RECYCLING OF PAPER AND BOARD IN THE NETHERLANDS IN 2019

KCPK

COLOPHON

TITLE Recycling of Paper and Board in the Netherlands in 2019

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PUBLICATION DATE
27-05-2020

NUMBER OF REPORT AND VERSION
2020-1

COVER IMAGE
Disclaimer: The brand shown in the cover image is not related to the content of this report.

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MANAGEMENT SUMMARY

This is the management summary of the report "Recycling of paper and board in the Netherlands in 2019". The report describes the current situation of paper recycling (reprocessing of used paper in a production process into new paper and board[1]) in the Netherlands and appoints the focus areas for the coming years that can contribute to further increasing the recycling of paper and board in the Netherlands. This report is based on two stakeholder workshops, on desk research and two inventories of the current limitations to recycling at all individual paper and board mills in the Netherlands that are affiliated with the VNP (Royal Association of Dutch Paper and Board Mills). The project is co-financed by the EU as part of the H2020 CIRC-PACK project, by KIDV (Netherlands Institute for Sustainable Packaging) and by PRN (Foundation Paper Recycling the Netherlands). This research has contributed to the development of a recyclable detergent powder packaging within the scope of the H2020 CIRC-PACK project. KIDV will use the content of this report for creating a recyclecheck for paper and board packaging and PRN for the new collection guidelines for *Paper for Recycling* for consumers.

In the Netherlands 3 million tonnes of paper and board is produced annually, of which 2,2 million tonnes is intended for packaging. 86 percent of all paper and board that is produced in the Netherlands, is produced from Paper for Recycling.[2] The Netherlands shows a really high collection rate of marketed paper and board(84 percent)[3]. The collection rate of marketed paper-based packaging is even higher (87 percent)[4]. Despite these high rates, there is still room to further increase the collection and recycling. This report has been written from the position of the Dutch paper and board industry and describes the measures that can be taken to improve the quality and quantity of the collected raw materials and thereby further increase recycling. The basic premise of the paper and board industry is that all paper and board is recyclable, on condition that the logistics and the recycling method are adapted to the paper-based product. In relevant cases, the principle can refer to the reuse of *Paper for Recycling* in other sectors than the paper and board industry.

[1] Confederation of European Paper Industries (2014). Pulp and paper industry, definition and concepts. 13-01-2019. http://www.cepi.org/system/files/public/documents/publications/statistics/2014/FINAL%20CEPI%20Definitions%20and%20Concepts_0.pdf

[2] Royal Association of Dutch Paper and Board Mills (2019). Annual report 2018, Fibre Future Factory. 23-05-2019. https://vnp.nl/over-vnp/jaarverslagen/

[3] Foundation Paper Recycling the Netherlands (2018). Results monitoring collection and recycling of non-packaging applications of paper and board, 2017. 23-05-2019. https://prn.nl/prn-en-het-prn-systeem/prn/rapportage/

[4] Packaging Waste Fund Foundation (2018). Packaging in the circular economy, recycling packaging in the Netherlands 2017. 23-05-2019. https://afvalfondsverpakkingen.nl/monitoring/publieksrapport

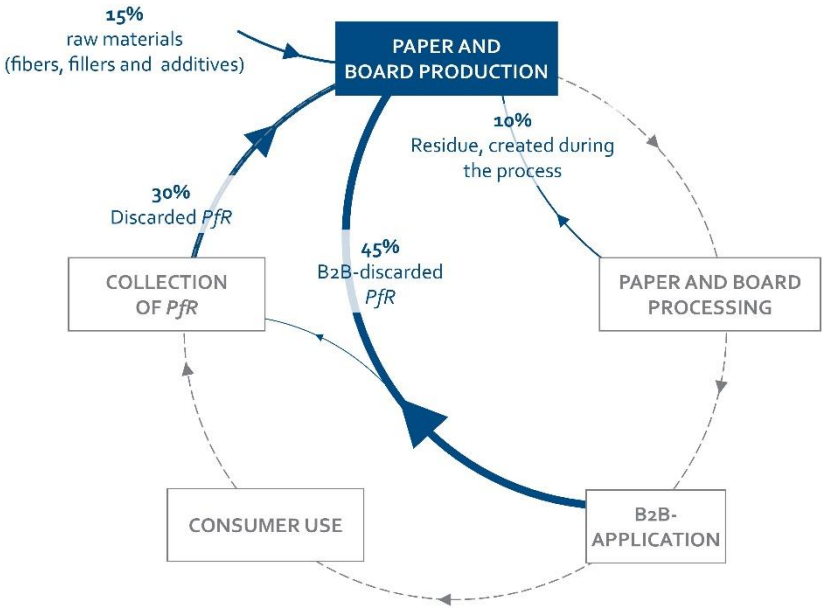

Figure 1: The material cycle of paper and board (simplified representation) serves as a source of raw materials for paper and board production (percentages and thickness of the arrows are an indication of the volume of the material flows)

The paper and board cycle in the Netherlands is characterised by five steps and these are connected in multiple ways: (see figure above)

1. Paper and board production; production of paper and board from *Paper for Recycling* (for better readability from now on *PfR*) and / or virgin fibres, fillers and additives in the 22 paper mills in the Netherlands (including recycling)
2. Paper and board conversion; conversion of paper and board into packaging, graphic products, hygienic products etc.
3. Use by B2B-applications; use of paper-based products by offices, stores, services and industry (including out-of-home consumption, such as at institutions, festivals and recreation parks)
4. Consumer use; use of paper and board based products by consumers.
5. Collection of paper; disposal and collection of *PfR* through the variety of collection systems in the Netherlands for the benefit of the consumer (including possible dry sorting)

The residu that is created during processing, serves as direct input for the production of new paper and board. The same applies to paper and boardbased products that are discarded from a B2B application. The cycle is not completely closed: a supply of fresh fibers, fillers and additives are always required.

Paper and board includes any cellulose-based fibrosus material formed from a suspension into a cohesive sheet or web, with or without the addition of fillers and or additives. Grammages up to 200 to 250 g/m² are called paper, while grammages from 200 to 250 g/m² are called board. Different groups can be identified within the types of *PfR* . There is an official standard (EN643) that describes the difference between the 57 quality groups.

For the overview, the system has been simplified to three main groups:

- Colored paper (85-90% of the total *PfR*); mixed *PfR* mainly used for the production of paper for corrugated board and for solid board
- White paper (10-13% of the total *PfR*); high-quality *PfR* that can usually be used again after deinking for graphic, hygiene, and technical applications as well as white packaging.
- Multi-materials (<2% of the total *PfR*); The most famous representative of the types of *PfR* that are difficult to recycle are the beverage cartons, that can only be recycled with an adapted process. These packages are now processed at one location in the Netherlands via separate logistics flows.

The basic premise of the paper and board sector is that all paper and board that is collected, can be recycled. The condition for this is that the logistics are well organized throughout the chain. When collecting, pre-sorting should already be done in the above subcategories: comparable qualities of paper should be collected together as much as possible. As a result, the *PfR* can be sent as a type-homogeneous stream either to an adapted paper mill that specializes in specific types of paper, or to a regular paper mill that can adjust its recycling process to the incoming flow. Type-homogeneous flows are particularly easy to realize in the event of a B2B disposal.
The performance of paper and board is continuously improved. An important development within this is the application of barrier properties, so that paper can be used as a substitute for plastics. Materials with barriers to oxygen, moisture and / or water vapor, among other things, are being developed and used in packaging. The materials that increasingly compete with plastics also behave more and more like plastics in paper recycling. When developing new paper and board-based packaging, the recyclability of the new materials must explicitly be taken into account.
Furthermore, the application must be "fit for purpose" and overdimensioning must be avoided as much as possible. When determining the fitness for purpose, account must be taken of the production and use phase as well as the options for collection and recycling.
Separation at the source, whether by consumers or in a B2B environment, is strongly preferred, with the *PfR* being collected as clean and type-homogeneous as possible. This is necessary to guarantee the hygienic quality of paper and to enable recycling with minimal treatment. The exception is the beverage carton in the PMD stream, which must be rinsed clean when it is discarded and collected separately.

For optimal recycling of paper and board, the following points of attention apply:

PRODUCTION

- A too low fiber content is not acceptable. Only material consisting of more than half of paper fibers is suitable for recycling.
- In addition to fibers, fillers and additives are necessary for many paper applications. There are several hundred different fillers and additives in use that largely do not negatively affect reuse. There are some specific additional materials, such as "high wet strength materials", which ensure that paper is so strong that adapted logistics are required to be able to recycle this material.

