycled flakes, which lowers the value and causes a bad smell. A special extrusion is needed in order to remove inks, which is an expensive and technically difficult process. This type of contamination causes problems in the recycled fraction, which requires the use of more additives. Losing sleeves and labels to incineration is preferred in order to achieve a high quality of the recycled PP.[113]

In-mould labelling is common for PP packaging products and it is good for sorting and recycling. However, this is expensive and could cause challenges in the recycling process depending on how much colour has been used for the in-mould label.[114]

If a less ideal material is chosen, it is important that the density is above 1 g/ccm so it can easily be separated from the packaging in conventional density separation processes.

IDEAL	GOOD	NOT IDEAL	BAD
LDPE PP	Removable in-mould label OPP	Paper PET PS	Metal PVC

Table 8 – Compatible sleeve and label materials for PP products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.1.5. Additives and Barriers

PP has low barrier properties and is therefore mostly used in packaging that does not require a specific oxygen barrier. In order for PP to achieve the same barrier properties as PET, it would require a very thick layer between two thick layers of PE.[115]

EVOH is a common barrier added to PP to increase its barrier properties. EVOH is accepted in the PP recyclate, in addition to PA-based barrier layers; however, their use should be minimised as they contaminate the recycled PP fraction. EVOH causes bubbly surfaces of the recyclate.[116] It is noteworthy that PP with EVOH is not as bad as PET with EVOH.[117]

By adding fillers and/or barriers to PP, the density of the packaging material will increase. If the density of PP increases to above 0.995 g/ccm, it will be difficult to separate PP from other plastic materials in the conventional density separation processes at the MRF. The amount of fillers and/or additives in PP is

[112] K-online (2016). *Plenty of Potential for Recycling.* Press Release. Available at: http://www.k-online.com/cgi-bin/md_k/lib/all/lob/return_download.cgi/FA02_Recycling_long_version_Logo_en.pdf?ticket=g_u_e_s_t&bid=3186&no_mime_type=0
[113] Martina Lehmann, MAKSC
[114] Martina Lehmann, MAKSC
[115] Paul East, RECOUP
[116] Karen van de Stadt, kidv
[117] Comment from participant at workshop

therefore very important. If the density increases to above 1.0 g/ccm, the most of the packaging will be lost in the recycling process.[118] It is for this reason that EVOH and PA-based barrier materials are separated in the Table below based on their content levels of the total pack weight.

The use of PVdC should be avoided as it causes discolouration of the recycled PET and can lead to malodour.[119]

IDEAL	GOOD	NOT IDEAL	BAD
None	None	PA (<1 % of total pack weight) EVOH (<10 % of total pack weight)	PA (>1 % of total pack weight) EVOH (>10 % of total pack weight) PVdC

Table 9 - Compatible additives and barriers for PP products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.1.6. Sorting and Recycling

The recycling of PP is rather straightforward.[120] Much of the PP fraction can today be recycled; however, as discussed in the sections above, there are many elements that could potentially cause contamination of the recycled fraction, giving it a lower quality. PP packaging should be kept to a density below 0,995 g/ccm in order to separate it from other plastic types in the MRF.[121]

PP can be used for a wide range of applications and therefore has value on the end market. However, the recycling market for PP today is not very extensive. This is mostly because the cost of recycling PP is so high, which in turn makes the recycled material very costly.

In summary, it is acceptable to mix PP used for different applications.[122] All PP products are processed at about 220°C temperature, so they can be melted and reprocessed together.[123] PP-film is a different type of PP material that has similar propertied to rigid PP but should be avoided in the rigid PP fraction if possible. It is acceptable to have roughly 5 % PP film in the rigid PP fraction.[124]

The more monomaterials that exist in the recyclate, the higher the quality it will have. If the recycled PP contains other materials, they will affect the properties of PP. More than 3 % PET in PP could be detrimental, and more than 5 % PS is not good for the PP fraction either.[125] However, the amount of other materials in PP is dependent on the end product. Some PE in the PP fraction is not so bad, less than 5 %, but it heavily depends on what end product the recycled PP is going to.[126]

There is an existing market for recycled PP in a very wide range of products such as automotive applications, buckets, caps and closures, garden furniture, pallets, pipes, and more.[127]

[118] Oliver Lambertz, Tomra
[119] RECOUP (2016). *Plastic Packaging. Recyclability by Design. The Essential Guide for all those Involved in the Development and Design of Plastic Packaging*. http://www.recoup.org/p/130/recyclability-by-design
[120] Antonino Furfari, Plastics Recyclers
[121] Oliver Lambertz, Tomra
[122] Martina Lehmann, MAKSC
[123] Martina Lehmann, MAKSC
[124] Oliver Lambertz, Tomra
[125] Martina Lehmann, MAKSC
[126] Martina Lehmann, MAKSC
[127] Miliken Chemical

6.2. High Density Polyethylene (HDPE) products

SUMMARY – HDPE
A well-developed end market for mixed HDPE consumer packaging is visible. Virgin plastics as well as recycled HDPE are used for bottles, jugs for cleaning supplies, personal hygiene products, tubs and various chemicals. A range of colours on the recycled HDPE end product is acceptable in today's market. The use of carbon black causes problems as it cannot be sorted by NIR technology and is therefore not recycled. Caps and lids should be made in HDPE or LDPE so they do not cause harm to the end recyclate. PP is accepted but can create problems in the recycling process if it is not removed from the HDPE fraction.

6.2.1. HDPE applications

HDPE is found mostly in milk jugs, household cleaner containers, shampoo bottles, cereal box liners and various other types of bottles and tubs. HDPE can be recycled into pens, picnic tables, benches, fencing, pipes and other types of bottles and containers.[128]

HDPE has a clear and even surface and has some good barrier qualities, though it is not a good barrier to oxygen. It is also durable against shocks and heat.

6.2.2. Colours

HDPE bottles are typically opaque, although they can have many different colours. Ideally, they are unpigmented. All bottles are placed together in the recycling process where the recycled plastic has a greyish, blue-green colour due to the mixing of different colours. It is possible to separate HDPE into different fractions based on their colour, but a large, extensive MRF is needed for this.[129]

Although carbon black HDPE bottles are unwanted, as they cannot be separated into their proper waste stream, they are more valuable on the market today.[130] Markets exist for commonly coloured HDPE material so it is therefore economical to process.[131]

6.2.3. Closure Systems

There are different types of caps that are normally used on an HDPE bottle and the type of cap that is chosen will determine the type of material used. PP caps are common, as are HDPE caps.[132] As with many other elements in a plastic manufacturing process, the choice of closure systems by the product manufacturer is often dependent on price. PP caps are cheaper than HDPE caps and are therefore more widely adopted for HDPE bottles.[133]

Although a small fraction of HDPE in PP is okay, small amounts of PP in HDPE could be detrimental. PP has a higher melting temperature than HDPE, which will cause problems in the formation of regranulates. However, it is important to note that this heavily depends on the end product and use of the recycled

[128] Natural Society (201). *The Numbers on Plastic Bottles: What do the Recycling Symbols Mean?* Website. Available at: http://naturalsociety.com/recycling-symbols-numbers-plastic-bottles-meaning/
[129] Martina Lehmann, MAKSC
[130] Martina Lehmann, MAKSC
[131] Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines for HDPE.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/HDPE_APR_Design_Guide.pdf
[132] Martina Lehmann, MAKSC
[133] Martina Lehmann, MAKSC

HDPE. If the HDPE is going to be used to create pipes, PP material in this fraction will cause less stability and breakage of the pipes. This material could then not be used for pipes, a product that requires stable materials that can handle high pressure.[134]

Aluminium lids are only acceptable on HDPE bottles if the consumer will definitely remove them.

IDEAL	GOOD	NOT IDEAL	BAD
HDPE LDPE	PE (+ EVA)	PET (conditional) PP, OPP	PS PVC Silicone Metals

Table 10 - Compatible closure systems for HDPE products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.2.4. Sleeves and Labels

The sleeve or label material on a HDPE bottle is highly dependent on the final, recycled HDPE end product. As shall be further explained in the following sections, some products made from HDPE and PP have qualities that are ideal, while for other products, this mix could be disastrous. The question is how much foreign material is okay in the HDPE fraction. For many products, PP is not good to mix with HDPE. In those cases, a PET sleeve may be better. However, for this to be possible, good washing and reprocessing facilities are required.[135]

PS should not be used for sleeves, but it can be used for labels, although this is not ideal either.

