LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
Department of Environmental Technology
Sustainability Science and Solutions

*Noora Kallström*

# RECYCLING OPTIMIZATION FOR DISPERSION COATED BARRIER BOARD

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| Examiners: | Professor | Lassi Linnanen |
| | Post-doctoral researcher | Kaisa Grönman |
| Supervisor: | D.Sc. | Saila Kettunen |

# ABSTRACT

Lappeenrannan teknillinen yliopisto
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**Recycling optimization for dispersion coated barrier board**

Master's thesis

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99 pages, 27 figures and 14 tables

Examiners: Professor Lassi Linnanen
Post-doctoral researcher Kaisa Grönman
Supervisor: D.Sc. Saila Kettunen

Keywords: cartonboard, dispersion coating, recycling, recovered fiber facility

There are no strict recycling streams for dispersion coated barrier boards because there has not been this type of material in the market before. Therefore, the waste streams for dispersion coated barrier boards are important to identify. The target of this master's thesis is to study recycling of dispersion coated barrier boards in Finnish and German markets as well as to recognize the most crucial recycling flows in those market areas. The goal was to recognize economic and ecological benefits from manufacturing, using and recycling the dispersion coated barrier board.

In the theoretical part of master's thesis, the dispersion coated barrier board, recycling of the material as well as recycling legislation and practices of the chosen market areas were studied. This part includes the basics of the paperboard, different barrier coatings and their features, coating methods, recycling paperboard, pulping and recovered fiber facilities. Also, recyclability and repulpability of the dispersion coated barrier board is proven.

In the empirical part, most valuable recycling streams of the chosen market areas were identified with cooperation partners. Based on the identified streams, a recycling scheme was done. The scheme can be used as a guideline for recycling the dispersion coated barrier board. The functionality of the recycling scheme was tested in a small-scale experiment in the mill environment. Based on this master's thesis, the water-based dispersion coated barrier board can be recycled with conventional and available recycled fibre facilities' processes and it is possible to identify ecological as well as economic benefits, such as saving resources and getting more profit, for the product's entire life cycle.

# TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
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Noora Kallström

**Vesipohjaisen dispersiopäällystetyn barrier-kartongin kierrätyksen optimointi**

Diplomityö

2018

99 sivua, 27 kuvaa ja 14 taulukkoa

Tarkastajat: Professori Lassi Linnanen
Tutkijatohtori Kaisa Grönman
Ohjaaja: TkT Saila Kettunen

Hakusanat: kartonki, dispersiopäällystys, kierrätys, kierrätyskuitulaitos

Dispersiopäällystetylle barrier-kartongille ei ole tunnistettu suoria kierrätysvirtoja, sillä materiaalia ei ole aiemmin ollut markkinoilla. Tämän takia materiaalille on tärkeää tunnistaa nämä virrat. Työn aiheena oli tutkia vesipohjaisen dispersiopäällystetyn barrier-kartongin kierrätystä Suomen ja Saksan markkinoilla sekä tunnistaa hyödyllisimmät kierrätysvirrat kyseisillä markkinoilla. Tavoitteena oli tunnistaa taloudellisia ja ekologisia hyötyjä dispersiopäällystetyn barrier-kartongin valmistuksesta, käytöstä sekä kierrättämisestä.

Diplomityön teoriaosuudessa käsiteltiin dispersiopäällystettyä barrier-kartonkia, sen kierrättämistä sekä valittujen markkina-alueiden lainsäädäntöä sekä kierrätysmenetelmiä. Tämä osuus sisältää yleisestä tietoa kartongista, erilaisista barrier-päällysteistä ja niiden ominaisuuksista, päällystysmenetelmistä, kartongin kierrätyksestä, pulpperoimisesta sekä kierrätyskuitulaitoksista. Myös, barrier-kartongin kierrätettävyys ja pulpperoitavuus on todistettu.

Empiirisessä osassa tunnistettiin valittujen markkinoiden merkittävimmät kierrätysvirrat yhdessä yhteiskumppaneiden kanssa. Tunnistettujen virtojen avulla tuotettiin kierrätysmalli. Kierrätysmallia voidaan käyttää toimintaohjeena dispersiopäällystetyn barrier-kartongin kierrätykselle. Kierrätysmallin toiminnallisuus kokeiltiin käytännössä pienen mittakaavan kokeella tehdasympäristössä. Tämän diplomityön perusteella barrier-kartonki vesipohjaisella dispersiopäällystyksellä voidaan kierrättää tavallisten, käytössä olevien kierrätyskuitulaitosten prosesseilla, ja barrier-kartongin käytölle voidaan tunnistaa sekä ekologisia että taloudellisia hyötyjä, kuten luonnonvarojen säästäminen ja liikevoiton lisääminen, tuotteen koko elinkaaren ajalle.

## ACKNOWLEDGEMENTS

This thesis has been an interesting project and that is why I want to express my gratitude to Kotkamills Oy for giving me the topic of my thesis and a possibility to get a closer look to paper and board production as well as the Kotkamills' new innovation.  I would like to thank my colleagues from the Consumer Boards but especially my supervisor Saila as well as Stefan, Esa and Ari. The meetings with you helped me overcome many blocks and gave me new ideas to work on. I would also like to thank professor Lassi Linnanen and post-doctoral researcher Kaisa Grönman for the guidance and needed support during this project.

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In Kotka, 10th of December 2018

Noora Kallström

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## ABBREVIATIONS

| | |
|---|---|
| CEPI | Confederation of European Paper Industries |
| CTMP | Chemi-thermomechanical pulp |
| DSD | Duales System Deutschland |
| EN | European Standard |
| FBB | Folding box board |
| FSC | Forest Stewardship Council |
| HD | High-density |
| ISO | International Organization for Standardization |
| LD | Low-density |
| LLDPE | Linear Low-density Polyethylene |
| OCC | Old corrugated containers |
| PE | Polyethylene |
| PHA | Polyhydroxyalkanoate |
| PHB | Polyhydroxybutyrate |
| PLA | Polylactic acid |
| PP | Polypropylene |
| RCF | Recycled fibre |
| rpm | revolutions per minute |
| SBR | Styrene butadiene rubber |

# 1 INTRODUCTION

Purpose of the package is to make storing, distribution and protecting the package's inside content easier (EN 134030 2005, 6). Different packages have always been used but packaging technology was develop during the industrial revolution. Nowadays, packages are still fulfilling the purposes why they were invented in a first place but they are also used as a key element for marketing products. Many times packaging is the first thing which a consumer sees so it can attract consumer's attention and convince the consumer to buy the product. Therefore, companies are spending more time and money to design and choose model, material and appearance of the packaging.

There are many different packaging materials, such as paperboard, plastic, metal and glass. The packaging material is typically chosen based on the inside content of the packaging and which material is the most suitable for the inside content. Paperboard and plastic have both been used as packaging materials for many years due to their excellent features. Plastic is light and durable. However, the durability makes the material hard to demolish. Conventional plastics are also made from non-renewable resource, oil. The main material of paperboard is natural wood fibre which is renewable resource. Paperboard is paper-based material but generally it is heavier than paper. Typically, board grammages vary between 125 and 600 g/m$^2$ (Kiviranta 2000, 55–58) which makes the material relatively light and versatile.

Nowadays, packaging materials have important role when a consumer is making the purchase decision since climate change, global warming, increasing waste amounts and other environmental problems and their impacts have been raising the awareness of the importance of environment protection. Also, urbanisation has centralized consumers to cities which has increased waste amounts in small areas and made the waste management problem present. Because of the increased knowledge, many consumers in the developed countries currently demand ecological packages which can be recycled and reduce consumers' carbon and water footprints.

Compared to oil-based products, paperboard made from wood is more ecological and environmental friendly option. However, different materials can also be combined with each other and for example, board can be coated with plastic layer. This material combination is typical in the food packaging industry. However, the combination makes the recycling of the board more difficult because the plastic layer must be removed before the fibres can be recycled. This consumes time, energy and money and therefore, the board is many times converted to energy by incinerating instead of recycling it. (Love 2018.) Therefore, food packaging industry has a need for new innovations and more ecological packages.

Environmental problems as well as resource scarcity and economic aspects have been driving forces when developing new packages and packaging material. Nowadays, packaging should be easy to recycle to other materials or packages, or they should be produced from the recovered material. The packaging is easier to recycle when it is not combined with other materials, e.g. paperboard coated with plastic. From the recycled material, it is possible to make other products, and recovered paper and paperboard is cheaper than using virgin fibres as a raw material. Also, technical aspects of environment and energy, legislation sanctions and availability are some of the reasons why the recycled paper and board are currently used.

## 1.1 Background of the study

Consuming habits have changed in recent years due to the modern and busy lifestyle. Consumption and production have also been increasing which have grown solid waste amount. (Aarnio & Hämäläinen 2007, 612.) Today, consumers have increased demands for takeaway products and therefore, retailers prefer to use light, single-use packaging for their products. Paper cups and other paper or paperboard based packages are used because they are light to transport, easy to store and paper made from virgin fibres is completely hygienic.

Paper and paperboard are not perfect materials to takeaway products as they are because the materials do not have all needed features. However, with the different coating layers, significant features can be added to board. For example, different coatings can prevent, decelerate or limit different substance for contaminating the board and package's inside content. Those substances can be for example, grease, water, steam, oxygen or mineral oil vapour. Currently, the most common barrier is a thin polyethylene (PE) plastic layer which gives all the mentioned features. PE layers are used almost in every disposable paperboard cups in the market. (Kimpimäki 2008, 60.) However, because PE plastic is oil-based, there is a need for eco-friendly coating option.