PROCESSING

- Papers that are completely moisture-resistant ("glued") or wet-resistant on both sides are not given enough time to disintegrate in regular paper recycling processes. Thus they are largely separated as discarded material.
- Combined use of white and colored fibers automatically limits recycling to colored applications and should be avoided as much as possible due to downcycling.
- Foreign material (all materials that are not necessary for the functionality of the paper and board) should be avoided as much as possible in *PfR*. In the aforementioned EN643 quality standard for paper, a maximum percentage of 1.5 of foreign substances is set at bale level.
- *PfR* from which substances dissolve during recycling can lead to disturbances in the process (unwanted slime or odor nuisance) or have a negative effect on product quality. Therefore, avoid adding such substances in every link of the chain. Important recommendations for this include:
    - Minimize the use of synthetic, non-water-soluble glues and adhesives.
    - If processing and application allow, use paper based tape instead of plastic tape and avoid the use of pressure sensitive adhesives as much as possible.
    - For white papers, avoid using water-soluble inks because they cannot be removed.
- Classic UV inks and varnishes do not dissolve, but splinter / desintegrate and as colored dots, they can have a negative effect on the quality of a white paper or board. Recyclable UV inks / varnishes are now commercially available. The use of the classic variants should therefore be avoided as much as possible.
- Chlorinated substances such as PVC and PVDC can form unwanted conversion products when burned and should therefore be avoided in every link of the chain.
- In any case, the use of health-damaging substances must be avoided in every link of the material cycle. This also includes mineral oils, bisphenol A, phthalates, unreacted photo-initiators, etc..

COLLECTION (B2B OR OUT-OF-HOME)

- For concentrated flows of wet-strength papers (including bottle labels, paper towels or coated drinking cups), a separate logistics channel can be set up so that the materials can be recycled in an appropriate recycling process. If such a special logistics route is not available, wet-strength products should be avoided as much as possible. This also applies to silicone paper, greaseproof and transparent paper.
- A paper-plastic or paper-plastic-aluminum laminate is not repulped in usual recycling processes and is rejected with the waste. Laminates of this type are therefore undesirable in the regular *PfR* stream. Laminates (including beverage cartons and coffee cups) have separate logistics (respectively via PMD and via B2B return systems). In adapted recycling processes, specifically designed for hard-to-recycle paper and board, the layers can be separated from each other and recycled separately.
- Food does not belong at all in the *PfR* because it causes deposits, odor nuisance and overloading of the water purifications in the paper recycling process.

- For beverage cartons, coffee cups and ready-to-eat meals, pre-rinsing for disposal via specially designed recycling logistics (such as PMD or B2B return flows) is necessary, because otherwise the food residues can lead to undesirable hygiene situations.

These do's and don'ts, based on current recycling practice, can be used as the basis for an optimal design for recyclability of, among other things, packaging, , and for the optimal organization of the collection *PfR*.

There are applications of paper and board that make it undesirable for the paper and board to be recycled via the usual routes and used for the production of food contact packaging. This includes fibers recovered from sewers and diapers.However, *PfR* is also used for applications other than recycled paper. The requirements for the raw material are such that the use of fibers that cannot be used for paper and board can be used in other applications. Many of these alternatives have the advantage of long-term use of the material and thus long-term storage of the CO_2 stored in the fibers.

1 INTRODUCTION

1.1 MOTIVATION

Paper and board is often considered as a sustainable packaging material that is easy to recycle. But, because paper cannot always provide the barriers that the packaged product requires, increasingly complex packaging materials are being developed. However, there is a lot of uncertainty about the influence of paper additives on recyclability. More and more packaging designers and manufacturers are looking for an answer to one of the following questions:

- Can I call my packaging a paper packaging?
- Can I instruct consumers to discard my packaging with the *PfR*?
- Can I put on my packaging that it is recyclable through the paper recycling process?

That is why the Centre of Competence Paper and Board (KCPK), co-financed by the EU (as part of the H2020 CIRC-PACK project), the Netherlands Institute for Sustainable Packaging (KIDV) and Foundation Paper Recycling the Netherlands (PRN), has conducted research into increasing the recyclability of paper and board packaging.

1.2 RESEARCH

This report is based on two stakeholder workshops, desktop research and two inventories into the current restrictions in recycling at all individual paper and board mills in the Netherlands that are affiliated with the VNP (Royal Association of Dutch Paper and Board Mills). In addition, various kinds of packaging have been recycled in the lab to get a better picture of how certain components behave during the paper recycling process. The aim of this research is to increase knowledge about the recyclability of paper and board packaging in order to further close the paper cycle.

1.3 SCOPE

This report describes the current situation of paper recycling in the Netherlands and lists the guidelines that can contribute in the coming years to further increase paper and board recycling in the Netherlands. The scope is delineated to the following points:

- Design for recyclability. It only discusses how to take the paper recycling process into account during design and production. Other ways to close the cycle, such as reuse, are outside the scope.
- Packaging made of paper and board. Other paper products (such as graphic paper) are outside the scope, although many of the guidelines do apply to such products. Special types of paper (group 5 of EN643[5]), including multi-materials, are out of scope because they cannot be recycled through the regular paper recycling process.
- Dutch situation. The guidelines are only written for packaging that is both produced in the Netherlands and recycled in the Netherlands.

[5] Confederation of European Paper Industries (2013). EN643 European list of standard grades of paper and board for recycling. 20-05-2019.
http://www.cepi.org/system/files/public/documents/publications/recycling/2013/CEPI_EN%20643_brochure_FINAL_0.pdf

1.4 READING GUIDE

In chapter 2 paper and board will be discussed as packaging material. Chapter 3 handles the vision of the Dutch paper and board industry on recycling and recyclability. Chapter 4 discusses the guidelines that emerged from the study. Chapter 5 concludes briefly with regard to the future perspective of recycling of paper and boardin the Netherlands.

2 PAPER AND BOARD PACKAGING

2.1 DEFINITIONS

2.1.1 PAPER AND BOARD

The definition of paper and board used in this report is based on the definition of the Confederation of European Paper Industries (CEPI) [6] and reads as follows:

"all cellulose-based fibrous materials which have been formed from a suspension into a cohesive sheet or web, with or without the addition of fillers and / or additives"

Paper is often used as a general term for both paper and board, which is why the term paper will refer to both paper and board in the rest of this report. The difference between paper and board is usually based on the thickness of the sheet or the grammage. Grammages up to 200-250 g / m² are usually called paper, while grammages from 200-250 g / m² are called board. Sometimes, however, the name is based on the properties and / or the application of the material.

According to the Confederation of European Paper Industries (CEPI), certain additions to paper are permitted, either during sheet formation or afterwards, without the product losing its identity as paper. On average, 15,2 percent of paper (after leaving the paper machine) consists of non-fibrous material, as shown in Figure 2. However, there is a wide spread in the percentage of additives. Fiber levels range from less than 50 percent in certain types of coated graphic paper to more than 98 percent in certain hygiene products. Commonly used additives are clay and calcium carbonate, both of which can act as a filler or coating. Furthermore, starch is often used to strengthen the paper. Such additions are considered an integral part of the paper.

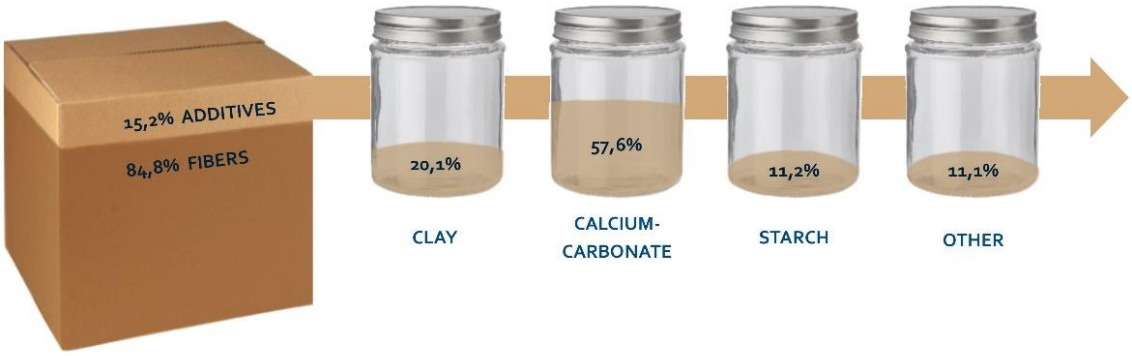

Figure 2: The average composition of paper, based on [7]

[6] Confederation of European Paper Industries (2014). Pulp and paper industry, definition and concepts. 13-01-2019. http://www.cepi.org/system/files/public/documents/publications/statistics/2014/FINAL%20CEPI%20Definitions%20and%20Concepts_0.pdf

[7] Confederation of European Paper Industries (2018). Key statistics 2017, European pulp and paper industry. 04-02-2019. http://www.cepi.org/keystatistics2017

After the paper machine, further additions can be made to the paper. Foundation Paper Recycling the Netherlands (PRN) calls these additives either product-specific contamination or product-foreign contamination[8]. Product-specific contamination refers to additions to the paper that are an essential part of the product, such as the window in an envelope or staples. Product-foreign contamination refers to all other contamination that is added to the product during use or disposal. In the EN643 quality standard for collected paper, a maximum percentage of 1,5 percent of foreign material is set[9].