IDEAL	GOOD	NOT IDEAL	BAD
In-mould label of compatible material	PE (MDPE, LDPE, LLDPE) PP, OPP	Paper (conditional) PET (conditional) PS	PS PVC Metals

Table 11 - Compatible sleeves and labels for HDPE products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.2.5. Additives and Barriers

HDPE does not have any natural gas barriers, so if the contents of HDPE packaging require oxygen barriers, HDPE in itself is not sufficient.[136] HDPE with PA or other additives gives a good barrier against gases; however, this is not a recommended solution from a recycling perspective.[137]

EVOH is the recommended layer material for HDPE that will increase its barrier properties.[138] As it cannot be separated, it will be part of the HDPE recyclate. Although this is potentially problematic, it is generally accepted. However, the content of EVOH should be reduced to a minimum.[139]

IDEAL	GOOD	NOT IDEAL	BAD
None	None	PA (<1 % of total pack weight) EVOH (<10 % of total	PA (>1 % of total pack weight) EVOH (>10 % of total

[134] Martina Lehmann, MAKSC
[135] Oliver Lambertz, Tomra, Martina Lehmann, MAKSC
[136] Nina Ackermans, Borealis
[137] Comment from participant at workshop
[138] Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines for HDPE.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/HDPE_APR_Design_Guide.pdf
[139] Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines for HDPE.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/HDPE_APR_Design_Guide.pdf

		pack weight)	pack weight) PVdC

Table 12 - Compatible additives and barriers for HDPE products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.2.6. Sorting and Recycling

Recycling HDPE is straightforward.[140] Recycling systems for HDPE are widespread and common and the market price for HDPE is good. HDPE has a high-end market value today and is heavily recycled. The recycling process is not too costly and the final recycled product is not too expensive for product manufacturers.

There are some movements to replace PP with HDPE because recycling systems for HDPE are common, more so than for PP.[141] However, to provide HDPE with the same functionality and product protection as PP, the HDPE must be thicker. This leads to a less resource efficient material.[142]

There are differences between HDPE and PP in a MRF.[143] Some say 6-8 % PP in HDPE is acceptable, while others say max 2 %.[144] This is determined by what the products of the HDPE recyclate will be. Some PP in the HDPE fraction could be detrimental for certain end products.[145] When HDPE and PP are mixed, it is very difficult to separate them because of their similar densities. However, HDPE and PP can also be processed together into PE/PP regranulate to form high-grade products.[146] HDPE has a melting temperature of 130°, while PP has 160-170°.

PET in the HDPE recycling stream is very problematic and can contaminate the recyclate as they have very different melting temperatures.

[140] Antonino Furfari, Plastics Recyclers
[141] Nina Ackermans, Borealis
[142] Nina Ackermans, Borealis
[143] Oliver Lambertz, Tomra
[144] Eirik Oaland, Grønt Punkt Norge
[145] Martina Lehmann, MAKSC
[146] K-online (2016). *Plenty of Potential for Recycling.* Press Release. Available at: http://www.k-online.com/cgi-bin/md_k/lib/all/lob/return_download.cgi/FA02_Recycling_long_version_Logo_en.pdf?ticket=g_u_e_s_t&bid=3186&no_mime_type=0

6.3. Polystyrene (PS) products

SUMMARY – PS
Polystyrene is used in packaging for a range of applications, however is it mostly used for dairy products. PS is generally used for small packaging units that constitute a small weighted portion of the total amount of all packaging materials consumed. PS is a marginal packaging type of which only a small amount is recycled. PS in packaging products is normally the type that breaks easily when it is compressed during collection. Shattered PS and smaller components will in most MRFs be through a mesh grid discharged together with other fine particles. Transparent, white and light colours are preferred, seen from a recycling perspective. It is further recommended to use components that have a lower density than 1 g/ccm for lids, caps, sleeves and labels, if a material other than that of the main packaging body is chosen. PP and PE can be separated from PS in the washing process. If PS is chosen, it can be separated from the packaging body with the use of a wind turbine. Aluminium components are not recommended.

6.3.1. PS applications

PS is used in many applications, though it is decreasing in use.[147] Yoghurt cups is a well- known application. PS is also used for containers such as clamshells, lids, bottles, pots, trays and disposable cutleries. PS is often found in compact disc cases, egg cartons, meat trays, yoghurt containers, and disposable plates and cups.[148] When PS is recycled, it can be used in egg cartons, vents, foam packaging and insulation.[149]

PS is injection moulded; vacuum formed or extruded, has good thermoforming properties, and can be made very fast. It also has a good stability for heat, though it is not flame retardant.[150]

Expanded polystyrene (EPS) is either extruded or moulded in a special process and is decreasing in use.[151] EPS is used as transport packaging, for example as fish crates in Norway. EPS is sometimes used to protect valuable goods, also as "chips", but is less used as sales packaging.

6.3.2. Colours

Polystyrene can be all colours, but is mostly white. The end product primarily determines its colour.[152] However, for recycling reasons, the less colour PS has, the more valuable the recyclate is. Solid, dark colours and the pigment carbon black are not ideal for PS. The volume of PS is so small and is therefore seldom recycled today. For this reason, different coloured PS products are not separated out individually.

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[147] Comment from participant at workshop

[148] Natural Society (201). *The Numbers on Plastic Bottles: What do the Recycling Symbols Mean?* Website. Available at: http://naturalsociety.com/recycling-symbols-numbers-plastic-bottles-meaning/

[149] Natural Society (201). *The Numbers on Plastic Bottles: What do the Recycling Symbols Mean?* Website. Available at: http://naturalsociety.com/recycling-symbols-numbers-plastic-bottles-meaning/

[150] Martina Lehmann, MAKSC

[151] Comment from participant at workshop

[152] Martina Lehmann, MAKSC

6.3.3. Closure Systems

Aluminium lids are acceptable for PS if the consumer will without a doubt, remove them. Aluminium can create problems in the recycling process.

Lids and other types of closure systems should oppositely sink or float in relationship to the base material. In the case of PS, lids should be made from a material that floats. Use of closure systems that are the same material as the container, PS, is desired when the colours are the same.[153]

The lidding film on a PS container can be made up of many different types of materials. Common for all of them is that they are lightweight. PET can contaminate the PS fraction if it is mixed into it. PS mixed with various other materials, such as PE or EVA is a good option.

IDEAL	GOOD	NOT IDEAL	BAD
HDPE, LDPE PP, OPP	PS, OPS (conditional)	PET	PVC Aluminium

Table 13 - Compatible closure systems for PS products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.3.4. Sleeves and Labels

Sleeves and labels on PS packaging should be minimised and should not cover more than 60 % of the packaging product in order for it to be correctly sorted in the MRF. They should also have a density of less than 1 g/ccm in order to be separated from the PS fraction. PS has a higher density but as it is the same material as the packaging body, they can be recycled together.

Removable in-mould labels that detach in hot caustic water are encouraged for PS.[154]

IDEAL	GOOD	NOT IDEAL	BAD
Removable in-mould label PS, OPS	PP, OPP PE	Paper Permanent in-mould label	Metal PVC PET

Table 14 - Compatible sleeves and labels for PS products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.3.5. Additives and Barriers

Coatings and layers are generally discouraged for PS, unless they are compatible with, or easily separable, in conventional recycling systems.[155] There is little information on this topic and further studies are recommended

Calcium Carbonate used as a filler in PS products will increase the density of the product. Density variations can disturb the washing process and influence the properties of the regranulates. Although some say, it is not a solution to fill PS with $CaCO_3$, further impact studies are needed here.[156]

IDEAL	GOOD	NOT IDEAL	BAD
None	None	PA (<1 % of total pack weight)	PA (>1 % of total pack weight)

153 Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines: An Executive Summary*. Available at: http://www.plasticsrecycling.org/images/pdf/Other-Resins/APR_Guide_Other_Thin_Wall_Packaging_Excerpt_2014.pdf

154 Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines: An Executive Summary*. Available at: http://www.plasticsrecycling.org/images/pdf/Other-Resins/APR_Guide_Other_Thin_Wall_Packaging_Excerpt_2014.pdf

155 Association of Postconsumer Plastic Recyclers (2013). *APR Design for Recyclability Guidelines: An Executive Summary*. Available at: http://www.plasticsrecycling.org/images/pdf/Other-Resins/APR_Guide_Other_Thin_Wall_Packaging_Excerpt_2014.pdf

156 Martina Lehmann, MAKSC

		EVOH (<10 % of total pack weight)	EVOH (>10 % of total pack weight) PVdC

Table 15 - Compatible additives and barriers for PS products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

6.3.6. Sorting and Recycling

PS packaging is a marginal fraction in the plastic packaging recycling market. A trend has also been seen of replacing PS with other materials. PS is easy to sort out at MRFs, but it is difficult to recycle because the weight fraction is so small, albeit the huge volume.[157] For this reason, MRFs often do not sort out PS packaging. There are few post-consumer PS recyclers today as the market for PS is small.[158] Instead, PS ends up in a mixed plastics fraction or as waste for incineration. In Germany, the systems sort out PS for recycling, e.g. for injection moulding, but the quality of the sorted material is often poor and thus not attractive for recycling. The recycling market for PS is rather limited for these kinds of plastic packaging, however it also depends on the type of PS. PS Normal and PS High Impact (HIPS) are the most valuable fractions and the most common types of PS.[159]

PS has a specific weight of 1.06 g/ccm and can be divided from the other plastic fractions.[160] If the density is higher than 1.06, it will more difficult to separate it from the other plastic fractions using the conventional processes in place today.[161]

PS can cause contamination of the other plastic fractions, even in small quantities. If PS is mixed with LDPE is causes a bad smell and does not blend properly in the melting process as they have different melting temperatures.[162] PS in the PP, fraction causes impurities and impacts the quality of PP.[163] There are some recommendations that involve switching from PS to PP entirely.[164] PS also has some health related challenges, influencing the conversion. However, this move is expensive, as PP cannot be formed using PS equipment.[165]

EPS packaging from households is not sorted out for recycling. EPS also harms the sorting process.