Dispersion coated barrier board offers one answer to the resource scarcity and increasing littering problem of urban areas because the board has water-based dispersion barrier instead of oil-based PE plastic coating. With the barrier coating, it is possible to get the same qualities to the paperboard as with the PE coating. When comparing water-based dispersion coated barrier board and PE coated board, dispersion coated barrier board has clear environmental advantage over the PE coated board. The dispersion coated barrier board does not produce any long term landfill waste like plastic coated board and recycling of the barrier board is easier than plastic coated board. (Kimpimäki 2008, 60.)

## 1.2 Scope and aims of the study

This study examines recycling options for Kotkamills' dispersion coated barrier board in two countries. Finland and Germany were chosen because they are significant for Kotkamills' business. Kotkamills' headquarter as well as the mill area are in Finland, and Germany is important market area for Kotkamills. Germany has also interesting recycling system and they are using a lot of recovered paper and paperboard. It was also possible to get primary data from both countries. Those market areas are also interesting due to the different waste legislations and actions even though, they are based on the same EU waste legislation. Also, waste management and recycling practices differ from each other.

The study focuses on Kotkamills' dispersion coated barrier board which are cartonboards, and which has a water-based dispersion barrier. Extrusion coatings, such as PE coating, are not investigated in the theoretical part even though all comparisons are made between Kotkamills' dispersion coated barrier boards and PE coated board. Because of the confidentiality of this study, the water-based dispersion barriers, which Kotkamills are using, are not defined either thus dispersion barriers are studied with more holistic view. Also, the product names and cooperating companies are coded with letters and numbers.

The aim of this study is to investigate water-based dispersion barrier board's recycling in two countries and to design a value adding recycling scheme for dispersion coated barrier board with cooperation partners. The processes, which were identified with the scheme, were implemented and the functionality was examined with a small test made in Kotkamills' own mill as well as in few events. The purpose of the recycling scheme is to guide how the dispersion coated barrier board is profitable to recycle, and how the customer can benefit from using the dispersion coated barrier board. Dispersion coated barrier boards' economic and ecological values are compared with PE coated cartonboard and they are presented in the end of the study.

## 1.3 Research method

In the theoretical part of this study, the water-based dispersion barrier board and its recycling are investigated. The recycling takes into account the applicability of different fibres and processes as well as recovered fibre facility's processes and repulping. Also, some recycling and repulping tests of different barrier boards are presented. After that, Kotkamills' two market areas and their legislation, recycling practices, and cost of the recycling are familiarized. Theoretical part is based on literature, interviews with the specialists as well as recycling tests made in different laboratories.

In the empirical part, a designed recycling scheme is presented. Sheeting and converting facility, waste management companies in Finland and Germany as well as end users were cooperation partners when designing the recycling scheme. In the empirical part, the functionality of the recycling scheme has also been investigated and a small scale test of the recycling scheme is presented. The test was done mainly in the Kotkamills' mill area. The recycling schemes as well as economic and ecological values, which are identified based on the recycling schemes, are identified for dispersion coated barrier board and compared with PE coated cartonboard.

## 1.4 Kotkamills Oy

Kotkamills Oy is located in Kotka, in the south-east coast of Finland. It is a mill complex which produces saturating base kraft paper, cartonboard and sawn products. The mill itself was founded in 1872 when a sawn mill was built in the same location as the mill area is nowadays. The owner of the mill was W. Gutzeit & Co. In the past decades, the mill has been developing its business and achieve its current form. Today Kotkamills is owned by Finnish MB Funds which bought the mill complex from OpenGate Capital in 2015. Before that, Kotkamills was owned by Stora Enso Oyj. Kotkamills is still producing the sawn products but nowadays, it is also producing Absorbex® saturating base kraft paper as well as AEGLE® folding boxboard and ISLA® food service board. (Kotkamills 2018a.)

In 2016, Kotkamills started production in new board machine. With the new board machine, it is possible to add the water-based dispersion barrier straight on the surface of the board thus an off-line coater and PE or any other barrier coating are not needed. The Kotkamills new cartonboard with water-based dispersion barrier has several advantages. The cartonboard is for example, easier to recycle and repulp because of the water-based dispersion barrier and the material does not produce any long-term landfill waste. Kotkamills launched AEGLE® Barrier Light in February and ISLA® Duo in May 2018. (Kotkamills 2018b.)

## 2 DISPERSION COATED BARRIER BOARD

Cartonboard has rather weak barrier properties by itself and therefore, it is typically combined with different material, such as coated with different barrier materials. With the materials, board can achieve better barrier properties such as water-, grease-, light-, vapour-, gas-, oxygen- and microbe-barrier. (Vähä-Nissi et al. 2005, 1958.) Barrier coatings can include different kind of polymers. Extrusion coating is done with plastic such as polyethylene (PE) or polypropylene (PP) and dispersion coating is typically made of latexes or biopolymers. (Kimpimäki 2008, 60.) PE is the most common plastic in use and it is also commonly used in disposable products and food packaging due to its excellent barrier properties, such as hydrophobicity and low price (Lee et al. 2017, 155).

There have been significant improvements in barrier dispersion coatings which have resulted in product innovations and many commercial applications. Using polymer dispersions as barrier coating has recently increased interest due to increased environmental awareness of consumers, improved properties of dispersion barriers and more stringent environmental legislation. There are different types and grades of boards and they all can be coated with dispersion barrier. Coating can be done on-line or off-line coaters with various methods. (Kimpimäki 2008, 60.)

Dispersion coating is not new innovation. According to Ovaska (2016, 13–14), first generation dispersion coatings where invented already in 1961. Those coatings were based on aqueous synthetic polymers, e.g. polyolefin dispersions and hydrocarbon resins. Second generation dispersion coatings, pigmented dispersion coatings, were invented only seven years later, in 1968. After that, there has been progress in coating formulation, characterization as well as processes, such as drying of dispersion coatings and, latex and talc combinations and repulpability. Third generation dispersion coatings were invented in 2001, and those were coatings with synthetic and bio-based polymers. However, even though the dispersion coatings have been investigated, they have not been taken into production use until recent years.

This chapter studies the dispersion coated barrier board. The chapter includes basic information about a structure of a board, short presentation of dispersion coatings as well as their material and coating methods. In the end of this chapter, the applicability of different recycling fibre classes in EN 643 standard and different processes are studied.

## 2.1 Structure of the board

Basically, paperboard is the same product as paper but they are used in different purposes and grammages differ. Paperboard is heavier than paper and typically, grammages of the paperboard are above 150 $g/m^2$ but they can vary from 125 to 600 $g/m^2$. Paperboard has often many layers unlike paper and those layers can have different features and qualities. The goal of the paperboard production is to make a product with good stiffness and printability levels. (Kiviranta 2000, 55–58.)

Typical classification of paperboard grades is to divide them in three classes. Those are cartonboards, containerboards and special boards. (Kiviranta 2000, 55.) The classification of the paperboard grades is presented in Figure 1.

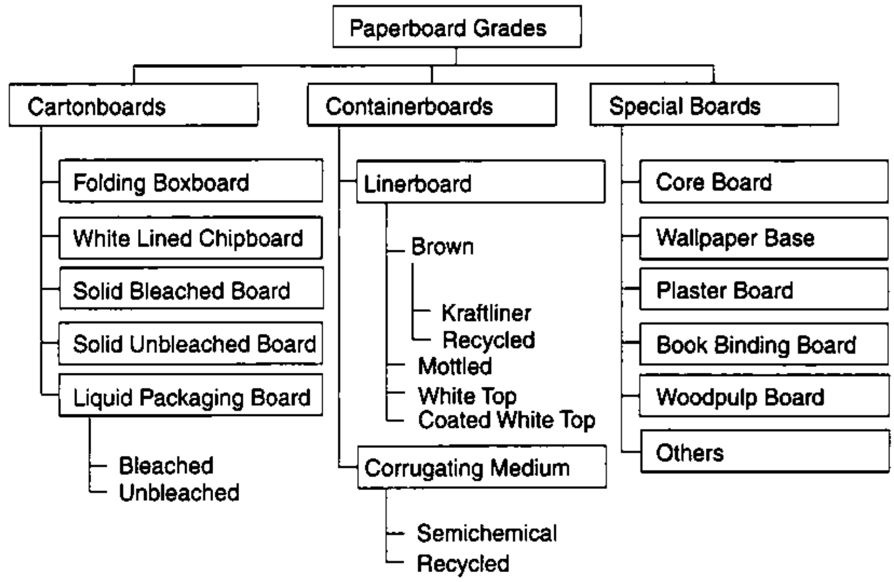


**Figure 1.** Classification of paperboard grades (Kiviranta 2000, 55).

Cartonboards are used for consumer packaging products. The class includes Folding Boxboard (FBB), White Lined Chipboard (WLC), Solid Bleached Board (SBS), Solid Unbleached Board (SUB) and Liquid Packaging Board (LPB). This class is used in boxes and cases which need to have good compression strength and which can be piled up. Cartonboards have typically many layers and they have to have good burst strength so that the inside content of the box will stay untouched. (Häggblom-Ahnger & Komulainen, 2005, 72–73.) In Finland, FBB is the most popular cartonboard and it is used for food, cigarette, cosmetic and medicine packaging (Mansikkamäki 2002, 144–145).

Container boards include linerboard and corrugating medium. All container boards need to have good weather resistance and therefore, they have several layers and the board is thick as there is air between the layers. Due to the air, the board is also light, it isolates heat and the board is rather shockproof. Corrugating medium is the most popular packaging material in the world. Examples of special boards are core board, plaster board, book binding board and woodpulp board. (Kiviranta 2000, 55; Laakso 2007, 150–151.)