2.1.2 PACKAGING

The definition of packaging used in this report is based on the definition of the "Besluit Beheer Verpakkingen" [10] and reads as follows:

"a product that can be used to contain, protect, handle, deliver and present other products"

Packaging can be used for all kinds of products, ranging from raw materials to finished products. In addition, packaging can be used at any time in the product lifecycle. In the context of this report, a difference is made between functional packaging for the transport of the packed product on the one hand and communicative packaging for the sale of the packed product on the other, see Figure 3.

Figure 2: Examples of functional packaging [11] and communicative packaging [12]

A functional packaging often consists of corrugated board made of colored (i.e. unbleached) fibers with starch for extra stiffness. This type of packaging is also referred to as transport

[8] Confederation of European Paper Industries (2018). Key statistics 2017, European pulp and paper industry. 04-02-2019. http://www.cepi.org/keystatistics2017

[9] Confederation of European Paper Industries (2013). EN643 European list of standard grades of paper and board for recycling. 20-05-2019. http://www.cepi.org/system/files/public/documents/publications/recycling/2013/CEPI_EN%20643_brochure_FINAL_0.pdf

[10] Ministry of Infrastructure and the Environment (2014). Packaging management decision 2014. 13-01-2019. https://wetten.overheid.nl/BWBR0035711/2016-01-01

[11] https://image.shutterstock.com/image-illustration/corrugated-cardboard-box-package-isolated-260nw-176430923.jpg

[12] https://www.merci.us/en/home/

packaging or secondary / tertiary packaging. To this packaging often tape or staples are added to close the packaging and (black) inks or stickers are used to indicate information that is important during transport.

The composition of a communicative package is much more diverse, but, as in the example in Figure 3, it may consist of folding board made of white fibers (i.e. bleached) and fillers. Often a (clay) coating is used to make it possible to print the board in a colorful way. Glistening foils are sometimes used to attract the consumer's attention. This type of packaging is also known as primary or consumer packaging.

2.2 PAPER AND BOARD AS PACKAGING MATERIAL

73 percent of all paper produced in the Netherlands is destined for packaging. The remaining 27 percent is used for graphic, hygiene or technical applications, among other things.[13] Paper is used for packaging in a wide variety of products. It is possible to package both food and non-food products in paper and the shape of the product (liquid or solid) does not preclude the choice of paper as packaging material. Naturally, each product requires different types of packaging properties, which can be created by choosing certain raw materials and additives.

Paper can be chosen as the basic material for packaging for several reasons. Paper is very easy to print, the tearability ensures that the packaging is easy to open and paper is a sustainable material, because the raw materials come from renewable sources. With regard to the fiber material, the choice can be made on the one hand between white and colored fibers and on the other hand between virgin or recycled fibers. Usually white and / or virgin fibers are used for food contact packaging, while colored and / or recycled fibers are often used for the other packaging. In addition, fibers are sometimes chosen from sources other than wood, because of the sustainable image.

In order to adapt the packaging to the product to be packaged, one can work with fillers during production as discussed in section 2.1.1. On the other hand, after the production of the base paper, materials can be added in the form of an additional coating or laminate. Plastics, aluminum and wax can improve the moisture resistance of paper, or add barriers to gas, moisture, grease or odors to the paper. In addition, these materials can ensure that a paper packaging can be sealed or that the packaging does not unfold by itself. However, such materials fall outside the scope of this report because they cannot be recycled through regular recycling processes.

2.3 THE LIFE CYCLE

The life cycle of a paper packaging, as shown in Figure 4, starts with the production of paper from fibrous material. The purchased fibrous material will optionally be mixed with fibrous material of other quality and fillers to create the desired properties. After the fibrous material has been brought into suspension, it is distributed over a large screen, where the water is extracted from the fibrous material. The resulting paper web is then pressed by means of

[13] Royal Association of Dutch Paper and Board Mills (2018). Annual report 2017, Paper and board ready for the future. 23-05-2019. https://vnp.nl/over-vnp/jaarverslagen/

cilinders. The water that is still present in the paper afterwards is removed by heat. At the end of the paper machine, the paper can be coated or impregnated to improve the paper properties.

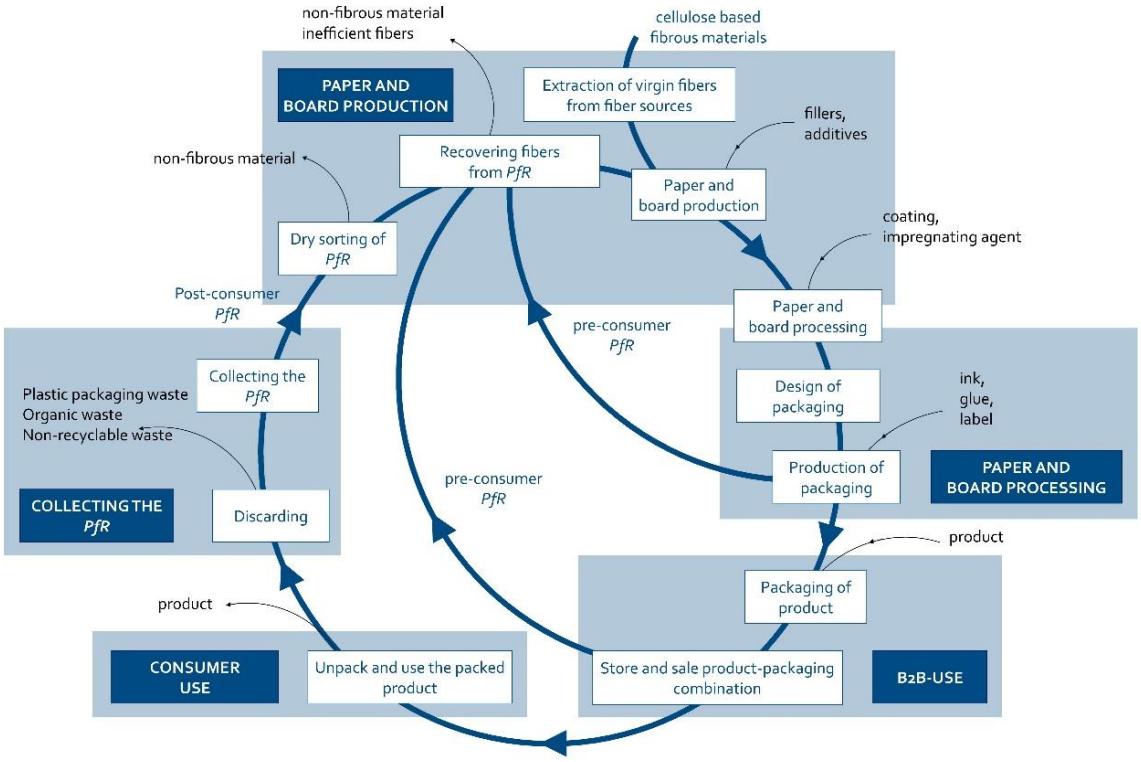

Figure 3: The life cycle of paper and board packaging

After this, the paper is ready to be processed into packaging. All kinds of additions can be made to the paper to provide it with the desired properties. Examples of this are coatings and prints. After this, the material will be cut, folded and glued, so that an actual packaging is created. The scrap and misprints that result are discarded as pre-consumer *PfR* and classified as one of the 57 types from the EN643[14], offered for recycling. Table 1 gives an overview of the different types of paper according to this guideline.