[157] Comment from participant at workshop, Martina Lehmann, MAKSC
[158] Thomas Etien, Danone
[159] Martina Lehmann, MAKSC
[160] Martina Lehmann, MAKSC
[161] Oliver Lambertz, Tomra
[162] Martina Lehmann, MAKSC
[163] Martina Lehmann, MAKSC
[164] Thomas Etien, Danone
[165] Comment from participant at workshop

6.4. Polyethylene Terephthalate (PET) Products

SUMMARY – PET
The application of PET in packaging is increasing as it replaces other types of materials. PET is more affordable and has good barrier properties that are desired for many products. PET bottles are collected in deposit-return systems in Norway and Sweden and are recycled to produce new bottles or other high value products. Separate from the deposit-return systems, PET is still a large fraction of the municipal waste stream, though the quality is a mix of different coloured bottles, trays, tubs and other thermoformed packaging. The market for PET recycling needs to be further developed, especially for thermoformed PET-filmed, as there is no functioning recycling market on these applications for the moment in Europe. In these circumstances, focusing on design for recycling could play an important role. The following general recommendations are given: - Choose transparent and light colours if possible - Choose closure systems and sleeves/labels that are made of PP/OPP and PE that can be separated from PET in the washing process. - Avoid the use of barrier materials if possible.

6.4.1. PET Applications

Polyethylene terephthalate, commonly abbreviated PET, PETE, or the obsolete PETP or PET-P, is the most common thermoplastic polymer resin of the polyester family and is used in fibres for clothing, containers for liquids and foods, thermoforming for manufacturing.[166]

PET is a combination of two monomers. PETG is of the same chemical composition as PET but with the addition of glycol. With just this one addition, the chemical composition is completely changed, creating a completely new plastic.[167] rPET refers to PET made from recycled material. Although the term rPET is often used for packaging which includes a quantity of recycled material.

The volume of PET packaging is increasing. PET has replaced glass and PVC bottles and has also started to replace other polymers, for example, PE and PP. PET has good barrier properties, but for some applications, there are needs for even better barrier materials.

Because PET is an excellent water and moisture barrier material, plastic bottles made from PET are widely used. Collected PET beverage bottles for food contact in the Nordic countries are mainly part of deposit-return systems. Some beverage bottles also end up in the general plastic packaging waste stream or as residual waste. Other PET bottles collected is a mix of some deposit bottles, bottles for other food and non- food. PET film/thermoformed packaging such as tubs, pots and trays is a fast growing application.

The best quality of PET packaging for recycling is the food-grade PET beverage bottles. These should be transparent. The Nordic deposit-return systems collect most of these bottles. Other bottles, partly non-food, represent a lower, but still a relevant quality, depending on quality criteria for recycling. All other PET fractions, and mixes, can still be characterized as more challenging, again also dependent on quality criteria.

The intrinsic viscosity (IV) varies between PET applications: bottles: 0.8 IV; films: 0.7 IV; fibres: 0.6 IV; straps: 0.9 IV. This means in theory that bottles and thermoformed fractions shall not be recycled

[166] Wikipedia, PET
[167] Wheaton

together without altering the properties of the plastic. In practice, some of the PET thermoformed applications have been sorted out together with PET bottles. To a certain extent, this has been accepted in the market, at least monolayer PET.

6.4.2. Markets

The markets for all PET packaging are characterised in general by falling raw material prices and several new packaging solutions with different properties. PET packaging has two main segments:

- The PET bottle-to-bottle (B2B) recycling market works well. This market is characterized by strict quality specifications and high prices. The deposit-return system in Norway (Infinitum) and Sweden (Returpack) has very strict rules, and penalties, related to design for recyclability.
- All other PET packaging products, sorted out as different mixes, are partly recycled to film and fibres. PET thermoforms are difficult to characterize and it is therefore difficult to sort monolayers from multilayers, and between different multilayers. Due to different properties of different PET applications, incl. the intrinsic viscosity, and the use of multilayers, the recycling processes have considerable losses.

Recycled material, approved for food contact, obtains the best prices in the market. Colourless PET is part of a well-functioning market, while coloured PET market has a weak market and outlets.

6.4.3. Colours

As the outlet of recycled PET is mostly transparent or lightly coloured bottles and trays, the recycling market is less interested in strongly coloured PET. The recycling of coloured PET is thus a challenge because there is a limited end market for these products. In addition to this, such strong colouring can harm the recycling process.[168] Opaque white bottles with titanium (TiO_2) also harm some recycling processes.

Light colours are thus acceptable, while darker colours might be suitable. Carbon black and opaque colours are not acceptable.

6.4.4. Closure systems

PP and PE are the recommended materials used for closure systems on PET. Some PET types cannot be used for caps, as they are not made for injection moulding. Some says that PET should be avoided in closure systems altogether.[169]

A lidding film that can be completely removed by the consumer is the preferred option for PET thermoformed trays. If this cannot be guaranteed then a PET lidding film is recommended.[170] More knowledge is needed to find out how much of these films are removed, in practice.

IDEAL	GOOD	NOT IDEAL	BAD
PP	PE*	PET (conditional)	Metals PS PVC Silicons

Table 16 - Compatible closure systems for PET products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

[168] Antonino Furfari, Plastics Recyclers
[169] Martina Lehmann, MAKSC
[170] RECOUP (2016). *Plastic Packaging. Recyclability by Design. The Essential Guide for all those Involved in the Development and Design of Plastic Packaging. http://www.recoup.org/p/130/recyclability-by-design*

*Highly filled PE is deemed unfit. PE laminate is unfit for PET trays.

6.4.5. Sleeves and labels

The design of sleeves and labels are important for both sorting and recycling. For the sorting, it is a key issue that the NIR instrument can identify the PET bottles. In practice, the sleeve thus shall just cover max about 60 % of the bottle.

For the recycling process, it is important that the sleeves can be separated by density, from the bottle. For splitting the sleeve from the bottle in the washing process, the sleeve shall have a density of less than 1 g/ccm, for example, OPP. PVC labels are especially undesirable because of the poor thermal stability of PVC when mixed with PET[171]. It is difficult to separate PET from PVC because their densities are very similar.[172]

Polyolefin labels are ideal for PET, so PP or PE. PE is especially ideal for sleeves as it can easily be recognised by the NIR scanner as a mix of PET and PE.[173] PP is ideal for labels.

A PET sleeve on a PET bottle, although it can easily be sorted into the PET fraction, is not an ideal combination, as the sleeve cannot be separated from the bottle. The properties of the bottle are different to the sleeve and could cause trouble in the recycling process.

Furthermore, a sleeve label must not discolour the PET flake or plaques moulded from PET flakes[174]. Printing inks can contaminate wash water and stain PET flakes[175].

IDEAL	GOOD	NOT IDEAL	BAD
PP, OPP PE	Removable in-mould label EPS	Paper PET* Permanent in-mould label	Metal PS PVC

Table 17 - Compatible sleeves and labels for PET products. The colours illustrate the compatibility of each option, with dark green listed as ideal, green as acceptable, orange as less ideal, and red as problematic.

*Foamed PET or PETg is okay

6.4.6. Additives and Barriers

PET has in many cases good barrier properties, and in some cases; there is little need for additional barriers. A thicker PET material can improve the barrier and at the same time be a good measure to improve recyclability.

The best options for inserts is HDPE, LDPE, PP and PET/paper as a second best option. Solutions that are not suitable are PVC, PS, EPS, PU, PA, PC, PMMA, or thermoset plastics/metallic[176].