Kotkamills is producing bleached chemi-thermomechanical pulp (CTMP) based folding boxboard and recyclable barrier boards, which both are cartonboards. TMP is fibre mass which is produced by mechanical grinding process (Komppa 2006, 6). All the products have three-layer baseboard with Kotkamills own special integrated CTMP. Grammage of the board is varying from 160 to 360 g/m$^2$. Figure 2 shows the structure of both sides dispersion coated barrier board.

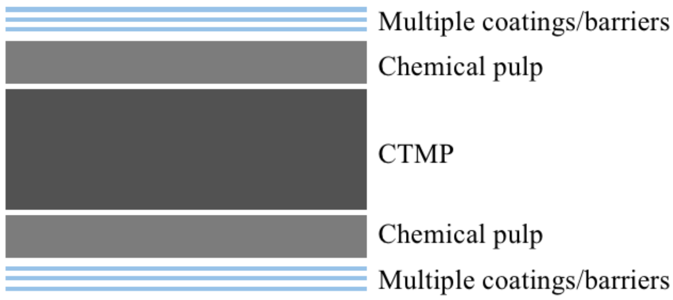


**Figure 2.** Structure of Kotkamills' consumer board.

Kotkamills' baseboard consists CTMP which has chemical pulp on both sides. Kotkamills' board machine has on-line coating process and it is possible to spread four coatings to top side of the board and three to the reverse side of the board. Thus, there is a lot of variation with the board types. Kotkamills' barrier boards are typically used as food packages thus the board will be in contact with food. Therefore, the same proper hygiene level is important to ensure as when producing food. Kotkamills has to obey the Commission regulation 2023/2006/EC on good manufacturing practice for materials and articles intended to come into contact with food (Leppänen-Turkula 1998, 274; 2023/2006/EC 2006). Kotkamills' barrier boards are produced from virgin pulp so the product safety and purity can be uphold.

There are some basic functions which are required from the packaging. Those are mechanical strength, optimum material properties, ergonomics of design and barrier properties. Optimum material properties can be stiffness, smoothness, brightness and varnish ability, and barrier properties are for example moisture, oxygen and light resistance. (Leppänen-Turkula 1998, 271.) Because Kotkamills barrier boards can be used as food packaging, the board is required to prevent grease, liquids or moisture from penetrating into the package.

## 2.2 Dispersion barrier coating

According to Kimpimäki (2008, 60), dispersion coating is typically a polymer dispersion. Dispersion coating is an even, solid, homogeneous and nonporous film of latex which has certain barrier properties and which has applied, metered and dried. Dispersion coating can be done on a paper as well as on a cartonboard. Latexes can be defined as dispersions of water and fine polymer particles, and a diameter of one latex particle is typically 50–300 nm.

Dispersion formulations can contain bio-based and synthetic polymers as well as additives and inorganic minerals (Ovaska 2016, 17). Most typically used polymers are various polyacrylates, polymetacrylates, polystyrene, polybutadiene, polyvinylacetate and polyolefins. Usually, latexes include also several different additives and fillers. The additives can be for example stabilizers, chelating agents, biocides, thickeners and antifoamers. It is also possible that there is a small percentage of monomers and emulsifiers. Fillers are added because they improve barrier properties, runnability, blocking resistance, optical properties or price competitiveness. Commonly used fillers are for example, calcium carbonate, kaolin and talc (Krogerus 2007, 58, 74). The most commonly used latexes contain ten to twenty components (Kimpimäki 2008, 61).

Dispersion coating applications require a latex that can form a film. There are four steps in film formation: evaporation of water, dense packing, coalescence and final film (Kimpimäki 2008, 62, 76). The main steps are presented in Figure 3 from left to right.

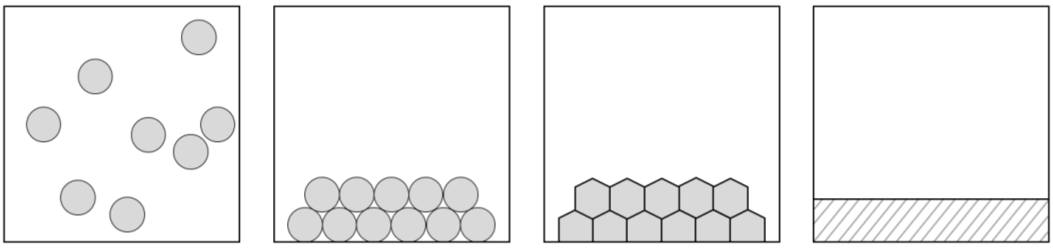

**Figure 3.** Latexes’ film forming mechanism which is used in dispersion coating (Kimpimäki 2008, 62, 76).

In the first step, the emulsion polymers are added to the board's surface. After the application, the water is evaporated from the system and the latex particles start coalescing. The particles first form a dense pack but in the third step, particles have formed a tight layer where the dense packaging has coalesced. In that phase, the dispersion coating takes a honey comb structure where the particles have not melt together but they stack together. (Kimpimäki 2008, 62–63, 76.)

The honeycomb structure turn to final film when the certain temperature is achieved. That temperature is called minimum film forming temperature and it varies depending on the dispersion coating. In the final step, the particles have created almost a homogeneous film where the particles have lost their individual shapes. It is important that the final film is uniform so there is no pinholes. The pinholes are allowing liquids to get to the baseboard which make the board soft. In the worst case scenario, the pinholes are allowing the liquids get straight through the board so the board cannot resistance liquids. (Kimpimäki 2008, 62–63, 76.)

## 2.3 Dispersion barrier coating methods

Dispersion barrier coating can be applied either an off-line or an on-line method. The off-line method uses a separate converting machine but in the on-line method, the dispersion coating is applied on the board at the board machine. Both of the methods have advantages. For example, off-line coating allows modifications in speed and the web is cool before coating. However, on-line coating produces less waste and it does not need as much time or employees since the board does not have to be transported to the off-line coater and coated over there. (Kimpimäki 2008, 63.)

On-line and off-line coaters can use same methods. Paper and board industry uses various coating methods, such as blade, rod, spray, curtain, reverse and gravure (Rantanen 2014, 11). A blade coater is the most common method and it gives the board a smooth surface. Because of the metering method, the barrier layer has thickness variations which can debilitate the barrier properties. However, the blade coater allows good printability to the surface. An air knife coater gives contour coating layer and therefore, the smoothness is not as good as in the blade coating. Roughness of a rod and a bar coaters' dispersion layer is between the blade and the air knife coaters. (Kimpimäki 2008, 68–69.) The blade coating and the air knife coating methods are shown in Figure 4. Curtain coating produces a contour-type surface which resembles air knife coating.

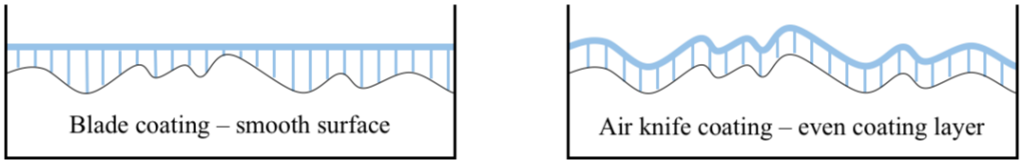


**Figure 4.** Two different coating methods (Kimpimäki 2008, 63).

The main goal of the dispersion coating is to achieve a barrier layer which protects the board. Thus, the goal is to produce an even contour-type film onto the surface of the board instead of smooth surface. Therefore, the air knife and the curtain coaters are favoured even though the blade coater is more common. Depending on the application, typical weight of dry dispersion is 4–15 g/m$^2$. (Kimpimäki 2008, 63.) With Kotkamills' board machine, it is possible to apply different coatings with different methods. A sectional view of Kotkamills' dispersion coated barrier board is presented in Figure 5.

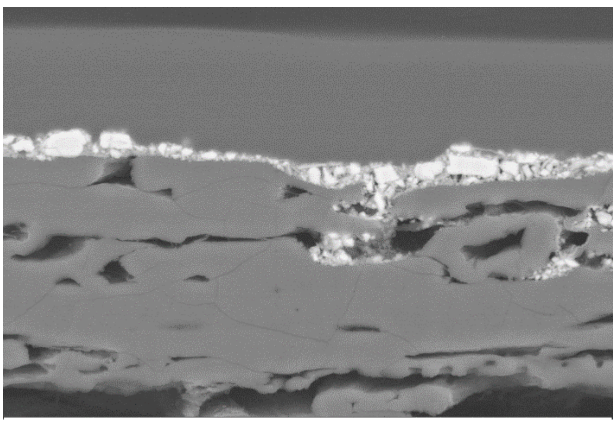

**Figure 5.** A sectional view of Kotkamills' dispersion coated barrier board.

The bottom layer in the Figure 5 is fibres in a top ply. White and grey layers on top of the fibre are different coating layers. From the sectional view, it is possible to see that the barrier layer is a homogeneous film on the top of the board.

## 2.4 Coating materials

There are different coating materials for dispersion barrier coating. Like mentioned before, Kimpimäki (2008, 60) has enumerated that the most typically used polymers are various polyacrylates, polymetacrylates, polystyrene, polybutadiene, polyvinylacetate and polyolefins. Polyethylene (PE) and polypropylene (PP) are common polyolefins which are thermoplastic resins. Low-density polyethylene (PE-LD) was the first commercial extrusion coating process used for coating paper and board. It is still the most commonly used polymer in extrusion coating industry since it has excellent sealing properties as well as adequate moisture resistance and low price. (Kuusipalo et al. 2008, 138–141.)