Once the packaging has been produced, it can be put into use by packing a product in it and closing the packaging by means of, for example, gluing or sealing. The packaging will be transported to the consumer, via any intermediate parties, such as a wholesaler and a retailer. Out-of-home use of packaging, such as drinking cups at a festival, also falls under B2B use. Some of the packaging is only intended for transport (functional packaging) of packaged products (communicative packaging) and is therefore discarded after this phase as preconsumer waste paper and classified as one of the 57 types from the EN643[15], offered for

[14] Confederation of European Paper Industries (2013). EN643 European list of standard grades of paper and cardboardboard for recycling. 20-05-2019.
http://www.cepi.org/system/files/public/documents/publications/recycling/2013/CEPI_EN%20643_brochure_FINAL_0.pdf

[15] Confederation of European Paper Industries (2013). EN643 European list of standard grades of paper and board for recycling. 20-05-2019.
http://www.cepi.org/system/files/public/documents/publications/recycling/2013/CEPI_EN%20643_brochure_FINAL_0.pdf

recycling, see Table 1. This classification is based on the value of the paper (i.e. strength and color of the fibers and the amount of impurities).

Table 1: Types of paper according to EN643

Quality	Colored paper	White paper
Low	Group 1: Ordinary grades From sort 1.01 until 1.11	
Medium	Group 4: Kraft grades From sort 4.01 until 4.08	Group 2: Medium grades From sort 2.01 until 2.12
High		Group 3: High grades From sort 3.01 until 3.19
Special	Group 5: Special grades * From sort 5.01 until 5.07	

** This group contains paper types that can only be processed in a specialized paper recycling process and therefore fall outside the scope of this report.*

The consumer opens the packaging to consume the packaged product and then discards the packaging. If the packaging is discarded via the *PfR*, the packaging will be sorted and recycled together with the *PfR*, as explained in the following paragraphs. Furthermore, the consumer has the option to discard the packaging via one of the other flows: the plastic packaging waste flow, the organic waste flow or the non-recyclable waste. However, these disposal routes and the associated packaging do not fall within the scope of this report.

After discarded by the consumer, the *PfR* is either collected door-to-door or from centrally located containers. It is important that *PfR* is collected separately. Paper that has not been collected separately, but which has been recovered from the non-recyclable waste by post-separation, must always be designated as such, because it is not suitable for use in the paper industry[16]. The quality of the *PfR* depends strongly on the way it is collected[17] and in all cases *PfR* must be clean and dry.

In some cases, the collected *PfR* is sorted very coarsely in a dry process. The worst contamination is removed during this step and the flow is separated into white paper on the one hand and colored paper on the other. After sorting, the *PfR* is offered for recycling. The paper is fiberized in a paper mill into a suspension, among other things the inefficient components and contaminants will be separated. Different cleaning steps are performed depending on the application. The recycling process is discussed in more detail in section 3.2.

2.4 Perspective

Throughout the packaging chain, there are all kinds of material flows that are relevant for the recyclability of packaging made of paper and board and thus for the scope of this report. All this is also shown in Figure 5.

[16] Confederation of European Paper Industries (2013). EN643 European list of standard grades of paper and board for recycling. 20-05-2019.
http://www.cepi.org/system/files/public/documents/publications/recycling/2013/CEPI_EN%20643_brochure_FINAL_0.pdf

[17] Foundation Paper Recycling the Netherlands (2016). Foreign product contamination in household paper 2016. 20-05-2019 https://prn.nl/wp-content/uploads/2019/01/PRN-Vervuilingsrapportage-2016.pdf

In the Netherlands, approximately 3 million tons of paper are produced annually [18]. The majority (84 percent) is colored paper, the rest (16 percent) is white. In the Netherlands, about 3 percent of all paper is processed into laminate, the rest is used as mono material. The main applications are packaging paper (73 percent), graphic paper (23 percent) and hygiene paper (4 percent).[18] Hygiene paper leaves the paper cycle after discarding (as shown in Figure 5), although there are several initiatives to recycle hygiene paper, as discussed in section 5.3. Graphic paper and packaging paper are replaceable after disposal: both types are collected and recycled via the same route. This means that the application that the paper had before disposal is not necessarily the same as the application after recycling.

There are several routes through which *PfR* can reach the recycling process. First of all, a difference can be made between pre-consumer and post-consumer *PfR*. Preconsumer *PfR* (66 percent of the total amount of *PfR* collected in the Netherlands) has never reached the consumer, because it comes from the commercial sector (offices, shops, services or industry).[19]. Preconsumer also includes *PfR* that is discarded after out-of-home use, such as drinking cups at a festival. This flow has the advantage that its composition is homogeneous, allowing the paper recycling process to be tailored to this (if the volume is large enough). In addition, the origin of this material flow is known, so that possible food safety can be guaranteed. Post-consumer *PfR* (34 percent of the total amount of *PfR* collected in the Netherlands), on the other hand, is discarded by the consumer via household waste. This stream is very varied and the origin of a specific product from this stream is unknown. That is why it is more difficult to coordinate the recycling process.

Finally, there is a lot of trade in *PfR*. The major part (78 percent) of the paper produced in the Netherlands is marketed abroad [20]. At the same time, the majority (72 percent) of the waste paper that is recycled in the Netherlands comes from abroad [21]. Trade in (products of) paper also takes place at intermediate moments in the packaging chain (no figures are available). Therefore, the improvements made in the Netherlands in the design and production of packaging do not directly affect the recyclability of the paper recycled in the Netherlands. Nevertheless, this report focuses on the Dutch situation because that is the area where influence can be exerted.

[18] Royal Association of Dutch Paper and Board Mills (2018). Annual report 2017, Paper and cardboard ready for the future. 23-05-2019. https://vnp.nl/over-vnp/jaarverslagen/

[19] Foundation Paper Recycling the Netherlands (2018). Monitoring results for collection and recycling of non-packaging applications of paper and cardboard, 2017. 23-05-2019. https://prn.nl/prn-en-het-prn-systeem/prn/rapportage/

[20] Royal Association of Dutch Paper and Board Mills (2018). Annual report 2017, Paper and cardboard ready for the future. 23-05-2019. https://vnp.nl/over-vnp/jaarverslagen/

[21] EUWID (2017). EU recovered paper exports on the increase in 2016. Recycling and waste management, Vol. 23 (10.2017).