[171] Association of Postconsumer Plastic Recyclers (2016). *Selecting Shrink Sleeve Labels for PET Packaging – an APR Design Guide Bulletin.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/Technical-Bulletins/APR_PET_Sleeves_Tech_Bulletin.pdf
[172] Martina Lehmann, MAKSC
[173] Oliver Lambertz, Tomra
[174] Association of Postconsumer Plastic Recyclers (2012). Principles for Sleeve Labels on PET Bottles. Available at: http://www.plasticsrecycling.org/images/pdf/PET-Resins/PET-Bottles/principles_for_sleeve_labels_on_pet_bottles.pdf
[175] Association of Postconsumer Plastic Recyclers (2016). *Selecting Shrink Sleeve Labels for PET Packaging – an APR Design Guide Bulletin.* Available at: http://www.plasticsrecycling.org/images/pdf/design-guide/Technical-Bulletins/APR_PET_Sleeves_Tech_Bulletin.pdf
[176] RECOUP (2016). *Plastic Packaging. Recyclability by Design. The Essential Guide for all those Involved in the Development and Design of Plastic Packaging*. http://www.recoup.org/p/130/recyclability-by-design

6.4.7. Sorting and recycling

Recycling of PET is the only example on large scale where the circle is closed at the highest level and where new high quality packaging can be made out of recycled resin. Recycled PET bottles are used to make new bottles and thermoforms. PET thermoforms (mainly trays) which are produced with a content of r-PET (recycled PET) often above 70 % are fully complying with food contact regulations.[177] However, due to the variety of PET packaging, with quite different properties, there are many challenges related to both sorting and recycling of PET. PET thermoforms (trays and other applications) have different properties from PET bottles and are thus not recyclable together. Monolayer PET trays are more fragile and have different melting temperatures. An acceptable, but not ideal, limit of PET from other products in the PET bottle recyclate fraction is 10 %. However, this percentage is disputed or at least not accepted by all recyclers.

There is research underway to find technical solutions to meet these challenges, even for thermoformed PET products. These thermoformed applications can be monolayer or multilayers. However, these two products are difficult to split by sorting. The multilayer PET fraction has not been regarded recyclable due to technological challenges and because there have been no end markets for the recycled product. For example, Solayr - a Spanish recycler, offers solutions for multilayer PET trays. More information is needed to evaluate these solutions.

PET is easily contaminated and harmed by other plastics that make their way into this fraction, but also by glass fragments, dirt, grit, paper, glues, and product residues.[178] As little as 20ppm PE in a PET bottle can cause problems, depending on the quality standards and the type of end product.[179] PE has a lower melting point than PET (120 vs. 200) which means that as the melt starts to solidify, the PE will cause defects on the bottle.[180]

Due to very similar density to PET, it is very difficult to separate from PET. Yet, a small percentage of PVC would be detrimental to any PET recycling process. However, there is little PVC packaging left in the Nordic markets.

[177] Petcore Europe (2015). *Petcore Europe Organised Workshop on Recycling Rigid PET Thermoforms in Brussels.* Press Release. Available at: https://petcore-europe.prezly.com/press-release-petcore-europe-organised-workshop-on-recycling-rigid-pet-thermoforms-in-brussels
[178] Petcore Europe (2014). *Recycled Products*. Available at: http://www.petcore-europe.org/recycled-products
[179] Martina Lehmann, MAKSC
[180] Martina Lehmann, MAKSC

7. Attachments

7.1. Abbreviations and Definitions

Abbreviation	Description
Alkali conditions	Conditions that have a pH greater than 7
B-OPP	Biaxial oriented polypropylene
Crystalline structure	Ions, molecules or atoms held together in an ordered, 3D arrangement
Density	The mass per unit volume of a substance under specified conditions of pressure and temperature.
Deposit-return system	A surcharge on a product when purchased and a rebate when it is returned.
EPBP	European PET Bottle Platform
EPS	Expanded polystyrene
EuPIA	European Council of Paint, Printing Ink and Artists' Colour Industry
EVA	Etylene vinyl acetate
Extrusion	Raw plastic is melted and formed into a continuous profile
EVOH	Ethylene vinyl alcohol, a copolymer and plastic resin
HDPE	High density polyethylene
Hydrocalcite	A hydrous form of calcium carbonate, $CaCO_3$ H_2O
Injection moulding	A manufacturing process for producing parts by injecting material into a mould.
IV	Intrinsic viscosity is the measure of the flow time of a solution through a simple glass capillary
Laminate	Also lamination. Technique of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability or other properties from the use of differing materials.
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
Melting point	Melting point of a solid is the temperature at which it changes state from solid to liquid at atmospheric pressure
Monolayer	A single, closely packed layer of atoms, molecules or cells
Monomaterial	Made from a single material
Montmorillonite	Type of nanoclay
Municipal solid waste	Consists of everyday items that are discarded by the public
MRF	Material recovery facility
Nanoclays	Nanoparticles of layered mineral silicates
Nanofillers	A doping agent in the matrix of a composite (material with 2 or more phases), whose individual elements have at least one of their dimensions in the nanoscale
NIR	Near Infrared (radiation)
OPP	Oriented polypropylene
OPS	Oriented Polystyrene
PA	Polyamide (nylon)
PC	Polycarbonate
PET	Polyethylene terephthalate
PETG	Polyethylene terephthalate glycol
PLA	Polyactic acid
PMMA	Polymethyl methacrylate
Polyolefins	Any class of a polymer produced from a simple olefin as a monomer.

	Examples are PE and PP.
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVdC	Polyvinylidene chloride
PVC	Polyvinyl chloride
PVOH	Polyvinyl alcohol
Recyclate	Raw material sent to, and processed in, a waste recycling plant or materials recovery facility
Regranulates	Plastic granules are the basic product from which plastic products are made. Regranulate refers to recycled plastic from production waste.
Solvent-based primer	Oil-based ink
Stiffness	The rigidity of an object
Tensile strength	The capacity of a material or structure to withstand loads of tending to elongate
Thermoforming	A plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mould, and trimmed to create a usable product.
Vacuum-forming	Simplified version of thermoforming, where a sheet of plastic is heated to a forming temperature, stretched onto a single-surface mould, and forced against a mould by a vacuum.
Water-based primer	Water-based ink
Wind turbine	Used in MRFs to separate lightweight plastics from plastics that have a higher density.
Yield	The measure of a films coverage per unit weight.

7.2. Description of Types of Plastics

The table below lists the key plastic types. Each type has its number 1-6 while number 7 comprises other types. These number codes are used internationally. On a voluntary basis, plastic converters often mark the packaging with these symbols. It is important to stress that these symbols are not used for sorting plastic packaging because this sorting is done automatically by sorting machines and because almost all plastic packaging is included in the collection systems. In some countries, the collection is limited to just a few of the numbers on the list. Green Dot Norway and FTIAB recommend industry to use national consumer friendly messages and other symbols.

Code	Name and Abbreviation	Density	Properties	Usage areas
1 PETE	Polyetylene terephthalate (PET) (PETE)	1.34-1.39	• Clear and smooth surface • Barrier against air and water • Durable against shocks and heat	Widely used for drink bottles, but also as packaging for other products, including trays and cups.
2 HDPE	High Density Polyethylene (HDPE)	0.91-0.94	• Rigid and tough material • Good properties in terms of solvents • Stretchable	Widely used for bottles, also for chemical products. Heavily used in building materials and in car parts.
3 V	Polyvinylchloride (PVC)	1.16-1.30	• Resistant against fats and oils • Very strong material	Mainly used within construction for pipes, flooring, but also for garden furniture, shower curtains and toys. Found in rigid and soft products
4 LDPE	Low Density Polyethylene (LDPE) Linear Low Density Polyethylene (LLDPE)	0.91-0.94	• Good durability in relation to acids and organic oils, • Transparent	Used carrier bags, food packaging, and transport packaging.
5 PP	Polypropylene (PP)	0.90-0.92	• Good container for acids, alkalis and solvents • A strong material with a high melting point	Moulded products for buildings, cars and EE. Flexible, and rigid packaging products.
6 PS	Polystyrene (PS)	1.04-1.09	• Good protection against liquids that have a short life time • Rigid- and foam shaped • Poor transporter of heat • Low melting temperature	Often used for food packaging and for drinks. EPS is used for isolation.
7 OTHER	Acrylonitrile butadiene styrene, (ABS) Polyamide (PA) Polymethyl methacrylate,	Other plastic types [181] and laminates 1.13-1.15	• A range of different types of plastics with varying properties.	Products that are base don other types of plastic or a combination of plastics, for instance laminated plastics used for packaging.

[181] http://plastics.inwiki.org/Polymer_abbreviations, table developed by Mepex for "økt ressursutnyttelse av plastavfall", a report for the Norwegian Environmnetal Agency, 2012

Code	Name and Abbreviation	Density	Properties	Usage areas
	(PMMA) Polyurethane (PUR) Styrene-acrylonitrile (SAN)			

Table 18 – Explanation of plastic types (American Chemistry).

The classifications in the table above are independent of the raw material being used, whether it be fossil-based or biobased. In addition to these, new materials are developed continuously, biodegradable options and combinations that do not necessarily fall within one of the categories listed in the table. This can be a challenge in terms of sorting and recycling of predefined material qualities.

7.3. Sorting and Recycling

Knowledge of the sorting and recycling processes for plastic packaging is vital to the understanding of what material types can be separated from the waste stream and recycled into new products. It is also important to understand that sorting and recycling facilities are different, and that no facilities are identical. They are designed and operated in different ways. In general, this report focuses on post-consumer plastic packaging.