PE as well as PP are synthetic and based on non-renewable sources and therefore, they are non-biodegradable (Tokiwa 2009, 3722–3723). PE and PP are petroleum-based but since they have good temperature and grease resistance, they are commonly used as extrusion coating for food packages (Cheng et al. 2015, 42472(1)). There is also a bio-based PE which is also known as renewable PE. For example, a Brazilian company launched LLDPE (linear low-density polyethylene) and HDPE made from sugarcane ethanol in 2007. (Türünç 2011, 1357.)

Styrene butadiene rubber (SBR) and styrene acrylate (SA) are commonly used polymers for barrier dispersions. Both latexes are produced from synthetic polymers which generate water dispersions. SBR has many qualities, which improve the barrier properties of the cartonboard, but can also cause yellowing in UV light. (Häggblom-Ahnger & Komulainen 2006, 188–189.) Molecular properties of such latexes can be modified for different end-use needs. Typical properties are for example, molecular weight, film forming ability and binding strength. Those modifications and properties are also affecting barrier properties and runnability. (Kimpimäki 2008, 78.)

Vähä-Nissi et al. (2011, 3) have defined biopolymers which can be used in dispersion coating. There are biopolymers which are extracted from biomass, bio-derived polymers and polymers produced by organisms. In the classification, some biopolymers are also synthetic non-renewables. Classification is presented in Figure 6.

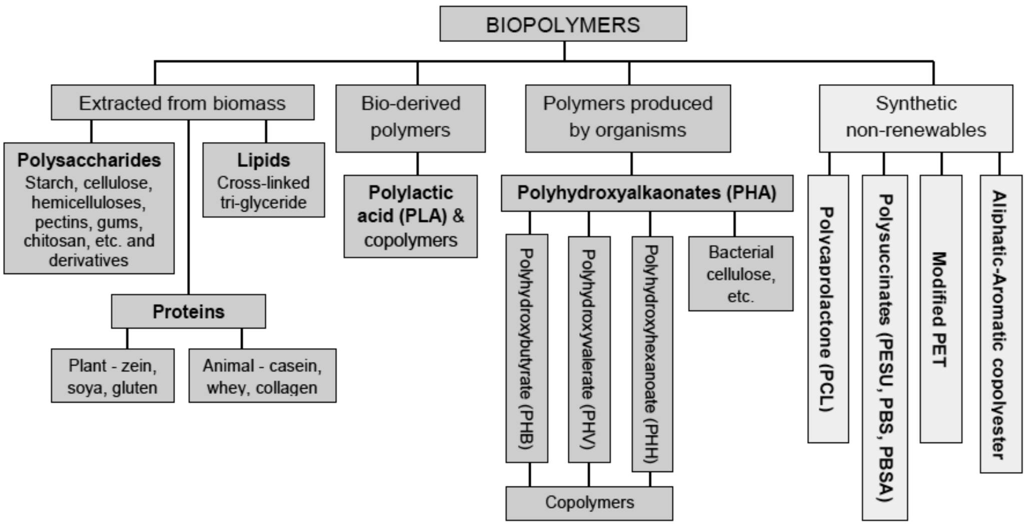


**Figure 6.** Classification of biopolymers (Vähä-Nissi et al. 2011, 3).

Polylactic acid (PLA) is bioderived polymer (Vähä-Nissi et al. 2011, 3) and biodegradable thermoplastic (Tokiwa et al. 2009, 3730). PLA has poor mechanical properties, thermal stability and processability and therefore, it has only limited applications. Nevertheless, the market potential of PLA is believed to be large since it is the most promising biopolymer and it is biodegradable. There are industrial processing techniques which are using PLA for example, extrusion coating, blown extrusion, and thermoforming for cups. (Cheng et al. 2015, 42472(1).)

Polyhydroxyalkanoate (PHA) and polyhydroxybutyrate (PHB) are polymers produced by organisms. PHA and PHB can be produced with even 250 different organisms and different organisms are affecting the features and qualities of final product as well as velocity of the process. With different applications of PHA and PHB dispersions, it is possible to achieve many different features. In food packages, PHB is more used than PHA. (Plackett 2011.) Both, PLA and PHA, can be generated by fermentative biotechnical processes and source material can be agricultural products and micro-organisms (Tokiwa 2009, 3732).

When using bio-based polymers as dispersion coating, it is possible to achieve relatively thin one layer coating compared to extrusion technology. Bio-based polymers also provide freedom for formulation. (Vähä-Nissi et al. 2011, 3.) Unlike plastic laminated, extrusion coated cartonboard, cartonboard with dispersion coating can be recycled easier since repulping does not demand any special treatment. Dispersion coated cartonboard can also be composted or incinerated without any difficulties. Due to these reasons, dispersion coatings have environmental benefits over plastic coatings. (Ovaska 2016, 13–14.)

The dispersion barrier is not a plastic based extrusion coating like PE but typically, a rubber based material like latex or bio-derived polymer, such as PLA or polymers produced by organisms, such as PHA and PHB. PHA is 100 % bio-based and it is biodegradable even difficult environment, e.g. in cold sea water. PLA is also 100 % bio-based but because it is only industrially compostable, it requires certain conditions for biodegradation. (Carus et al. 2017, 10–11; Vähä-Nissi et al. 2011, 3.) In the Table 1, a comparison between petrochemical and bio-based plastics and their biodegradability are presented.

**Table 1.** Comparison between bio-based and petrochemical plastics and their biodegradability (van den Oever et al. 2017, 15).

| | Petrochemical | Bio-based |
|---|---|---|
| Non-biodegradable | PE, PP | Bio-PE |
| Biodegradable | PBS | PLA, PHA, PHB |

However, this study concentrates water dispersion coatings because Kotkamills' barrier boards have a water-based dispersion coating. The used dispersion coating is not plastic according to the European Parliament and the Council since the barrier cannot be a final product's main structural component (2018/0172). The water-based dispersion coated cartonboard is compared with PE-LD coated cartonboard since it is the most common extrusion coating in current products which needs to resist water or grease.

## 2.5 Applicability of different recycling fibre classes

It is supposed that dispersion coated packaging waste and basic paperboard waste can be handled in the same way since different dispersion coated paper and paperboard grades with barrier latexes are repulpable. The pulper can be a conventional pulper because dispersion barrier coatings do not need any special treatments. The repulped material, which is typically recovered paper or paperboard, is slushed in the pulper and afterwards the same wood fibre can be recycled many times. (Kimpimäki 2008, 61.) The dispersion coated barrier board's fibres can be utilized to other products in secondary production.

The European Standard EN 643 (2014, 7) contains criteria for classification of standard paper and paperboard recycling grades. It has been made to assist industry professionals, organisations and individuals who are interested paper-recycling sector in buying and selling recyclable paper and board without a need of excessive sorting before the material can be used. When using the standard grades of paper and paperboard, the paper mill can be confident that the quality of bought material, recovered paper or paperboard, is what the company wants to use as their raw material.

According to EN 643 (2014, 9), natural fibre based paperboard is suitable for recycling. The paperboard can also include constituents which cannot be dry sorted or separated from the paperboard. Those can be for example coatings and laminates. EN 643 standard also determines which materials are prohibited. Those are any materials which can be hazardous for health, safety and environment, e.g. medical waste, contaminated products of personal hygiene, organic waste such as foodstuffs, and hazardous waste.

In the standard, there are five groups and every one of them has specific classification. The first two numbers stand for the group of the grade and the two final numbers possible subgrade. First group consist of ordinary grades, second medium grades and third one high grades. First group includes mixed paper and board, second sorted office paper and third white newsprint. Fourth group is kraft grades and the last group is special grades, such as used liquid packaging. (EN 643 2014, 13.) Table 2 presents the recycling classifications of board grades which are investigated in this study. There is a code for recycling classification, name of the material, maximum amount of non-paper components, unwanted material as well as maximum amount of FBB in percentages which is allowed in the grade.

**Table 2.** Recycling classifications of investigated boards grades (EN 643 2014, 17–29).

| Code | Name | Max non-paper components [%] | Total max unwanted material [%] | Max FBB [%] |
|---|---|---|---|---|
| 1.02.00 | Mixed paper and board | 1.5 | 2.5 | 100 |
| 1.03.00 | Boxboard cuttings | 1 | 2 | 100 |
| 1.04.00 | Corrugated paper and board packaging | 1 | 2 | 30 |
| 1.05.00 | Ordinary corrugated board | 1.5 | 3 | 10 |
| 3.11.00 | White heavily printed multiply board | 0.25 | 0.5 | 100 |
| 3.12.00 | White lightly printed multiply board | 0.25 | 0.5 | 100 |
| 3.13.00 | White unprinted multiply board | 0.25 | 0.5 | 100 |
| 5.02.00 | Mixed packaging | 1.5 | 3 | 100 |

Non-paper components comprise all foreign materials which are not components of paper and paperboard products and which can be separated by dry sorting. These materials are for example metal, plastic, glass, textiles, wood, sand and building materials as well as synthetic materials. Unwanted material includes the material which is not applicable for paper and paperboard production, such as non-paper components, paper, and paperboard which may compromise production, as well as paper or paperboard which is not applicable for deinking. (EN 643 2014, 11.)

Mixed paper and board (grade 1.02.00) can include paperboard from different grades but there can be only 40 % newspapers and magazines. Boxboard cuttings (grade 1.03.00) are for printed as well as unprinted white lined and unlined grey paperboard or mixed paperboard. However, no corrugated material is allowed in boxboard cuttings. Two following grades are for corrugated paper and board. The first one, corrugated paper and board packaging (1.04.00), is for used paper and paperboard packaging and there has to be at least 70 % of corrugated board. The second grade, ordinary corrugated board (1.05.00), has to contain at least 90 % used corrugated board such as boxes and sheets and they can be various qualities. Rest of the material can be various paper and paperboard packaging in both grades. (EN 643 2014, 17.)