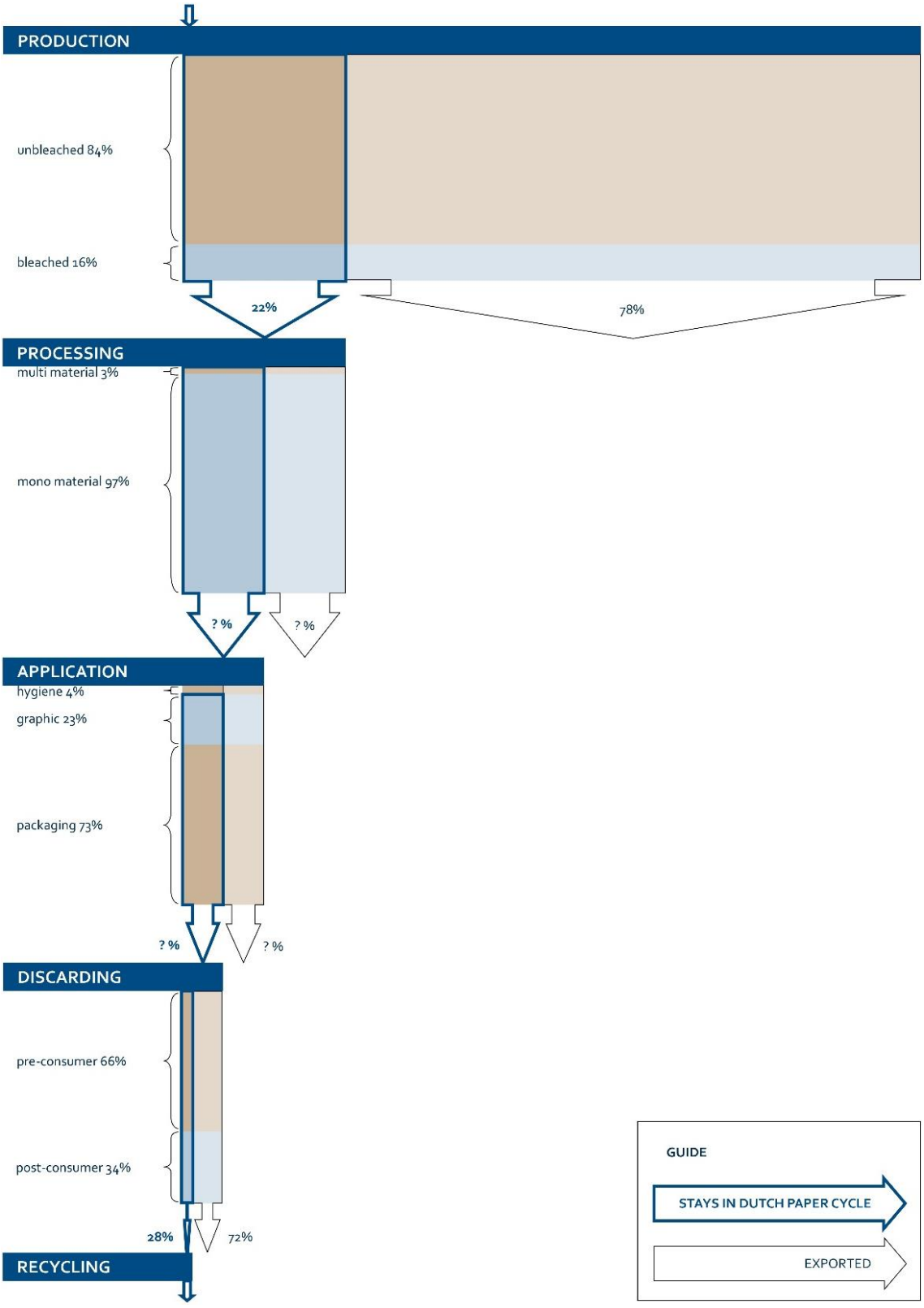

Figure 5: The scope of this report (outlined in bold) only concerns paper and board packaging that are both produced and recycled in the Netherlands. The sizes of the blocks indicate the sizes of the flows and put the scope in perspective. The figures are based on the Dutch situation in 2017 and imports are not included in the figure because this is outside the scope.

3 RECYCLING

3.1 DEFINITIONS

3.1.1 DEFINITION OF RECYCLING

Once a product has reached the end of its life cycle, the discarded product can be processed in different ways, as shown in Figure 6. A distinction can be made between linear and circular processing strategies. In the case of a linear processing strategy (landfill or incineration, with or without recovery of the energy produced thereby), the material value of the discarded product is not used. Circular processing strategies (recycling, remanufacturing, refurbishing, repairing and reusing), on the other hand, close the life-cycle of a product. The value of the discarded product is restored, after which the product (or parts thereof) serve as input for a new life cycle.

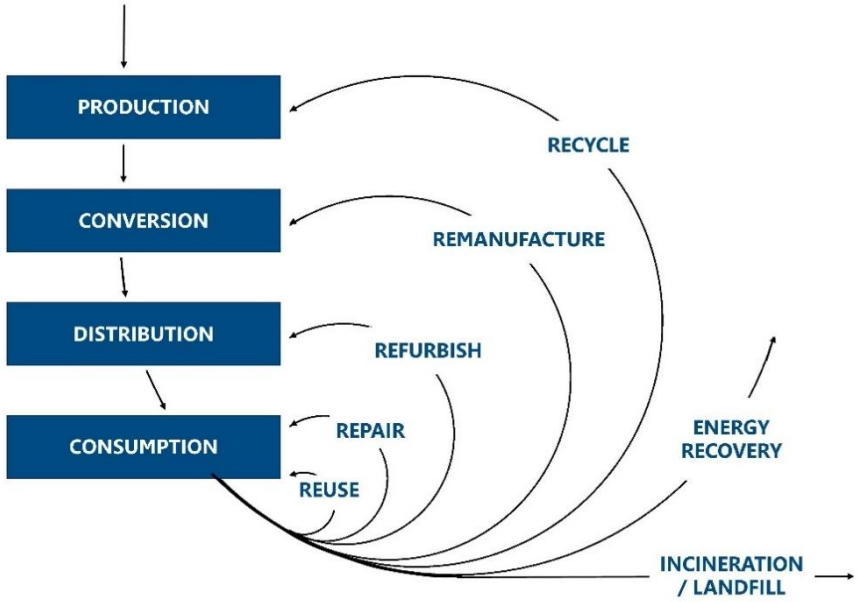

Figure 4: Different strategies for closing product chains [22]

The circular processing strategies can be distinguished from each other by the level at which the value of the discarded product is restored and the phase of the life-cycle for which the recovered product serves as input. This is specified for each of the treatment strategies in Table 2. In the case of recycling, a discarded product is recovered at the raw material level. The recovered raw materials then serve as input for the production of new products. Specifically for paper, the fibers are recovered from a discarded paper product and are used for the production of new paper products.

[22] Holwerda, H. (2018), Recyclability of multi-material packaging – improvement by supporting the consumer's value proposition.

Tabel 2: The difference between recycling and other treatment strategies for discarded products

	Processing strategy	Product is being restored at … level	Restored product serves as input for the… of (new) products
Circular	*Reuse*	Function	Consumption
	Repair	Product	Consumption
	Refurbish	Component	Distribution
	Remanufacture	Material	Conversion
	Recycle	**Raw material**	**Production**
Linear	*Energy recovery*	Energy	-
	Incineration	-	-
	Landfill	-	-

It depends on a specific situation which strategy can best be applied for processing a discarded product. In the case of paper, recycling is used in most cases because paper quickly loses its functionality compared to other materials. In addition, both the recycling and the production of paper are relatively simple processes and the vast majority of the recycled fibers are reused.

This report focuses only on recycling paper packaging, excluding other processing strategies such as reuse from the scope. The definition of recycling used is based on the definition of the Confederation of European Paper Industries (CEPI)[23]:

"reprocessing PfR in a production process into new paper or board"

Organic recycling, also known as composting, is often classified under the definition of recycling, such as in the definitions of COST Action E48[24] and Rijkswaterstaat[25]. However, organic recycling is excluded from the definition for this report for two reasons. First of all, the cycle of paper packaging is interrupted in the case of composting. The fibers from the packaging leave the cycle and cannot (directly) be used for a new paper product. Second, it is often wrongly assumed that biodegradable packaging is recyclable through the paper recycling process and that is certainly not always the case. To avoid confusion about this, organic recycling has not been included in the definition.

3.1.2 DEFINITION OF RECYCLABILITY

The definition of recyclability used in this report is based on the definition of the Confederation of European Paper Industries (CEPI)[24] and reads as follows:

"the ability of a paper or board product to be reprocessed in a production process into new paper or board"

[23] Confederation of European Paper Industries (2014). Pulp and paper industry, definition and concepts. 13-01-2019. http://www.cepi.org/system/files/public/documents/publications/statistics/2014/FINAL%20CEPI%20Definitions%20and%20Concepts_0.pdf

[24] COST Action E48. (2010). The future of paper recycling in Europe: Opportunities and limitations. Bury: The Paper Industry Technical Association.

[25] Packaging Waste Fund Foundation (2018). Packaging in the circular economy, recycling packaging in the Netherlands 2017. 23-05-2019. https://afvalfondsverpakkingen.nl/monitoring/publieksrapport

The ability of a paper packaging to be reprocessed in a production process into a new packaging depends on the preceding life cycle. This report focuses on how design and production can positively influence the recyclability of a packaging. This is also referred to as *design for recyclability*. *Design for recyclability* can be used to optimize the design and production of the packaging for the recycling process. Guidelines for this are discussed in Chapter 4 of this report.

3.2 THE PAPER RECYCLING PROCESS

Each paper mill has equipped its recycling process in such a way that the *PfR* stream they purchase can be properly processed into the intended end product. This means that every paper recycling process is different. As shown in Figure 7, the process depends on the color of the purchased paper and the intended end product (white or colored) and on the quality of the raw materials (according to the classification of the EN643, as discussed in Table 1). Two types of paper recycling processes can be distinguished: a process with a basic stock preparation, in which the fibrous material is recovered (by means of pulping and screening) and a process with a complex stock preparation, in which, in addition to the recovery of the fibrous material, the purity of the fibrous material is also increased (by deinking and bleaching). This complex stock preparation is mainly used for the production of hygiene paper and newsprint.