When mixed plastic packaging is collected separately from households, it is sent to sorting facilities where the aim is to sort the waste into different elements that can be recycled and the rest used for energy recovery. Automatic sorting technology is used to separate the plastic packaging into individual material fractions; e.g. PET bottles in one stream, LDPE packaging in another, and rigid PP packaging in a third, etc The aim for the sorting processes is also to remove impurities like food waste, papier glass, metal and other wastes, and.

Plastic packaging from Norway and Sweden is often sent to a clean material recovery facility (MRF) in Germany where this input is only a small part of its total capacity. There are differences between plants of how advanced the sorting systems are, and results have shown quite large variations.

The same sorting technology used in MRFs for plastic is used in facilities for separating plastic materials from mixed residual waste in a dirty material recovery facility (MRF) also called Mixed-waste processing facility (MWPF). This is not a common solution in Norway and Sweden, but this will probably be further developed and expanded in the future. The first plant is in operation in Norway (ROAF), one plant under construction (IVAR, Stavanger) and 3 more in the planning phase.

Sorting plants include a combination of different technologies:

- Drum swifter for size sorting
- Ballistic separator
- NIR detectors
- Wind-sifter
- Metal detectors

The sorted qualities of plastics are normally sent from sorting plants to separate washing and recycling plants. In this stage, separation technics are used to produce a quality for recycling and will normally include:

- water bath separator with a sink/float process
- drying and wind-sifter to separate lighter pieces of plastic film and paper from heavier pieces
- extruder with filters to remove impurities

Material properties are vital for the sorting and recycling ability in different processes. Different materials have different NIR-reflections, different densities and different melting points; all important factors for sorting and recycling processes. These properties will be discussed in the following sections.

The bullet points below explain what can happen to a HDPE bottle with a PET sleeve:

- The product is incorrectly identified as PET through a positive sorting process
- The product is not identified as unwanted in the PET stream through negative sorting and ends up as a contaminant in the PET fraction.
- In the washing facility for PET, HDPE will float and be extracted from the PET fraction, leading to a loss in this material from the circular economy.
- Some HDPE will remain in the PET stream.

- The remaining HDPE will melt at 130C and will not be separated through filtering, but end up in the final PET recyclate as a contaminant.

The remaining plastic material that has not been sorted into a material fraction, ends up in a mixed plastics fraction that is difficult to recycle. Some of it will also end up in the waste stream for incineration or landfill.

7.3.1. NIR sorting technology in sorting plants (MRF)

NIR technology is used to identify plastic material types and forms the basis of ensuring that they end up in the right fraction. NIR stands for Near Infra-Red and is used as a standard for source separated packaging material and in 60-70 % of all MRFs today.[182] However, few plants are fully automated, e.g. some sorting and quality control is still often done manually. NIR detectors can recognise different types of plastics by reading their reflection at the "surface" of the product. Each material type has a specific reflection with a range that can be recognised. The NIR detector can be optimised to identify and sort a wide range of packaging structures.[183] It can also detect different types of thin multi-material structures such as PET/PE and PE/PA based on the reflection going into the material and thin film layers. However, in general, laminated film still is regarded as a challenge. In the same way, the NIR technology neither manages to sort monolayer trays from multilayer trays.

The NIR detector works closely with jets that blow out compressed air. These jets are used to 'blow' the various material types into their respective plastic streams. The compressed air can vary in strength depending on the weight of the material that is 'blown' out. This way, heavy units with residues can avoid being separated to reduce the chance of contamination. The list below shows what the NIR technology can identify:

- *Material types:* PE, PP, PET, PS, PVC, etc.
- *Product shapes:* bottles and trays
- *Coloured plastics:* clear, opaque and solid colours
- *Specific branded products*: can remove specific unwanted packaging
- *Weight:* remove packaging with residues

For products that consist of various materials, such as a HDPE bottles with a PET sleeve and a PP cap, the NIR detector could mistakenly identify the product and send it into the wrong fraction. Sleeves, labels, caps, and film made from a different type of material than the packaging product body can contribute to incorrect sorting. If the secondary material covers a large part of the surface of the packaging body, the higher the chance is of incorrect sorting.

NIR technology has become incredibly useful in the separation of plastics, however there are also several challenges associated with this technology. The NIR detector cannot detect material containing the pigment carbon black, nor can it detect material combinations (film on rigid packaging, sleeves and labels, multilayer trays etc.). Technology with the ability to sort black plastic with carbon black pigment is under development and there are several technology suppliers that could potentially be on the market in the near future. So far the experience from operations is limited and the solutions for the market are not yet available.

A sorting plant can build up its own database of material spectrums that it can identify, this way allowing for more material to be sorted and recycled – local products can be common in some areas whilst unknown in others. It is expected that 70-90 % of all the plastic that enters a sorting plant will be sorted

[182] Oliver Lambertz, Tomra
[183] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.

into its correct material stream. However, every time the NIR detector is adjusted, other fractions that are similar, are lost from the waste stream.[184] The operation is thus optimized continuously.

Positive separation, which identifies the sought-after plastic material types, is used in combination with negative separation. Negative separation is used to remove unwanted items and to further increase the quality of the material streams sorted for recycling.

Sorting facilities are often assessed based on their functional abilities, which are generally based on the overall yield and quality (purity) of the plastic. The recycling yield is regarded as the proportion of a specific type of plastic packaging that can be separated and sent to recycling. Contaminations in the material stream are not included. Plastic packaging that contains a large amount of residues are unwanted because of their contents of either chemicals (that can influence recycling), or food that contributes to smell and growth of bacteria.

The purity of a material stream specifies how much of the stream has been correctly sorted (in wt %). The specified yield and quality normally includes moisture and product residues. The separation efficiencies for flexible packaging, including trays, compared to rigid packaging are less than would be expected due to the behaviour of the lightweight material on the sorting belt.[185] Yield and quality are controlled by testing the outgoing material streams, and often comparing them to the material that comes into the sorting plant. There are many tests that document the yield and quality of different material types that come out from the various sorting plants.

Material type	Yield (%)	Quality (purity) (%)
PE-film (incl laminated PE)	84-89	93-96
HDPE	74-80	97
PP-rigid	70-75	96-98
PET- bottles	70-75	97
PET-pots/trays/tubs (incl. film)	60-62	97

Table 19 – An example of yield and quality (purity) from a sorting plant in Norway.

7.3.2. Washing and recycling technology

Water bath technology is an additional way of separating plastic types and impurities from each other. Prior to the water bath that has a sink/float process, plastic packaging products are crushed into smaller plastic flakes, 10-15mm in size, making them easier to separate.

Plastic packaging materials have different densities which can be used to assist in their separation. Sink/float technology is used in washing facilities to upgrade the quality of the of the pre-sorted plastic material. In conventional washing facilities using hot or cold water, heavier plastics will sink and can be separated from the lighter plastics that float.

Most of the secondary materials, such as labels, sleeves, glue, caps, etc. are removed during this process. This also includes product residues that are water soluble. The following table shows the density of each polymer and their behaviour in the sink/float process.[186]

[184] Comment from participant at workshop
[185] McKinlay, R. and Morrish, L. (2016). *REFLEX Project – A Summary Report on the Results and Findings from the REFLEX Project.* Axion Consulting.
[186] Plastic packaging, Recyclability by design. Recoup 2015

Polymer	Density g/cm³	Behaviour in float process*
Ethylene vinyl acetate (EVA)	Less dense than water	Float
Polypropylene (PP)	0.90 - 0.92	
Low density polyethylene (LDPE)	0.91 - 0.93	
High density polyethylene (HDPE)	0.94 - 0.96	
Polystyrene (PS)	1.03 - 1.06	Variable
Nylon (PA)	1.13 - 1.14	Sink
Acrylic (PMMA)	1.17 - 1.20	
Polycarbonate (PC)	1.2	
Polyethylene terephthalate (PET)	1.30 - 1.38	
Polyvinyl chloride (PVC)	1.32 - 1.45	

Table 20 – Polymer types, their densities, and their behaviour in the sink/float process.

Colour pigments, fillers and other additives can impact the density of a plastic and contribute to less precise separation in the sink/float process. Biobased plastics such as PLA that have a density higher than 1, can have a similar density to PET, making it possible for the two materials to end up in the same fraction. It is crucial that PLA is not recycled together with the PET.

Wind sifters are used after washing and drying to separate thin, light film, paper, and other contaminants, from the thicker, rigid packaging. They are vital to upgrade the material streams to separate heavy fractions from the lighter ones.

The following table lists the various units, with a description of their function, that are often found in washing facilities.

Component	Function
Crusher	Opens the bales and coarsely grinds the material (80mm). Can be supplemented with a magnet to remove metals.
Pre-washer	Removes most of the product residues and heavy particles
Wet-mill (crusher)	Crushes the material to fragments of 10-15mm in size
Friction washer, warm water (turbowash)	Glues and labels are removed
Separation tank and centrifuge	Separates plastics of varying densities. Heavy plastics are efficiently separated (PET, PVC) from light, floating plastics (PE, PP)
Dryer	Dries the product
Wind shifter	Contaminants such as paper or film are removed
Extruder with filter	Melts the plastic material and produces flakes. Different filters can lead to different losses. Loss of material can vary from 2-6 %.