Next three grades of interest are for multiply board. White heavily printed multiply board (3.11.00) contains wood free or wood containing plies where the surface of the board is heavily printed. White lightly printed multiply board (3.12.00) consists only paperboard which is lightly printed, wood free and which is made of mechanical pulp-based plies. White unprinted multiply board (3.13.00) is otherwise same as the grade 3.12.00 but the paperboard is unprinted. No grey or brown plies are allowed in these grades. (EN 643 2014, 23–25.)

5.02.00 is a special grade which contains a combination of different types of used packaging made from paper and paperboard. However, the mixture has to be free from graphic papers. Material from the recycling points and centres in Finland are typically this grade since it includes various qualities of used packages, such as all grades, which are mentioned earlier, as well as plastic coated packages. Plastic coated material has its own grade. 2.11.00 is for paper and paperboard, which have plastic coating. The material can also be printed or unprinted and unbleached. (EN 643 2014, 21, 29.) Both of these grades need special treatments when they are recycled since the plastic layer has to be separated from the fibres and the mixed grade needs to be sorted before the recycling.

Since different grades have different quality demands, the price of the material is also different. Mixed paper and paperboard as well as the material, which needs special treatments, have the lowest price. The material, which can be used straight without any special treatments, is the most expensive. Therefore, well sorted, clean and bleached wood free recycling paper in large amounts have the highest price. The paper and paperboard market is global, which affects to the market price of the material, by making them almost the same all around Europe. (EUWID 2017, 6–9.)

## 2.6 Applicability of different processes

Material from different paper and paperboard grades can be utilized in various processes as well as in various products. The main principle of the recycled paper and paperboard is that the recovered material has to be applicable and it can be utilized in the next product. According to Dahlbo et al. (2002, 22), even though recycling is a growing trend and it has been enhanced, recycling the fibres has its limitations. The most significant factors of the recycling is related to the recycling system, usability of different recycled paper and paperboard grades in the end products, as well as the quality and purity of fibre in terms of pulp and paper production.

According to CEPI (2018, 23), the share of non-recoverable, recycling or recovery to other material than recovered fibres, and final disposal was 27 % of the total paper and paperboard consumption. However, there are always fibre losses in recycling systems due to the nature of material's use. For example, tissue and some other special grades cannot be recycled due to hygienic reasons and some of the packaging materials, which are in contact with food, are not applicable for recycling due to the impurities and organic matter in the product. Books and other products, which have long life span, are also causing fibre losses. (Dahlbo et al. 2002, 23.)

Other fibre losses are due to secondary production of recovered fibres and raw material requirements of the products which are made from the recovered fibres. Typically, board's additives, fillers, coaters as well as other unwanted and non-paper components are separated and removed from the recycled material. For example, some products need perfectly deinked material while some products can utilize material with printing ink. Also, fillers are suitable in printing paper but not in tissues. There are only few recycled fibre-based production lines, which can utilize material with plastic coating residues and therefore, liquid packaging and other plastic coated packages need recycling processes which are capable of removing plastics. There are also some fibre-based technical factors which are causing fibre losses. For example, at some point the fibre is too old and short to be recycled. (Dahlbo et al. 2002, 23–24.)

A general problem in all paper mills, which are using recovered paper as a raw material, is a presence of sticky contaminants as well as adhesives. Those can cause quality defects and contamination of the process. In particular, these compounds are problematic in products with low basis weight, such as tissue and newspaper. (Putz 2000, 447; Dahlbo et al. 2002, 24.) Figure 7 presents typical origins of the stickies which are frequently identified in paper machine deposit in the recovered fibre (RCF) facilities.

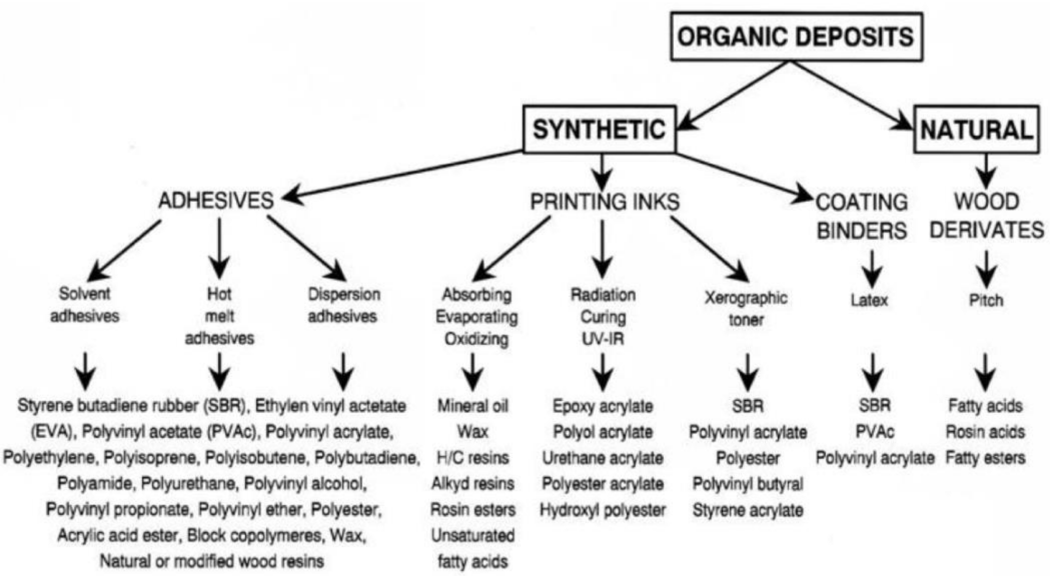


**Figure 7.** Origins of stickies which can be identified in RCF facilities (Putz 2000, 447).

In Figure 7, natural and synthetic materials, which are causing unwanted stickies, are presented. Pitch is one typical natural cause of the stickies. Synthetic materials, such as adhesives, printing inks, and coating binders are also causing stickies. Adhesives includes solvents, hot melts and dispersions and coating binders include latex. (Putz 2000, 447.)

However, approximately 62 % of the total paper and paperboard consumption was recycled in the paper mills. The net trade of paper for recycling was 11 % in CEPI countries in 2017. At the same year, utilisation rate for case material were approximately 94 %, carton board 37 % and wrappings and other paper and paperboard packaging 54 %. (CEPI 2018a, 22–23.) Table 3 presents the utilisation of paper and paperboard for recycling divided by sectors in shares and amounts.

**Table 3.** Utilisation of paper and paperboard for recycling divided by sectors in CEPI countries in 2017 (CEPI 2018a, 21).

| **Paper sector** | **Share [%]** | **Amount [tons]** |
|---|---|---|
| Newsprint and other graphic papers | 18.9 | 9 125 000 |
| Container board | 55.7 | 26 863 000 |
| Carton board | 6.8 | 3 287 000 |
| Wrappings, other packages | 9.7 | 4 695 000 |
| Sanitary and household | 5.8 | 2 812 000 |
| Other paper and board | 3.1 | 1 475 000 |
| **Total** | **100** | **48 258 000** |

According to CEPI (2018a, 21), 51.4 % of the recycled paper and paperboard grades is from corrugated and kraft, 19.1 % is from newspapers and magazines, 19.1 % mixed grades and 10.4 % from other grades. In the EN 643 standard (2014, 16–31), the corrugated grades are 1.04, 1.05, 4.01–4.08 and 5.04 and mixed grades include 1.01–1.03, 5.01–5.03 and 5.05.

Recycled pulp is typically used in container boards and cartonboard packages. Recycled pulp has good absorbency which makes it suitable for tissues. Due to the low quality demands of raw material, it is also suitable for container boards and multiply boards (WLC). Cartonboards, such as FBB, SBS, SUB, and LPB, have higher quality demands and they might have interactions with food which make recycled pulp hard to utilize. (Seppälä et al. 2005, 68–71.) Typically, paper production cannot utilize cartonboards if the fibres are brown due to the aesthetic reasons. Brown fibres are causing brown spots in the final product, such as newspaper or tissue. (Suomen Keräystuote Oy 2018.)

# 3 RECYCLING OF BOARD

Secondary production in recovered fibre (RCF) facilities uses recovered paper and paperboard as raw material. This material can be recovered paper or used packaging board as well as other kind of paperboard. Before the recycling, the material has to be cleaned from unwanted and non-paper materials such as rotten paperboard parts, stones and staples. (Seppälä et al. 2005, 68–71.) Cleaning of the paperboard can be done either in recycling centre or in the RCF facility. Typically in Finland, the recovered paper and paperboard is transported straight to the RCF facility where it is cleaned during the repulping process (Jussila 2018; Koskenheimo 2018).

Wood fibres can be repulped but because the fibre's quality decreases and fibre's length shortens every time it is repulped, it can be done from three to five times but occasionally even seven times (Finnish Forest Industries 2017). Fibres of the virgin and recovered material differs from each other. Due to the recycling process, recovered fibres are typically weaker and shorter than virgin fibre. Therefore, recycled fibres and products made from recovered fibres do not receive the same strength as products made from virgin fibres. (Seppälä et al. 2005, 68–71.)

Some packaging need features which cannot be achieved only with fibres. Many packaging and wrappings need for example, water and grease resistance and therefore, paperboard may need a barrier coating. The most commonly used coating for paperboard is extrusion coating with PE as presented in chapter 2.4. Extrusion coating gives an excellent barrier to the paperboard but at same time, it makes recycling of the packaging more difficult. However, not all the packaging applications need as high barrier level as the extrusion coating provides. Some products, such as disposable cups, plates, and trays for food service, are typically designed to hold liquid or grease only a short period of time. (Kimpimäki 2008, 102.) This has opened new coating and product possibilities, such as polymer dispersion coating.