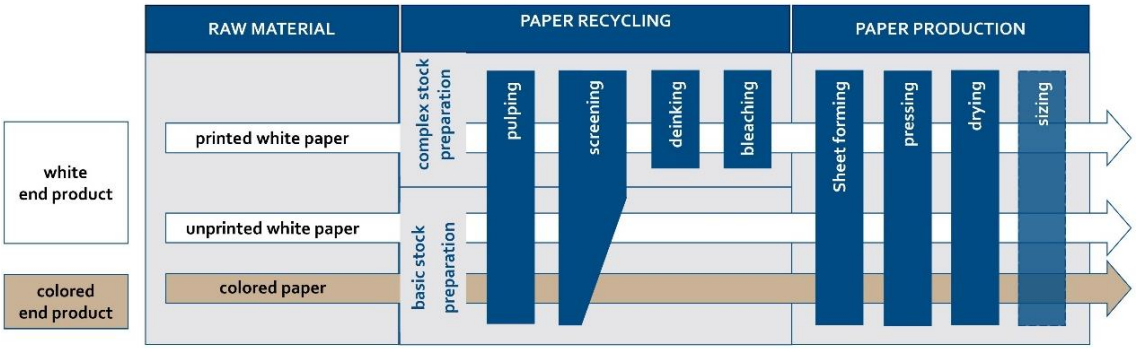

Figure 5: The recycling process and the paper production process are adapted to the purchased raw materials and the intended application

3.2.1 BASIC STOCK PREPARATION

In a basic stock preparation, the fibrous material is recovered from the *PfR* by disintegrating and screening. Fillers from the *PfR* are not removed during such a process and thus end up in the new paper. *PfR* usually enters the recycling process in the form of white bales (with unprinted paper based on bleached fibers) or colored bales (with paper based on unbleached fibers and printed paper based on bleached fibers). If the produced paper is not intended for the production of food packaging, it is sometimes also delivered unbundled. The *PfR* is thrown into the pulper: a large container with warm water (between 15 and 65 degrees Celsius) with a rotor inside. The water penetrates in the paper disconnects the individual fibers, possibly with the help of chemicals. This creates a fiber slurry: a suspension of water and fibers. This process is called pulping or desintegrating.

Because most *PfR* consists not only of fibrous materials but also of non-fibrous materials, the fiber slurry contains all kinds of impurities (whether or not permitted). The impurities, such as laminates, tape and staples, are separated from the fiber slurry if necessary and as far as possible. This is done from coarse to fine by means of a series of screens with decreasing slot

width. Furthermore, centrifugal cleaners are often used. This process is called wet sorting. If required by the raw material or application, additional cleaning methods are used to separate the fibrous material from the remaining non-fibrous material.

After the process steps just described, the recovered fibrous material is suitable for the production of colored paper. To use the recovered fibrous material for the production of white paper, the *PfR* must already be white at the time of purchase, or the fibrous material must go through the process steps described in the next section.

3.2.2 COMPLEX STOCK PREPARATION

In a complex stock preparation, in addition to recovering the fibrous material (as described in the previous section), the purity of the fibrous material is also increased by deinking and bleaching. Such a stock preparation is necessary for the production of white paper, unless the *PfR* was already white and unprinted at the time of purchase.

In order to obtain a fiber slurry that is homogeneous in color, the (printing) inks are removed. A method that is often used for this is flotation: air bubbles are created in the suspension by means of chemicals. The ink particles stick to the rising air bubbles, causing them float to the surface. Here, the ink particles can be removed from the fiber slurry. Furthermore, methods such as washing and dispersing can be used. The common name for removing ink particles is deinking. During this process, the fillers that come from the *PfR* are also removed.

After the loose ink particles have been removed from the fiber slurry, it is important that the inks and other dyes from the fibers themselvesare also removed. Oxygen bleached with hydrogen peroxide or ozone is usually used for this, but other chemicals are also sometimes used (chlorine has not been used for years). This process is called bleaching, after which the fiber slurry is not only homogeneous in color, but actually white in color. In current practice, hardly any bleaching is performed and this is not expected to be done anywhere in the Netherlands in a few years' time.

After the process steps just described, the fibrous material is suitable for the production of white paper. If these process steps cannot be carried out, the new paper may contain visible impurities from the purchased *PfR*.

3.3 CLOSING THE CIRCLE

The paper and board sector has years of experience in recycling paper. Fibers can be used for several life cycles in the production of paper. As a result, the sector has learned to deal with all the challenges involved. This has resulted in the paper cycle being almost completely closed. This high degree of circularity is clearly visible on the basis of the collection percentages of paper packaging.

As shown in Figure 8, 87 percent of the paper packaging placed on the market in the Netherlands is collected. This percentage is well above the Dutch target of 75 percent and the European target of 60 percent. The Netherlands is one of the leaders in the collection and recycling of paper both worldwide and at European level. The sector also scores well compared to other packaging materials. In the Netherlands, the collection of paper ranks second in relation to other packaging materials.[26] At the European level, paper even scores the highest of all packaging materials, with a percentage of 81.1 percent.[27, 28]

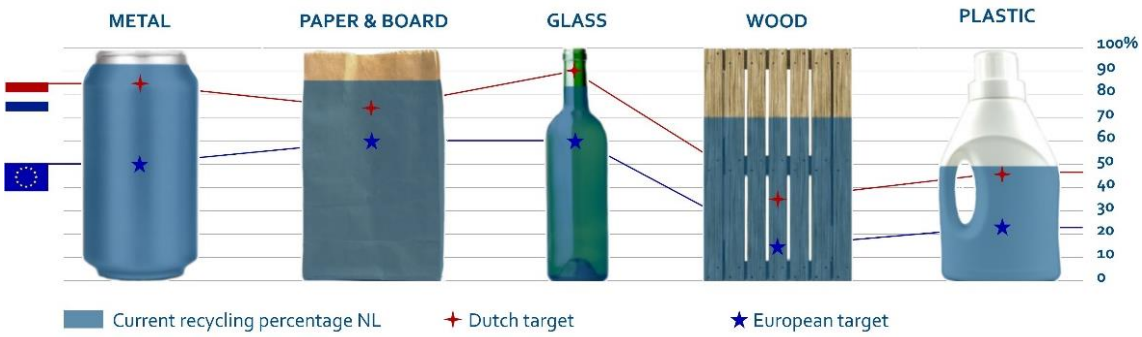

Figure 6: Current collection percentages of packaging materials and the corresponding Dutch target and European target. Based on [27]

The collection percentage of paper has approached a maximum in recent years. There are several reasons for this. Not all paper can be collected, such as bills and cigarette paper [29]. Furthermore, there are product groups that the industry (rather) does not use as a raw material because of their history, such as hygiene paper. However, there are several initiatives to reprocess such paper products in order to completely close the paper cycle. This is discussed further in section 5.3.

The recycling percentage is also approaching a maximum, because fibers cannot be recycled indefinitely. Each cycle has an impact on the mechanical and chemical properties of the fiber and there is a certain downcycling of the individual fibers. Therefore, a supply of fresh fiber material is always required for the production of the highest quality products. Nevertheless, in the Netherlands we have succeeded in exceeding a previously set theoretical maximum.

[26] Packaging Waste Fund Foundation (2018). Packaging in the circular economy, recycling packaging in the Netherlands 2017. 23-05-2019. https://afvalfondsverpakkingen.nl/monitoring/publieksrapport

[27] Impactpaperec (n.d.) Recycling facts. 12-04-2019. http://impactpaperec.eu/en/facts-figures/recycling-facts/

[28] European Paper Recycling Council (2016). Monitoring report 2016, European declaration on paper recycling 2016-2020.
http://www.cepi.org/system/files/public/documents/publications/recycling/2018/FINAL_Monitoring%20Report%202016.pdf

[29] European Paper Recycling Council (n.d.) Are there limits to the recycling of paper. 13-02-2019.
http://www.paperforrecycling.eu/questions-answers/

4 DESIGN FOR RECYCLABILITY

PfR contains all kinds of pollution (permitted or not), such as food residues, glue and coatings. This pollution complicates the paper recycling process and the paper production process, but does not make it impossible. Each paper mill has coordinated its recycling process in such a way that the *PfR* stream they purchase can be properly processed into the intended end product. As a result, not only packaging consisting entirely of fibrous material can be recycled, but also packaging to which all kinds of additions of non-fibrous material have been made. That is why it can be said that all paper packaging is recyclable, on condition that the logistics and the recycling process are adapted to this.

However, this does not mean that there is no room for improvement. *Design for recyclability* can contribute to a recycling process with minimal handling and to the quality of recycled paper. This chapter discusses guidelines for increasing recyclability through the design and production of paper packaging. Fitness for purpose must be taken into account when applying the guidelines. A design can be based purely on functionality (as in the left example in Figure 9). However, the advice is to match the design to the recycling process (such as the right example). During design for recyclability it is important that a good consideration is made.