There is also a potential to use NIR detectors to sort flakes from a mixed material composition with different plastics. To produce food grade material there is need for special processes to upgrade the recycled material. These processes are most common for PET-recycling.

After the plastics have been shredded, washed and the fragments have undergone processes to eliminate impurities, the material is melted and extruded into the form of pellets. The melting temperature varies between plastic materials, from 130C to 250C. If a stream of plastic with low melting temperature is contaminated with plastic with a high melting temperature, the contaminants will not melt and can decrease the quality of the recyclate if it is filled with grains for example. PET impurities in PE and PP will have a big influence on the quality of the recycled PE/PP. Some of the particles will be removed in the filters that have a width of 0,1-0,3 mm. The pellets are then used to manufacture other products. It is a general trend in the recycling market that customers require higher quality plastics.

Tests and calculations have also been made of material that has come out of the washing and recycling process. This process has several areas where there is a loss of contaminants, unwanted plastics, and a significant amount of plastic material that is fully recyclable. It is difficult to specify the amounts of loss in each fraction. Incoming material could consist of 5-10 % product residues and moisture and 5 % material that has been incorrectly sorted. 10-15 % of the incoming material is therefore not eligible for recycling. The following specifications are expected to be fulfilled for a complete washing and recycling facility with sink/float, wind shifter and extruder:

Material type	Yield	Quality (purity)
Film	65-70 %	Min 99,7 %
HDPE	75-78 %	Min 99,7 %
PP	70-75 %	Min 99,7 %

Table 21 - An example of yield and quality (purity) from a recycling facility.

7.3.3. Outline description of market for recycled plastics

Material	Market description
Rigid PP	PP is recycled into several products. There is a good market for PP-recycling both in Europe and in the Far East. Recyclers normally separate the different grades of PP material before processing; this creates a better quality product for onward sale to manufacturers.
HDPE	HDPE is a commonly recycled plastic material. Almost all European countries collect HDPE packaging for recycling. Recycled material is partly used as long- lived products such as pipes, partly as packaging.
PS	The market for recycling of PS-packaging is limited and not well developed. The content of PS in a mixed plastic packaging stream is normally limited and has often not been sorted out at sorting plants. PS is also often crushed into smaller pieces and all pieces less than 50 mm are normally removed in a residual fraction.
PET	About 50% of all PET bottles in Europe are recycled, partly into new bottles, partly into sheets and fibres. Bottles are in general suitable for recycling. The PET bottle producers and brand owners are in general clever to follow the industry guidelines for recyclability, EPBP. However, new PET bottles with a special barrier for milk products are not recyclable today and are thus sorted out for incineration (case France). Thermoformed plastics like trays are either monolayer or multilayer. Monolayer PET, might to a certain extent, 5-10%, be mixed with PET bottles for recycling. Multilayer PET packaging is difficult to recycle. Technologies to split or dissolve the layers are in progress. However, multilayers and mixes are for the moment often incinerated. Chemical recycling is an option for clear and clean PET flakes, e.g. very strict quality criteria.

LDPE-film	There is a good global market for recycling of LDPE film, especially clear film from commercial sources. Prices for recycled plastics of the right quality are quite high, but there is a large difference in prices depending on quality. Mixed, coloured PE-film from post-consumer plastic has a limited market and the prices are very low. The production of LDPE recyclate from household plastic packaging is limited and the prices low. In practice, recyclers often mix LDPE of different quality.
PP-film	In Europe, there is no specific recycling market for PP- film. However, the bottleneck for PP-film recycling is the missing demand for the recyclate. Users of PP-film have normally high requirements related to colour (clear/ light) and food contact.

7.4. Biobased, Oxo-degradable and Biodegradable Plastics

This text gives more information to the summary given in Chapter 4.11. This chapter is based on the Mepex report "Sources of microplastics" commissioned by the Norwegian Environmental Agency and published in December 2014. In addition, we refer to three recent studies related to recycling and recyclability.

Plastic items degrade, some more slowly than others, depending on the kind of plastics, the additives used and of course the conditions where the degrading takes place. In order to improve the quality of the plastic products, avoid degradation and thus prolong their life, special additives are used, for example in products that are exposed to the sun. In recent years, other materials have been added for the opposite reason, to start a process of defragmenting the plastics as a basis for further degradation.

There is some confusion of the definition of bioplastics vs. biodegradable plastics[187]:

- Bioplastics encompasses a whole family of materials, which differ from conventional plastics insofar as they are biobased, biodegradable or both.
- The term biodegradable refers to a chemical process during which microorganisms that are available in the environment convert materials into natural substances such as water, carbon dioxide and biomass. Artificial additives are not needed here.

The following table on biobased and biodegradable plastics illustrates the differences further, also with some examples on common plastic types.[188]

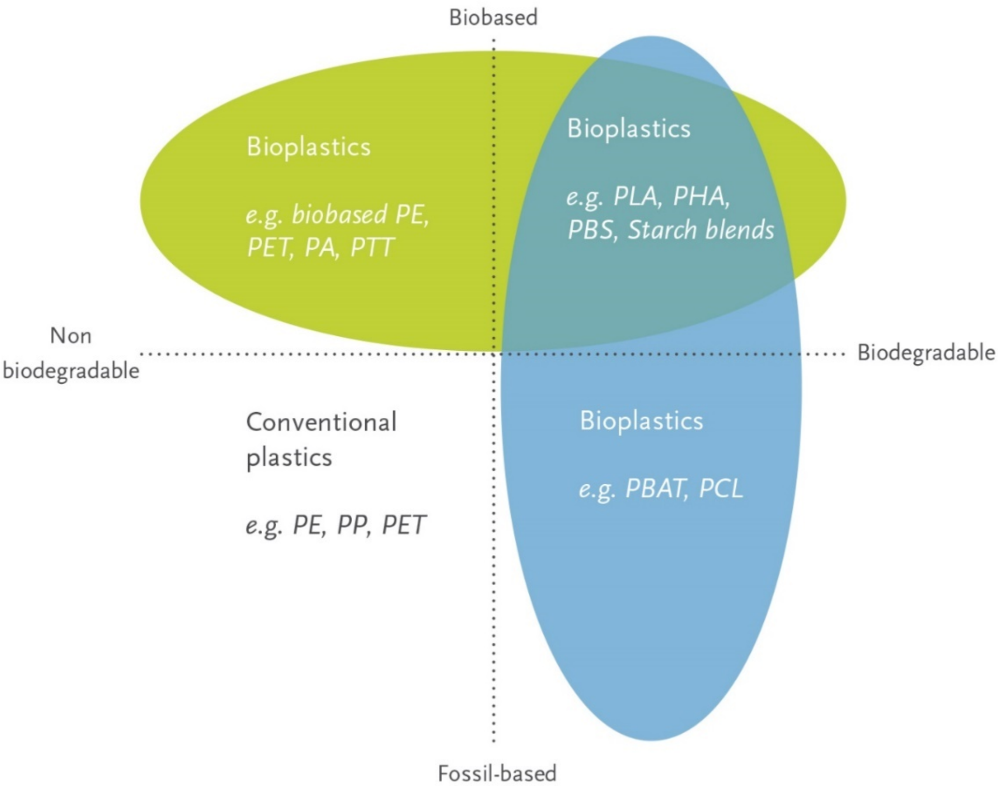

Figure 3 - Biobased vs. fossil-based plastics and biodegradable vs. non-biodegradable plastics.

[187] http://en.european-bioplastics.org/bioplastics/
[188] http://en.european-bioplastics.org/bioplastics/

7.4.1. Oxo-degradable plastics

Oxo-degradation results from oxidative cleavage of macromolecules[189], in which additives are used to facilitate this.[190] These plastics can be either fossil- or bio-based, however, the bioplastics industry does not regard oxo-degradable plastics as being biodegradable. Oxo-degradable plastics are normally fossil plastics with additives to initiate degradation.

More knowledge is needed to understand the processes of degradation and biodegradation. Oxo-degradable plastics are increasing in use, especially in the Middle East. Some carrier bags in Norway are marked as oxo-degradable.[191] These bags are LDPE bags that contain an additive, and will thus be sorted as LDPE film at the MRF and could cause problems in the recycling process - oxo-degradable material could have detrimental effects on some products that must be wrapped in virgin material[192]. The use of oxo-degradable film should for this reason be avoided.

7.4.2. Biodegradable plastics

Some plastics are developed to be compostable or biodegradable. These plastics can be either fossil- or bio-based. Some products can also be a mix of fossil- and bio-based plastics, for example, the Coca Cola PET bottles introduced in Norway. There are many products that claim to be more or less degradable or compostable, or have certain properties. The use of these plastics has so far been limited, however, further growth is expected, especially for packaging applications. Knowledge of all kinds of degradable plastics and their impacts is therefore heavily desired.