The water-based dispersion coatings can be based on materials which are repulpable, unlike extrusion coatings (Kimpimäki 2008, 103). Even though, recycling and repulping are the most desirable path for the dispersion coated board, the material can be also composted or incinerated (Ovaska 2016, 13). In many cases, recycling is the best option in ecological point of view but it is also possible that sometimes incineration or composting is economically better option. For example, if incineration plant is close to the recovered material and the nearest RCF facility is far, incineration may be better choice than recycling.

Paper and paperboard are repulped in the RCF facilities. Therefore, next chapter defines pulping process and different pulpers shortly and after that, an example of a RCF facility is presented. Then some recyclability and repulpability tests of dispersion coated barrier board are described. The tests gives evidences of recyclability of the studied dispersion coated barrier boards.

## 3.1 Pulping

Pulping is done for recovered paper and paperboard in different type of pulpers. Pulping is fibre slushing and disintegrating with presence of water and mechanical force. At the same time, pulping also separates contaminants from the recovered paper or paperboard. In the pulper, the recovered paper and paperboard is mixed with water so it forms pumpable fibre slurry. The pulper gets the slurry to high flow velocity and rotary movement and the difference between the flow velocities originate forces which separates fibres from each other by releasing fibre bonds. The accept, which is fibre yield, is channelled to a storage tank to wait for utilization. The reject, which includes contaminants and non-fibre material, is removed from the pulper and disposed for example, in an incineration plant. (Lumiainen & Harju 2000, 73–80, 146.)

RCF facilities can have different processes, pulpers, equipment and operating times because they can be designed for different raw materials or certain product. The products, which will be manufactured from the pulp made in the RCF facility, are determining which type of material is repulped in the RCF facility. For example, RCF facility can be designed for OCC, office paper, or mixed paper and paperboard waste. Therefore, it is difficult to compare efficiencies, water consumptions and the amount of reject between different RCF facilities. (Lumiainen & Harju 2000, 73–74.)

Different pulper types are for example, broke, hydra and drum pulpers and there are low and high consistency pulpers. The hydra pulpers can be either horizontal or vertical and they are designed particularly to repulping OCC, cartonboard and mixed paper and board waste. Pulpers can operate continuously or batch wise. Vertical pulper has typically better efficiency than horizontal pulper because of the gravity assists in sinking pulp bales or paper and paperboard. A batch wise pulper gives more homogeneous pulp than pulper which operates continuously since the pulp is always pulped the same period. (Lumiainen & Harju 2000, 74–80; Andritz 2018.)

Typically, the recovered fibres are used to produce same kind of products which they have been. This means that for example, multiply cartonboard is normally used to make other multiply cartonboard, OCC is used to make container boards and paper is made out of paper. However, it is also possible to make other products from the recovered fibres. (Dahlbo et al. 2002, 22; Seppälä et al. 2005, 68–71; Suomen Keräystuote Oy 2018.) For example, when mixing multiply FBB with office paper, it is possible to make tissues, combining multiply FBB with OCC, it is possible to make laminate and when combining mixed packaging waste of paper and paperboard, which includes also plastic coated board, it is possible to make cores.

## 3.2 Example of a RCF facility

Kotkamills has a RCF facility and it is designed for pulping OCC which is EN 643 standard grade 1.05.00. It has two continuously operating vertical hydra pulpers and the primary pulper’s capacity is 30 $m^2$ and the secondary pulper’s 18 $m^2$. The material is disintegrated in the primary pulper for 5 to 10 minutes. From the first pulper, the accept goes to forward in the process and reject goes to secondary pulper.

In the secondary pulper, the material will be disintegrated another 5 to 10 minutes and after that, the accept goes again forward and the reject will be removed from the process. Temperature in both pulpers is approximately 50 °C.

Kotkamills RCF facility has also tried to utilize mixed packaging waste from households which is EN standard grade 5.02.00. Therefore, there is data when the RCF facility has used OCC as its raw material and when the facility has used mixed raw material which consists 50 % of OCC and 50 % mixed packaging. The comparison is presented in Table 4.

**Table 4.** The main parameters of an RCF facility compared with two different raw materials.

| **Raw material** | **OCC** | **Mixed material** |
|---|---|---|
| Feeding capacity [t/d] | 200 | 100 |
| Reject | 10 % | 20 % |
| Cleaning [n/d] | 3–4 | 6–8 |

The feeding capacity with mixed material is halved from what it can be with OCC and the reject percentage is twice as high. In a day, fibre yield from OCC is 180 tons and from mixed material it is only 80 tons. This means that it takes 2 days and 6 hours to get the same amount of fibres with mixed material than with OCC which also means that the production needs 2,25 times more energy for production. Therefore, it can be concluded that it is more efficient to produce fibres from OCC than mixed material in Kotkamills RCF facility.

Due to the higher reject amount, the pulpers have to be cleaned also more often. Cleaning time is approximately 1 to 1,5 hours and pulpers cannot be operating during that time. During the cleaning, both of the pulpers are rinsed twice. This consumes water approximately 34 $m^3$ and with the OCC, the water consumption is 102–136 $m^3$/d and with mixed material, it is 204–272 $m^3$/d. Therefore, the water consumption increases 68–170 $m^3$/d with mixed material which is approximately 50–170 % increase.

## 3.3 Recycling tests

Recyclability of the dispersion coated barrier boards has not been studied widely before and therefore, Kotkamills has been testing their barrier boards in different laboratories and processes. The tested barrier boards have been test material from the production trials. All the presented tests have been made between October 2017 and August 2018. The tests have focused on recyclability and repulpability and they have given relatively broad understanding of the dispersion coated barrier boards' recyclability.

Following chapters present recycling and repulping test methods and results which give evidences of the recyclability of the dispersion coated barrier boards. First the recycling tests' methods and specifications are identified and then, the test results. There are laboratory scale tests as well as production scale tests. At the end of the chapter, there is a short summary of all the tests and a conclusion. The trade names of the Kotkamills boards have been changed to codes.

Recycling and repulping have been studied in various laboratories in this study. Those laboratories are mentioned by their names but companies, which have tested recyclability of the Kotkamills' barrier boards, have been encrypted. Papiertechnische Stiftung (PTS) has done most of the laboratory scale tests. PTS is a research and service institution which offers fibre-based solutions and tests for fibre-based material (PTS 2018). Other laboratory scale tests have been done in different universities and companies own laboratories. Also, some companies have also tested Kotkamills' barrier products utilizations as a raw material in their processes in production scale tests.

### 3.3.1 Methods and specifications of recycling tests

Many of the recycling tests have been done with PTS Method RH 021/97 in the same laboratory and with the same equipment. In the PTS Method RH 021/97, the test is always repeated three times with the same material and the final result is the mean of all three test results. In the test method, repulping is done in line with DIN

EN ISO 5263 where there is 2.5 % disintegration consistency, temperature is 40 °C and pulping time is 20 minutes with velocity of 60 000 rpm. Thus, the recycling test done according to PTS Method RH 021/97 includes also repulping test.

Assessment of recyclability is done only with a fractional residue from an apparatus called Brecht Holl. The Brecht Holl is a sifter which has 0,7 mm holes on it so the particles smaller than the holes are going to accept and particles bigger than that are called reject. The material is classified as repulpable if its Brecht Holl residue is less than 20 % and recyclable if the Brecht Holl residue is less than 20 % and the material has speck-free defibration and undisturbed sheet forming. This means that there cannot be sticky contamination or optical inhomogeneities. If the Brecht Holl residue is 20–50 % but there is no sticky contamination, the classification is recyclable, but in need of improvement regarding product design. If there is optical inhomogeneities, the result is partly recyclable. Partly recyclable means that the product is recyclable but only to products which can handle optical inhomogeneities.

Repulping tests have also been done with Voluntary Standard by Fibre Box Association (2013). The test is originally designed for corrugated fibreboard but it can be utilized also for other paperboards. One laboratory tested the material with different amount of rounds and in different temperatures but total volume was always 2 000 ml and disintegrator's velocity was 3 000 rpm. The paperboard is deflaked for four minutes in the temperature of 55 °C. Accepts and rejects are separated when mixture was run on a 0.245 mm slotted open flat screen, maintaining a 1″ water head for 20 min. In this method, the tested material is classified as repulpable if fibre yield from the test is at least 80 % when comparing to the total weight.

The hypothesis of both test methods is that the recyclability and repulpability should better when the share of pigment and barrier is smaller. This means that the test result should be better when the base board is thicker so there are more fibres which can be repulped and recycled. However, it is possible that barrier has formed tight bonds with the fibres so the pulping time is not enough to break those bonds and the reject contains barrier as well as fibres. It is also possible that some of the barrier is disintegrating into small pieces which are capable of going through the sifter's holes and which can cause optical inhomogeneities.

PTS and Darmstadt University have used PTS Method RH 021/97 in their recycling tests. Aalto University as well as Michigan University have tested only repulping and they have used Voluntary Standard. Michigan University followed the Voluntary Standard strictly but Aalto University tested how the repulping time and rounds affects the results. Companies have had various methods when they have tested recyclability or repulpability in their laboratories and production scale tests have been done in different RCF facilities and in different processes.

### 3.3.2 Laboratory tests

Seven different board grades have been tested in PTS laboratory. A0 and B0 boards do not contain water-based dispersion barrier coating but A0 board has pigments and B0 has not. All other board grades have pigments as well as barrier. Over all, there have been 11 tests in PTS laboratory and the test results are presented in Table 5. The second column from the left indicates the share of pigments and barrier from the whole board. The tested boards may have had different grammages and therefore, the value may change even though the board type is otherwise the same.