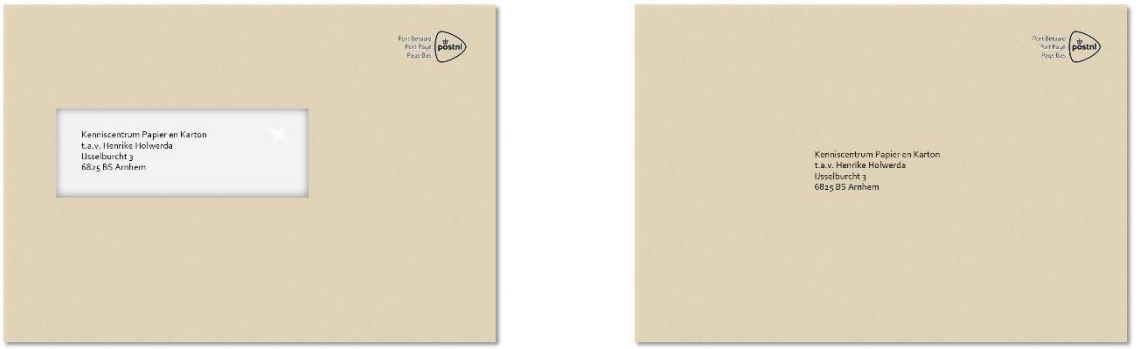

Figure 7: Two different designs for an addressed envelope: a window envelope (left) where the window adds functionality and a printed envelope (right) where the ink is a better recyclable alternative to the window.

4.1 ROUTE TO THE RECYCLING PROCESS

The life cycle preceding the recycling process determines how well a packaging can be recycled. Therefore, during the design and production of paper packaging, not only the paper recycling process can be taken into account, but also the previous stages. To ensure that a packaging is discarded, sorted and recycled by the most suitable route, the following guidelines can be used (in any order):

- Choose a packaging design that matches the intended disposal. Packaging that potentially is discarded via the *PfR* must be adapted to the paper recycling process. If it is more desirable or if the packaging is more likely to be discarded via one of the other material flows, adjust the design to the processing of the relevant flow.
- Ensure that the basic material of the packaging is recognizable to a consumer. Packaging that does not contain fibrous material, but which resembles paper, will probably be discarded through the *PfR*. Packaging that is based on fibrous material, but

which looks a lot like plastic, is probably discarded via the plastic waste. Both scenarios limit the closing of the individual material cycles.

- Add disposal instructions to the packaging. It is not always clear to consumers via which route a packaging must be discarded. Unambiguous instructions can contribute to this.[30].
- Choose a packaging design that facilitates clean and dry disposal of the packaging. The pollution that comes with dirty and wet *PfR* can interfere with the paper recycling process: water purification becomes overloaded, additional chemicals are required to suppress the paper machine pollution, and the pollution can also cause odor emissions. Therefore, design the packaging in such a way that any food residues are easy to remove. Consider, for example, a mat in a cake box, which can be discarded separately from the cake box.
- Adapt packaging to the collection, sorting and recycling processes that are available in the area where the packaging is discarded. If the intended logistics routes (collection, sorting and recycling) are not available in the environment where a packaging is discarded, it makes little sense to adapt the packaging accordingly.

4.2 BASIC STOCK PREPARATION

In a basic stock preparation, the fibrous material is recovered from the *PfR*. The fibrous material and the non-fibrous material must therefore be adapted in such a way that the separation proceeds optimally during the pulping. It is also important that both the fibrous material and the non-fibrous material are selected in such a way that they do not cause disturbances in the process and that the quality of the end product is not adversely affected. With the help of the guidelines in this section, a packaging design can be attuned to basic stock preparation.

4.2.1 FIBROUS MATERIAL

The guidelines below relate to the fibrous material. It is important that the process water can penetrate in the fibrous material well so that it breaks down into individual fibers and that as many fibers as possible can be recovered. The quality of the fibrous material is also important to enable high-quality recycling. Designers can take this into account using the following guidelines:

- Do not mix white and colored fibers in one packaging. Multiple types of fiber are often mixed in paper to achieve the desired quality. However, if fibers of substantially different qualities are mixed, such as white and colored, then all fibers will degrade during recycling to the quality of the lowest type present (in this case colored). Mixed fiber packaging is therefore not recommended for high-quality recycling.
- There is currently no preference for specific sources of fibrous material (either fibers from wood or fibers from alternative sources such as grass). Both types of fiber are easy to recycle (provided they have been made suitable for use in paper). It is still being investigated whether fibers from both sources can be recycled as often and what the impact of the deviating properties of alternative fibers is on the recycling process.

[30] Netherlands Institute for Sustainable Packaging (2018). Disposal Guide - Guidance for companies on how to dispose of disposal instructions. 23-05-2019. https://www.kidv.nl/6900/weggooiwijzer.html

- Do not use excessive amounts of fillers in the paper. If fillers are used in the usual quantities (see section 2.1.1), recycling will be possible, but excessive quantities will unnecessarily burden the recycling process and negatively affect the quality of the end product. If fillers are required, preference is given to the usual fillers such as starch, clay, calcium carbonate, etc.
- Avoid using silicone, translucent, greaseproof and wet strenght paper. Such papers are difficult to pulp in the regular recycling process because water penetration is impeded and are thereby rejected. These materials belong to the special paper grades and therefore fall outside the scope of this report.
- Only use kraft fibers if the application requires it and if possible without the addition of a moisture barrier. In comparison to recycled fibers, kraft fibers are relatively strongly connected. Therefore, kraft paper generally takes a little longer to pulp. The pulping process must not be further hindered by any moisture barriers.
- Leave both sides of the paper free from a moisture barrier. This gives the process water the opportunity to penetrate the fibrous material. Paper to which a moisture barrier has been added either on one side or on both sides partially or completely prevents this, as a result of which the fibrous material is not given enough time to pulp.

4.2.2 NON-FIBROUS MATERIAL

The non-fibrous material is rejected during the recycling process (in most cases with the exception of fillers) and is therefore not used for the production of new paper. Many applications are possible for the rejected material, but in many cases it pays more to incinerate the rejected material. This is because it is a very heterogeneous material flow that is difficult to sort. Therefore, in some countries (such as Germany, for example), a maximum is set for the permitted amount of non-fibrous material. If the percentage of non-fibrous material is below this limit (often 5 percent), the packaging will receive the designation 'mono material' and may be discarded via the *PfR*. The Netherlands strives for recycling at a higher level than many other countries. For that reason, the guidelines regarding the non-fibrous material are stricter and more nuanced.

- Minimize the amount of non-fibrous material. The non-fibrous material can hinder the recycling of the fibrous material. In addition, the non-fibrous material is not always used, or it reduces the quality of the new paper. The more fibrous material a package contains, the larger the part of the packaging that can be used for the production of new high-quality paper.
- Do not attach any non-fibrous material components, or as loosely as possible, to the paper. Non-fibrous material that is attached to the paper only at a few points is easier to separate from the fibrous material. As a result, it can be separated in time, either during disposal by the consumer or during recycling.
- Prefer an inorganic coating over a dispersion coating. Dispersion coatings break down into very small, barely separable components in the recycling process and therefore have the advantage of not hindering the pulping process. However, dispersion coatings can interfere with the process, as they may cause stickies. Inorganic coatings, on the other hand, have no disruptive effect on the process after dissolution and are often used together with the fibrous material for the production of new paper.

- Choose windows that can withstand the forces in the recycling process. During the paper recycling process, windows that are too thin or windows with too low shear strength become small particles that are difficult to reject and may interfere with the process. In addition, it is important that the material of the window has a different density than the paper. This makes it easier to separate the fibers and the plastic particles by means of centrifugal cleaners, in case the window cannot withstand the forces.
- There is no preference for biodegradable plastics over non-biodegradable plastics in the case of a coating or window. Biodegradable plastics do not degrade in the process water and therefore hinder the recovery of the fibrous material, like non-biodegradable plastics. The potential of biodegradable plastics is therefore not utilized through the paper recycling process.
- Avoid using chlorinated materials, such as PVC and PVDC. Chlorinated materials end up in the incinerator during processing and cause corrosion. To prevent this, extensive and expensive cleaning is required, which is very environmentally harmful.

4.3 COMPLEX STOCK PREPARATION

In a complex stock preparation, in addition to recovering the fibrous material, the purity of the fibrous material is also increased by deinking and bleaching. This means that (in) visible contaminants are removed as much as possible. Such stock preparation is necessary for the production of white paper, based on printed white *PfR*. The guidelines in this section, in combination with the guidelines in the previous section, can be used to match a packaging design to complex stock preparation.