7.4.3. Production volumes and applications

Compared to the annual global plastic production of about 300 million tons, biodegradable and compostable plastics amount to a very small, albeit rising, share. This includes all kinds of biobased plastics as well, which in total amounts to 1-2 million tons (in 2012).

The chart below, Figure 4, differentiates between biodegradable plastics (fossil or bio based) and non-biodegradable/biobased. As illustrated in the figure, the market is slowly growing, mostly for biobased plastics, such as green PE, e.g. plastics with the same properties as other (fossil) plastics. The chart does not include oxo-degradable plastics, normally fossil plastics with additives to initiate degradation. There is limited information on oxo-degradable plastics.

[189] According to CEN/ TR 15351
[190] The standard defines the processes, not materials, which means that the definition of Oxo-degradable plastics is not provided, according to Deconinck, S., & De Wilde, B. (2013). Benefits and challenges of bio- and Oxo-degradable plastics. A comparative literature study, OWS N.V, Belgium.
[191] For example, carrier bags from the TGR stores in Norway are marked with "This bag is oxo biodegradable and will naturally break down after 18 months".
[192] RECOUP Recyclability By Design (as is covered, page 52) http://www.recoup.org/p/130/recyclability-by-design

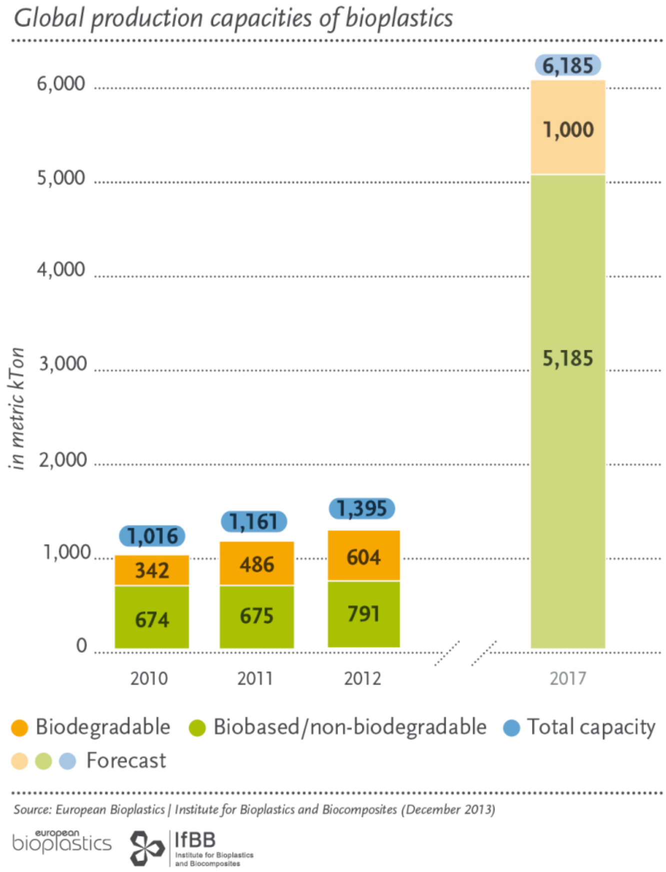

Figure 4 - Global production capacities of bioplastics (European Bioplastics)

Biodegradable, compostable and oxo-degradable plastics are often used for carrier bags, bin bags, including compost bags for food waste, beverage bottles, and packaging for catering. The bio-bags sold in Norway for food waste are examples of starch-blended bags.

The figure below, Figure 5, shows that global production capacities are related to different applications. Bio-PET, often called plant-based bottles, is one of the largest applications. Bio-PET has the same properties as fossil-based PET, both regarding recycling and degradation. The same can be said about bio-PE, often called green PE. Green PE is used to a certain extent in the Nordic market, for example as toilet paper packaging. Green PE from sugar cane and bio-based plastics from the woods will be more common in the coming years.[193]

PLA and PLA-blends are used in bottles, packaging, catering products and other specific products that are exposed to littering. Starch blends are used in biobags, bags that are designed for composting and can be certified according to the European standard for industrial compostable products, EN13432. Horticulture and agriculture is one sector where these products are promoted, for example for mulch film. There is likely to be further growth in compostable and biodegradable plastics, in addition to a variety of different types of such materials.

[193] Wik, Pär, Trioplast, Sweden, personal communication, presentation at Polymerdagene in Norway, September 2015

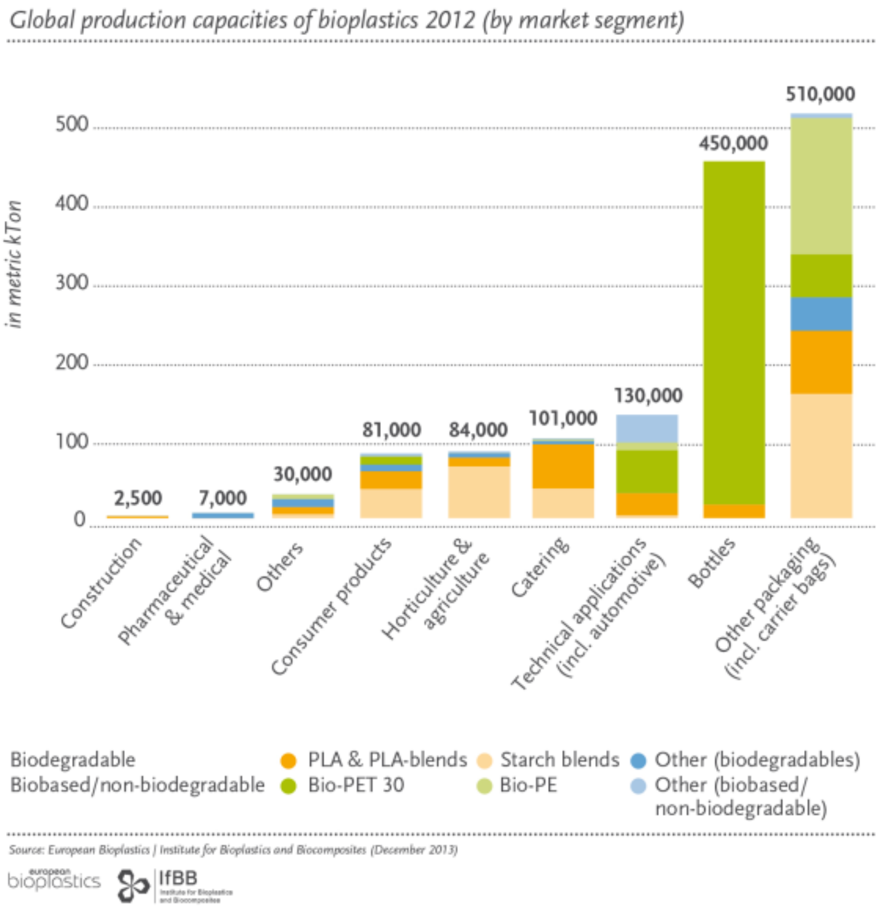

Figure 5 - Global production capacities of bioplastics 2012, by market segments (European Bioplastics).

Plastics are designed to meet certain defined properties, for example to be compostable. Standards, like EN 1324, are used as a tool in the market to identify these properties. Biodegradable plastics are often used for kitchen waste and follow the stream to compost or biogas plants. In Northern Europe, biogas plants are more and more common. At these plants, all kinds of plastics are sorted out and sent to incineration. Bio-bags are promoted in many countries, while LDPE and HDPE bags are taxed or banned. In this way, LDPE and HDPE bags end up in the MRFs, and are sorted out for recycling. However, the well-known Novamont bio-bag, do not contain LDPE which means it is sorted into the mixed waste fraction or as waste for incineration.

Below follows an updated chart on global production capacities of bioplastics 2016, by material type. The biodegradable bioplastics amounts to 24.1% of the total amount.[194] Non- biodegradable PUR amounts to as much as 41.2%, while non- biodegradable PET contribute with 22.8%. All figures relate to capacities, not to real tonnage put on the market.