**Table 5.** Recycling test results of PTS according to PTS Method RH 021/97.

| **Board** | **Pigment and barrier [%]** | **Brecht Holl, 0,7mm [%]** | **Adhering particles or picking of fibres** | | **Optical inhomoge-neities in accept** | **Result** |
|---|---|---|---|---|---|---|
| | | | **whole stock** | **accept** | | |
| A0 | 14.8 | 2.8 | No | No | No | Recyclable |
| A1.1 | 18.2 | 0.9 | Yes | No | Yes | Partly recyclable |
| | 18.4 | 0.7 | No | No | No | Recyclable |
| A2.1 | 18.2 | 5.0 | Yes | Yes | | Non-recyclable |
| | 18.4 | 2.3 | No | No | No | Recyclable |
| A2.2 | 12.6 | 3.9 | No | No | Yes | Partly recyclable |
| | 13.2 | 4.9 | No | No | Yes | Partly recyclable |
| B1.1 | 10.8 | 27.7 | Yes | No | No | Recyclable but in need of improve-ment regarding product design |
| | 10.8 | 24.3 | Yes | No | No | Recyclable but in need of improve-ment regarding product design |
| B1.2 | 7.8 | 13.3 | Yes | No | No | Recyclable |
| B2.1 | 15.5 | 9.7 | Yes | No | Yes | Partly recyclable |
| B0 + PE coating | 9.6 | 13.6 | Yes | No | No | Recyclable |

14.8 % of the A0 board's weight was pigments and 2.8 % of the A0 board was rejected with Brecht Holl apparatus. There were not adhering particles or optical inhomogeneities in the accept thus the board was rated as recyclable. A1.1 boards had bigger share of pigments and barrier in related to boards' grammage than A0 board. Even tough, the both of the A1.1 boards had almost the same share of pigments and barrier and the Brecht Holl apparatus gave almost the same results with the reject rates, the first A1.1 board had optical inhomogeneities and the second one did not. This result is inconsistent since the second A1.1 had bigger pigment and barrier share and smaller reject rate thus the result is contradiction with the hypothesis.

First A2.1 board was not recyclable due to the adhering particles in the accept but the second A2.1 board was clearly recyclable even though, there were almost the same amount pigments and barrier. A2.2 boards had less pigments and barrier than A2.1 boards but they had still almost the same reject rate. However, due to optical inhomogeneities in accept, both of the boards were rated as partly recyclable.

The same B1.1 board grade was tested two times and because of the high fractional residue of Brecht Holl apparatus (27.7 % and 24.3 %), PTS resulted the board as recyclable, but in need of improvement regarding product design. However, it is notable that the exactly same board had over three percentages difference in their reject rates. B1.2 board had relatively lower reject rate than B1.1 board even though, the share of pigments and barrier in relation to board’s total grammage did not change much. The result of B1.2 board was recyclable. All the B1 boards had bigger reject rates than pigment and barrier rates which means that the reject contained also fibres which could have been recycled.

B2.1 board had the biggest share of pigments and barrier in relation to total grammage of the board compared to other B boards but it had the lowest rejection rate. However, there were some optical inhomogeneities in B2.1 board’s accept and therefore, the result was only partly recyclable. B0 board coated with conventional PE layer was rated as recyclable in PTS test even though, PE coated board is not recyclable in most of the RCF facilities. The reject of the PE coated B0 board also contained recyclable fibres, such as B1 boards.

As inference, all tested barrier board grades are recyclable or partly recyclable according to PTS. Partly recyclable means that the board is recyclable but the board cannot be used as raw material in every secondary production due to the optical inhomogeneities in the accept. Therefore, it is important to find products which can handle optical inhomogeneities, such as cores and other industry products. It is also important to remember that typical raw material of secondary production does not consist solely one type of the board but several different grades and board types as a mixture. Therefore, optical inhomogeneities may not be a problem in the RCF facilities and secondary production.

PTS test method has caused some lack of confidence due to illogical and contradiction test result. In PTS tests, the exact same board had different reject rates like seen with B1.1 tests. However, these variations may be due to a human error or the share of long fibres. Also, because testing the the optical inhomogeneities is done by humans, there can be human errors. Because PTS tests have been only laboratory scale tests, they do not take into account the repulping processes and therefore, it is possible to conclude the PE coated board also as recyclable. Therefore, larger scale tests are needed so it can be tested if the barrier board can be repulped in the processes where PE coated board cannot be utilized. Because of these reasons, the barrier boards have been tested in other laboratories with the PTS Method RH 021/97 as well as other methods and there have been production scale tests in collaboration with cooperation partners.

Repulpability tests have also been done in universities. Aalto University studied both A1 and A2 barrier boards and compared the results to Kotkamills B0 board, which does not have any barrier layer or pigments on it, and PE coated board which was bought from a super market. Because the PE coated board was bought from the supermarket, there is no information about the plastic or pigment amounts. 11.5 % of A1.2 board was pigment and barrier and A2.1 board’s share was 13.8 %. The test results when the temperature was 52 °C is presented in Figure 8. The test was carried out in the beginning of 2018.

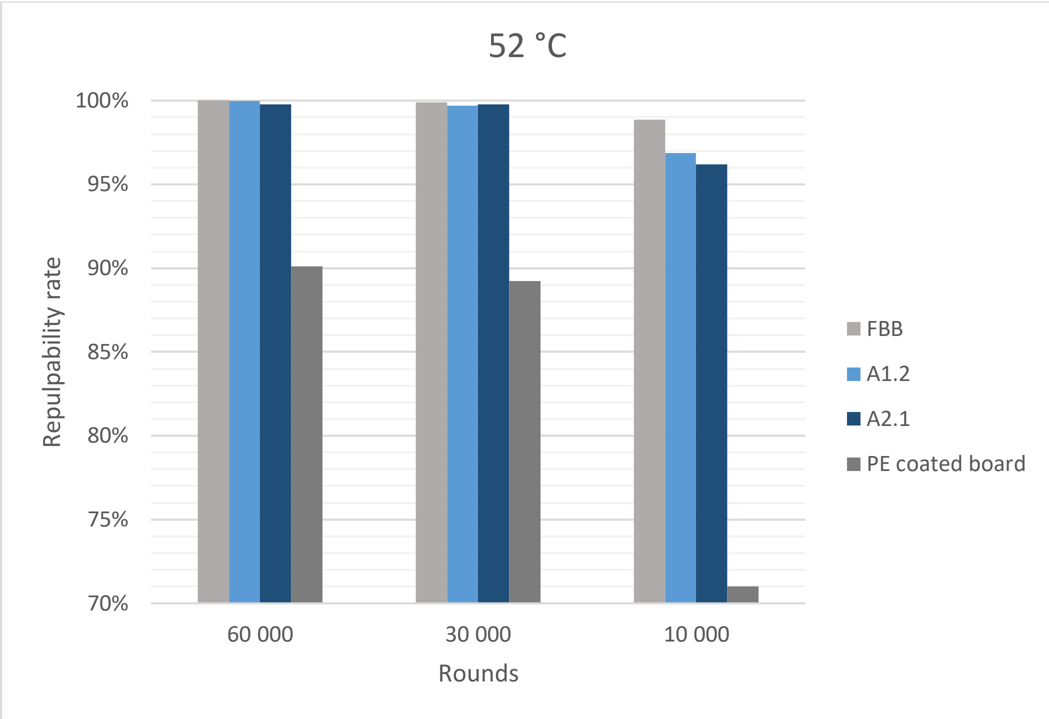


**Figure 8.** Aalto University's repulping test results in 52 °C with three different rounds.

The effect of temperature change was tested with 30 000 rounds and therefore, the temperature was decreased to 30 °C. The results are presented in Figure 9.

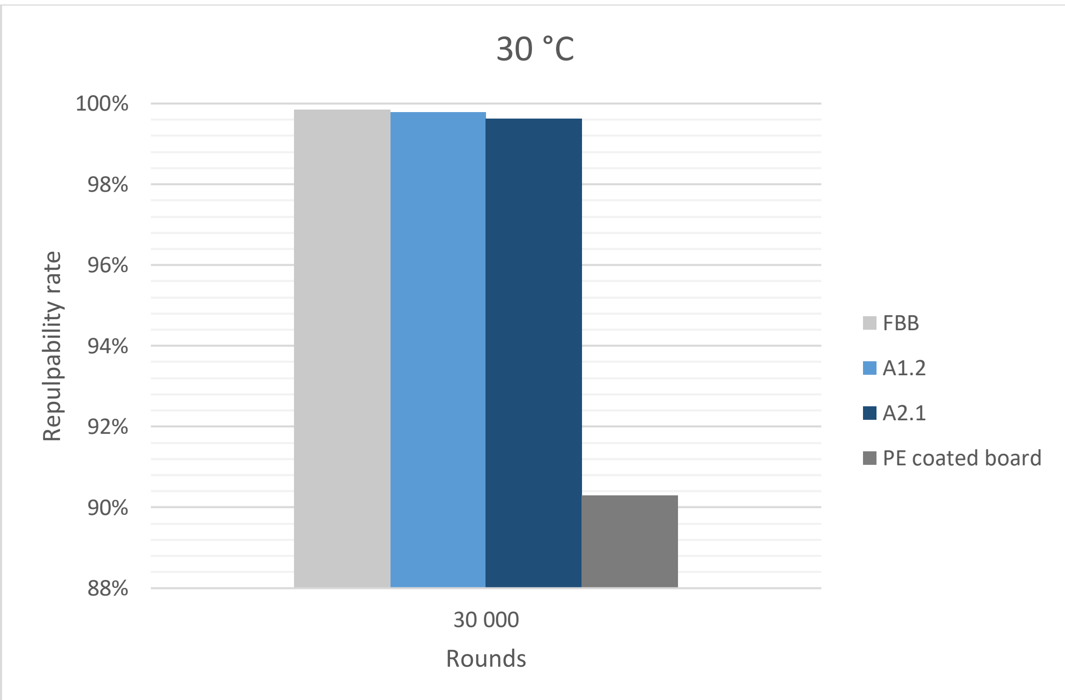


**Figure 9.** Aalto University's repulping test results in 30 °C with 30 000 rounds.

According to Figures 8 and 9, Kotkamills' cartonboards had clearly better repulpability rate than PE coated board with the test circumstances. Like expected FBB had the best repulping results in every test conditions since there is not barrier or extrusion coating on the board. Its repulpability rates were between 98.9–100 %. PE coated board had the worst repulpability in this test since its repulpability rates were between 71.0–90.3 %. The worst rate was resulted with 10 000 rounds in 52 °C and the best result was achieved with 30 000 rounds in 30 °C.