The purity of the fibrous material strongly depends on the type of *PfR* that is purchased and the disturbing components that may be present therein. In addition, the purity can be further improved by deinking and / or bleaching the fibers.

4.3.1 STICKIES

The term "*stickies*" refers to the sticky particles present in the fiber slurry, which are a major challenge in paper production. Stickies contaminate machine parts, such as the screens and the cilinders, so that the new paper for example sticks to the cilinders. As a result, the paper web breaks or holes and stains appear in the new paper. Therefore, stickies not only disrupt the process, but also lower the quality of the new paper. A distinction can be made between *primary stickies* (from already sticky substances such as glues) and *secondary stickies* (often from dissolved binders of, for example, coatings that become sticky due to changes in process conditions).[31] During the design and production of a packaging, the following ways can contribute to reducing the amount of (potential) sticky material:

- Minimize the amount of glue in a packaging. Alternatives are, for example, the use of staples to close the packaging (well rejectable during wet sorting).
- Preferably use cold-set glue, curing glue or water-soluble glue. These types of glue remain firm in the hot process and can therefore either be separated during wet sorting

[31] Sarja, T. (2007). Measurement, nature and removal of stickies in deinked pulp (Vol. 68, No. 04).

or dissolved in the process water and can be separated via water purification. Make sure that the chemicals that dissolve are not harmful to water purification.

- Avoid using hot melt and pressure sensitive adhesives. Such adhesives do not dissolve, but become viscous due to the hot process water, which makes rejection in the recycling process very difficult. If such adhesives are nevertheless required, apply the adhesive in a long stripe, rather than in small dots, so that the adhesive can be separated more easily.
- Base your choice of tape or label on the type of adhesive. While paper-based tape and labels are preferred because the fibrous material can be recovered from them, the type of adhesive has a greater impact on the paper recycling process. When choosing a tape, use the guidelines discussed in this section regarding adhesive.

4.3.2 INKS AND DYES

In order to use *PfR* for the production of white paper, it is important that all inks and dyes are removed from the fiber slurry. A distinction can be made between water-soluble and non-water-soluble inks and dyes. Water-soluble inks and dyes are difficult to remove because they discolour the total fiber slurry. Many chemicals are required to subsequently bleach the fiber slurry again. During the design and production of a packaging, the deinkability and bleachability of the fibrous material can be contributed to in the following ways:

- In the case of white paper, do not use inks / dyes that dissolve in the process water. The inks used during flexography and inkjet printing are water soluble and should be avoided for deinking. Inks used during offset printing and rotogravure, on the other hand, can be separated well during flotation.[32]
- Do not use UV lacquers or inks unless it is explicitly stated that the lacquer or ink is well recyclable. UV lacquers and inks are dried by means of UV light. This light causes the lacquers and inks to harden and become brittle. During recycling, this wafer-thin layer breaks into small pieces that cannot be separated during wet sorting or by flotation. UV lacquers and inks are being developed that do not become brittle and can therefore be separated during recycling[33].
- Base your choice of ink on EUPIA guidelines [34]. For food contact packaging, inks that are based on mineral oils should not be used, as these oils can migrate from the new paper to, for example, the packaged product. The use of mineral oil-based inks is also undesirable for packaging that is not intended for food applications. At the same time, it is true that inks based on vegetable oils are often more difficult to deink than inks based on mineral oils, but the recycling processes have now been adapted to inks based on vegetable oils.
- Do not use colored paper, in combination with paper based on white fibers. The dyes are very difficult to remove from the fiber slurry during the recycling process, which means that the *PfR* cannot be used for the production of white paper.

[32] INGEDE (n.d.). Suitability for flotation deinking.

[33] INGEDE (2019). INGEDE news February 2019. Deinkable ink for LE- and LED-UV printing introduced at the INGEDE symposium. 25-02-2019. http://pub.ingede.com/en-GB/1902-3/

[34] EUPIA (2010). Printing ink industry contribution to reduce mineral oil in paper and board packaging. 07-03-2019. https://www.eupia.org/fileadmin/FilesAndTradExtx_edm/2018-08-02_Printing_Ink_Industry_Contribution_to_Mineral_Oil_Reduction_in_Paper_and_Board.pdf

- Apply metallic ink or foil to the paper only if the application requires it. The sensors used during *PfR* recycling can be affected by metallic particles in the fiber slurry. The interference of the signal impedes the monitoring of the composition of the fiber slurry. In the case of decorative / communicative packaging, such inks and foils must be minimized.

5 CONCLUSION

5.1 DESIGN FOR RECYCLABILITY

All paper that is collected separately is recyclable, on condition that the logistics and the recycling process are adjusted accordingly. There are a number of preconditions that can be taken into account in the development, use and disposal of packaging to enable recycling with minimal handling and to guarantee the quality of recycled paper.

Improving the recyclability should not be at the expense of the function of the packaging, but at the same time, over-specification should be avoided as much as possible. A packaging must fulfill its role properly, but if a packaging is assembled in an unnecessarily complex manner, the recycling process can be hindered. If possible, mono materials should be used, as multi materials cannot be recycled through regular recycling processes. If a multi-material is inevitable, it is important that the packaging can be easily separated into mono materials by the consumer. To ensure that the recycling process runs as smoothly as possible, interfering substances must be avoided as much as possible. Think of glue, dispersion coatings, UV inks and materials containing chlorine. Furthermore, it is important to keep it clean and dry, and as much as possible to discard and collect it homogeneously as *PfR*. Finally, degradation from food contact packaging to non-food contact packaging and from white to colored paper by recycling should be avoided as much as possible.

5.2 FOLLOWUP ON THIS RESEARCH

This research was co-financed by the EU (as part of the H2020 CIRC-PACK project), the Netherlands Institute for Sustainable Packaging (KIDV) and Foundation Paper Recycling the Netherlands (PRN). This research has contributed to the development of a recyclable detergent powder packaging within the scope of the H2020 CIRC-PACK project. KIDV will use the content of this report to draw up a "Recycle check for paper and board packaging", with which companies can check how well their packaging can be recycled through the regular paper recycling process. PRN will use the content of this report to draw up the new waste paper collection guidelines, which explain to consumers which products they can / cannot discard via the *PfR*.

This report only deals with the recycling of regular *PfR* in regular paper recycling processes. The special papers (group 5 of EN643[35]), such as laminates, sized and wet-strength paper and silicone paper are outside the scope. The special paper grades cannot be properly recycled in the regular paper recycling process because the process conditions are not optimal. However, every paper mill has the option to adapt the process conditions to these types of paper, for example by extending the time, increasing the temperature or adding chemicals. In addition, there is one paper mill in the Netherlands that specializes in recycling special types of paper. The special paper types are therefore certainly recyclable, but require an adapted logistics and recycling process. To be able to say more about *design for recyclability* of these special types of paper, a follow-up study is needed.

[35] Waste Paper Trade (n.d.). EN643 European standard waste paper species list.25-03-2019. https://www.wpt-nl.com/downloads/8144-NL%20-%20Lijst%20van%20europese%20standaardsoorten.pdf#zoom=100

5.3 FUTURE PERSPECTIVE

As discussed in section 3.3, the Dutch paper and board sector is approaching maximum recycling. However, this does not mean that there is no room for improvement in the future. The performance of paper and board is continuously improved. An important development within this is the application of barrier properties, so that paper can be used as a substitute for plastics. More and more complex materials are being developed: paper with barriers for oxygen, moisture and or water vapor, among other things. A possible ban on multi-materials will only reinforce this shift to increasingly complex mono-materials. The guidelines discussed in this report contribute to the maintenance of the good recyclability of paper.

There are paper products that are not desirable to be recycled due to their application. Think of paper that is recovered from, among other things, the sewer and incontinence material. However, there are several initiatives to reprocess such paper products in order to further close the paper cycle. Such fibers can be used in other applications such as interior wall panels (Cellx®), insulating mats (EverUse®; isofloc®), construction panels (ECOR®; fermacell®), road construction and composites (Recell®). Many of these alternatives have the advantage of long-term use of the material and thus long-term storage of the CO_2 stored in the fibers. An alternative application is the use of the *PfR* for processing via chemolysis / solvolysis. An example of such a treatment is the G2 technology that converts natural fibers into lignin and nanocrystalline cellulose (NCC) or the DES technology that ensures the separation of lignin and cellulose. The products of chemolysis / solvolysis can then be used again in paper production.

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