[194] European Bioplastics, homepage

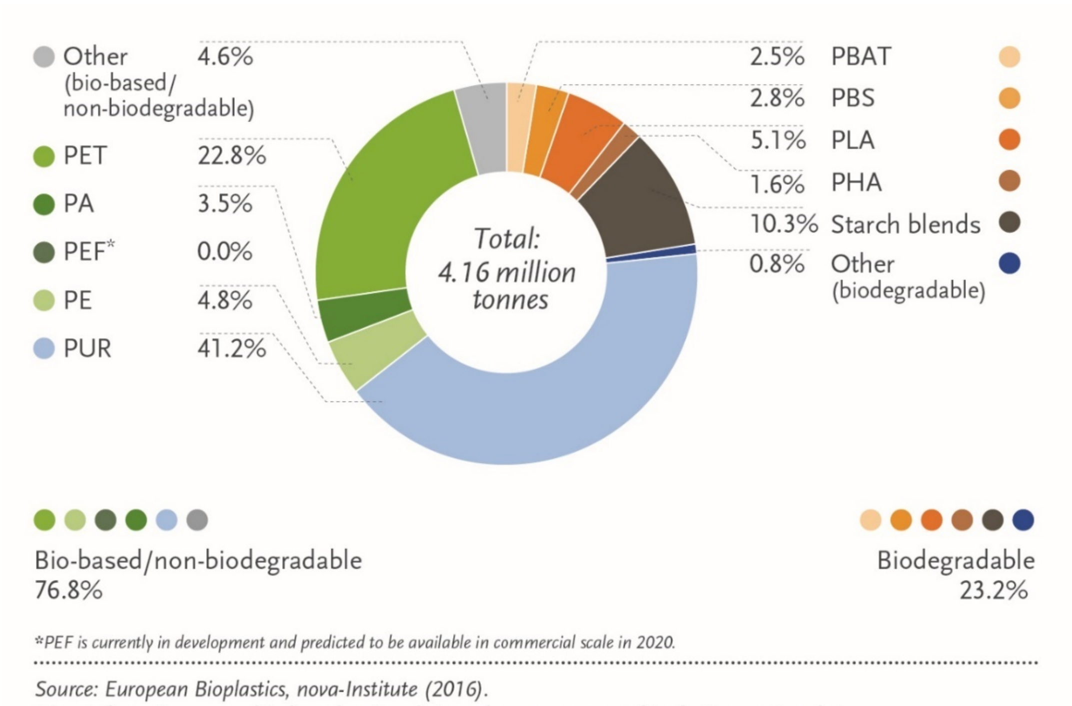

Figure 6 – Global production capacities of bioplastics 2016, by material type.

7.4.4. Sorting and recycling of bioplastics

Biobased plastics are not necessarily compostable and compostable plastics are not necessarily biobased.[195] There is already a variety of combinations, and it seems we will see many more. This variety indicates a high degree of innovation, and probably more challenges within collection, sorting and recycling.

In 2016, Cefur-center för forskning och utveckling in Ronneby, published a report underlining that plastics recycling today is challenging as there are so many different types requiring different and individual recycling treatments. Plastics also degrade differently during their lifetime. The introduction of various biobased plastics, contributes to an even more complex situation. There have not been enough studies on the impact of mixing different types of plastics and the degradability of bioplastics.

This Cefur-study demonstrates potential challenges for future recycling systems due to the variety of biobased plastics with similar, albeit not identical structures and properties with other plastics. Solutions could be new labelling systems, better sorting technologies and new additives/compatibilizers for the recycling processes.

In several applications, such as beverage bottles and carrier bags, biodegradable products are used side by side to fossil-based plastic products. It is difficult to separate biodegradable and biobased plastics from conventional forms. Some biodegradable products can harm the plastic recycling process so the use of and disposal of these is heavily debated. One PLA bottle in the PET fraction can contribute to severe quality problems for the PET recyclate. In a similar way, new biogas plants that replace former compost plants do not want plastics of any kind in their processes.

[195] World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company (2016). *The New Plastics Economy - Rethinking the future of plastics*. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_TheNewPlasticsEconomy_19012016.pdf

Biobased plastics such as PLA can be separated from other plastics using NIR technology. The NIR detector can separate PE, PP from PLA at least, and potentially other biodegradable plastics. Danone and other industrial players have run tests on these products.[196] The NIR detector can be programmed to identify biopolymers or variations of polymers (e.g. PLA or starch blends) if they have a different NIR signal. Existing sorting systems can easily identify bio-PET and its conventional counterparts.[197] The idea is that they are compostable and can be recycled into new PLA products.[198] However, just one PLA bottle sorted at PET by mistake can harm the quality of a whole lot of PET bottles.

The composition of degradable plastic bags and plastic film is often unknown, which makes it difficult for the NIR detector to identify these products. Biodegradable products can consist of LDPE film and thus be sorted out into that fraction in MRFs. Biodegradable plastic packaging could end up, by mistake, in different plastic fractions which can then harm recycling in the next step. In the MRF, there is no way to separate a piece of PE film from PE that has an xo-degradable additive, because the spectral information is identical.[199]

If biodegradable or degradable plastic film ends up in the LDPE film fraction, this will harm the recycling process and the end-products. This can damage the value of LDPE regranulates. According to an Ecoembes study in Spain, even small amounts of degradable material in the LDPE stream involve increased processing costs. Biodegradable polymers are incompatible as they have a different melt flow index.

According to the study "Impact of Degradable and Oxo-Fragmentable Plastic Carrier Bags on mechanical recycling" (Transfercenter für Kunststofftechnik GmbH, 2012), "[…] as little as 2 % oxo-fragmentable or degradable materials in the recycling streams can affect the quality of recyclates, hence the production of a new PE-film. The reasons for these problems are due to unsteady bubble and melt pressure varied during the extrusion of new blown film process, and decreased mechanical properties of all the mixes of degradables

It is likely that as the quantity of biodegradable plastics increases, especially for carrier bags, the more contamination of LDPE film will be evident in the MRF. Mechanical processes such as wind shifting, used to separate the heavy fractions from the lighter ones, will not be able to separate the different film-materials.[200] Certain reports conclude that the LDPE film fraction is ruined if more than 2 % is biodegradable plastics. Other tests state that the number is somewhat higher, depending on the properties in the end product. Some say a 10 % mix is okay.[201]

Bioplastics can be mechanically or organically recycled.[202] Biobased or biodegradable plastics are often designed to be either recyclable or industrially compostable. Some biobased plastics, such as PLA and PHA, are in theory both recyclable and industrially compostable.[203] The volumes of PLA are not yet at a sufficient level to make sorting economically viable.[204] Most bioplastics can be made ready for use in

[196] Oliver Lambertz, Tomra

[197] European Bioplastics (2015). *Mechanical Recycling.* Available at: http://docs.european-bioplastics.org/2016/publications/bp/EUBP_bp_mechanical_recycling.pdf

[198] Oliver Lambertz, Tomra

[199] Luca Stramare, Corepla

[200] Oliver Lambertz, Tomra

[201] Oliver Lambertz, Tomra

[202] European Bioplastics (2016). *Bioplastics – Furthering Efficient Waste Management*. Available at:http://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_end-of-life.pdf

[203] World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company (2016). *The New Plastics Economy - Rethinking the future of plastics*. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_TheNewPlasticsEconomy_19012016.pdf

[204] European Bioplastics (2015). *Mechanical Recycling.* Available at: http://docs.european-bioplastics.org/2016/publications/bp/EUBP_bp_mechanical_recycling.pdf

material recycling; however, it may require additional steps. PLA will have to go through an additional step of poly-condensation, or a special crystallisation stage.[205]Material recycling of biobased PE and PET PET fit into existing recycling systems for fossil-based plastics.[206]

Mepex concludes that the volumes of degradable, biodegradable, compostable and other biobased plastics still represent small volumes in the household waste. In addition, these products have so far, just to a limited degree been collected, sorted and recycled with other plastic packaging. Thus, the potential problems and challenges described above have so far not been recognized nor have they received got much attention in the debates. However, the volumes and the number of alternative compositions are increasing, especially for plastic packaging including shopping bags. This is partly due to national bans, taxes and other motivated initiatives.

As the LDPE film represents the major plastic packaging type in Scandinavia, these systems are vulnerable to contamination of this waste stream. A possible increase in the use of different types of degradable films represent therefore a certain risk for more contamination and thus a less attractive LDPE-material for sale. To reduce these contamination risks, better sorting technologies might be an option. On the other hand, "stricter" sorting might again increase losses (and investments and costs) in the sorting and washing processes. In addition, some degradable PE-film is regarded impossible to sort out from other LDPE.

As an alternative, discussed in Italy, all compostable plastics can be collected in a separate system. However, such a (small) system just for compostable materials will probably not accept other biodegradable and oxodegradable plastics (not compostable by the standard) and thus not solve the described contamination problem. Furthermore, Nordic biogas plants, and even compost plants, are probably not able (or interested) to treat these compostable plastics. The last option is then incineration, which again is a poor solution for a circular economy.

At this stage, biobased, oxo-degradable, and biodegradable plastics cannot be recommended as long as they might be collected as residual waste or the plastic waste from households. For industrial use, it is even more important to keep the degradable film apart from separate collected LDPE film, as these collected films are normally entering the recycling process directly.

[205] European Bioplastics (2015). *Mechanical Recycling.* Available at: http://docs.european-bioplastics.org/2016/publications/bp/EUBP_bp_mechanical_recycling.pdf
[206] European Bioplastics (2015). *Benefits of Biobased Rigid Packaging.* Available at: http://docs.european-bioplastics.org/2016/publications/bp/EUBP_bp_Rigid_Packaing.pdf

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