Practically, the only real difference between the tested barrier board, A1.2 and 2.1 was when material was pulped with only 10 000 rounds in 52 °C. However, these results were also really good since the repulpability rate was 96.8 % with A1.2 board and 96.2 % with A2.1 board. The effect of temperature change was tested with 30 000 rounds but it did not affect repulpability in a significant way. Therefore, it can be said that differences in repulpability rates are insignificant small and both board types can be repulped according to this method.

Dispersion coated barrier board has also been tested in Western Michigan University. The test was made in June 2018 and with exactly the same B1.1 as in PTS test so the share of barrier was 10.8 %. The test was done with the same method as Aalto University test but since the test was not about the rounds, the board was deflaked for four minutes in the temperature of 55 °C. Otherwise the test was exactly the same. The test was done two times and in the first time the amount of reject was 10.6 % and in the second time 10.0 %.

Technische Universität Darmstadt tested six Kotkamills' barrier boards from June to August 2018. One of tested material was A0 but other five were barrier boards. Recycling tests were made according to PTS Method RH 021/97. The test results are presented in Table 6.

**Table 6.** Recycling test results of TU Darmstadt.

| Board | Pigment + barrier [%] | Brecht Holl, 0,7mm [%] | Adhering particles or picking of fibres | | Optical inhomoge-neities in accept | Result |
|---|---|---|---|---|---|---|
| | | | whole stock | accept | | |
| A0 | 13.3 | 0.4 | Yes | No | No | Recyclable |
| A1.1 | 15.0 | 2.8 | Yes | No | No | Recyclable |
| A2.3 | 12.6 | 5.7 | Yes | No | No | Recyclable |
| B1.1 | 10.8 | 21.5 | Yes | No | No | Recyclable but in need of improve-ment regarding product design |
| B1.2 | 7.8 | 13.9 | Yes | No | No | Recyclable |
| B2.1 | 7.8 | 11.0 | Yes | No | No | Recyclable |

According to Table 6, all other boards were recyclable except B1.1 which is due to over 20 % rejection rate. All the boards had some bonding or picking in the whole stock but none of them had bonding or picking of the fibres in the accept.

Also some companies which are using recovery fibres as their raw material have tested dispersion coated barrier boards. They have had various test methods since the equipment and processes have huge differences. The companies which have done recycling tests are from Czech Republic, Finland, Germany and Russia. The companies have used their own laboratories and methods to carry out the test.

Company A from Czech Republic manufactures cardboard and corrugated board packaging also from the recovered fibre. Company A tested slightly printed final product of B1.1 board in their own laboratory in May 2018. There is no information how Company A did the test but they resulted that solvability and colouring on the tested board were harmless for their processes. Also, fibre quality was good and level of contaminant was very good. According to this laboratory test, Company A can use B1.1 board as their raw material and wanted to proceed to the production scale test so they can test whether dispersion coated barrier board can be utilized in their process and pulper.

Company B from Russia tested also B1.1 board in its laboratory at the same time as Company A. The share of the pigments and barrier was 10.2 % from the total grammage of the board. The samples were first chopped and put into three portion because one portion was disintegrated for 5 minutes, other 20 and the last one 20 minutes. The laboratory disintegrator's velocity was 300 rpm. The results are presented in Table 7.

**Table 7.** Repulping test results of Company B.

| Time [min] | Result |
|---|---|
| 5 | Insufficient repulping, big petals which barrier film with fibre, no changes in size |
| 10 | Petals which were mostly barrier film but little bit fibre, no changes in size |
| 20 | Small petals, no changes in barrier film size, no fibre |

Because of the barrier film, B1.1 board was not suitable for Company B's process so it cannot be used as a raw material in secondary production according to this laboratory test. This may be due to the relatively slow velocity of the disintegrator since the repulping rate was almost 100 % with A1 board with velocity of 3 000 rpm.

Company C is operating in the same business as Company A but it is a German company. Company C tested dissolvability of B1.3 board in its laboratory also in May 2018. First test was made with dissolver and the dissolving time was 10 minutes. The second test was made with laboratory mixer and this time, the dissolving time was only 2 minutes. The testing temperature was 23 °C in both tests. After that a laboratory sheets were made, they were evaluated optically. Company C concluded that and they resulted that in principal, the dissolvability was good. The laboratory sheets made from dispersion coated barrier board were nearly homogeneous so there were nearly no visible parts of surface coating. However, when the sheets were separated from the underlay, it stuck to the pad. According to this laboratory test, the material could be recycled with Company C's processes but first production scale trials are needed.

### 3.3.3 Production scale tests

Repulping of dispersion coated barrier board has been tested in Kotkamills own processes. Valmet tested repulping of barrier production's broke in cartonboard production line. Valmet's repulping test was made in May 2017 and since the test results showed that the broke slushing including deflaking worked well, currently the broke, which comes from dispersion coated barrier board production, is used again in the same production. Due to the capacity of the pulper, the broke can be used 120 tons in a day. Otherwise, it could be used more in a day.

Kotkamills also owns a RCF facility which produces material for Absorbex® production line. Absorbex® uses recovered OCC, which is in EN 643 standard class 5.02, as a raw material in Absorbex® Eco products so it was reasonable to make a trial in Kotkamills own RCF line. The test took place in January 2018 and the used material was A1 board. Dispersion coated barrier board broke was added in RCF pulper and three samples were taken from the pulp. Each one of the samples weighted three grams. The same test was also provided to mass made only from OCC in December 2017. Both test results are presented in Figure 10.

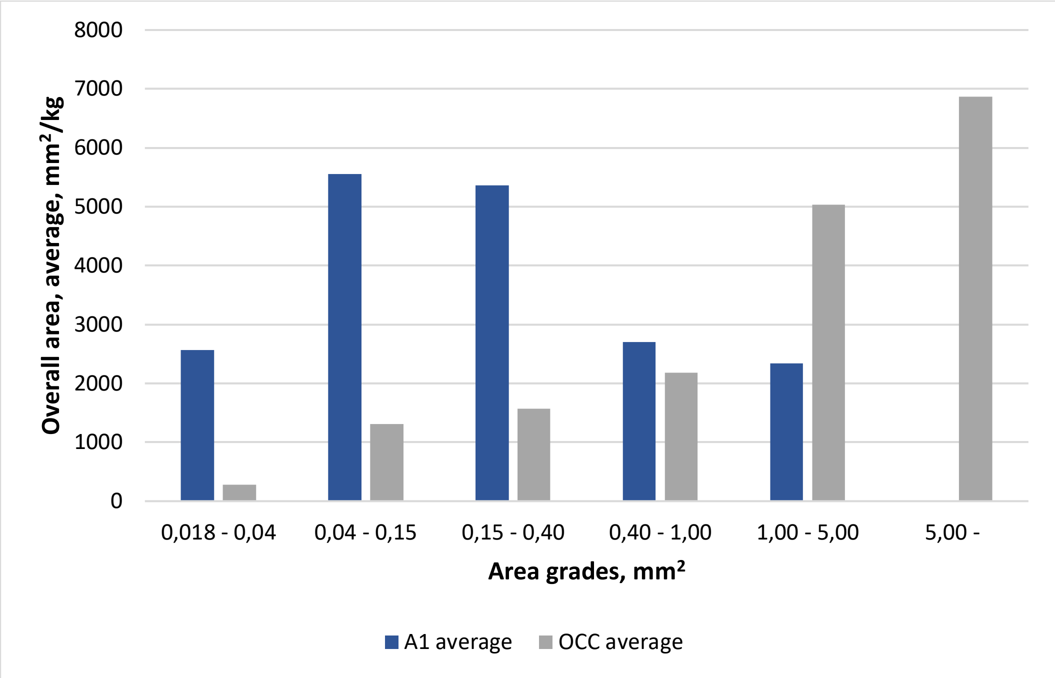


**Figure 10.** Overall area of stickies of OCC and A1 board divided in area grades.

OCC and dispersion coated A1 barrier board had almost same amount of sticky contaminants since overall area of sticky contaminants of FBB were approximately 18 500 $mm^2$/kg and OCC were 17 300 $mm^2$/kg. According to Figure 10, most of the sticky contaminants of A1 board were area grade of 0,04–0,4 $mm^2$ whilst OCC's sticky contaminants are increasing through area grades so highest amount of sticky contaminants were in area grade 5,00 $mm^2$. According to the test results, the RCF facility which is currently using OCC as a raw material can also use dispersion coated FBB as a raw material since there is not too much sticky contaminants and the runnability of the pulp was good. However, since the RCF facilities differs from each other, the conclusion is that dispersion coated FBB can be used as a raw material when it is mixed with OCC.

Company D from Finland tested B1.1 board in their laboratory and in a production scale test in June 2018. The laboratory test was a repulping test which produced a hand sheet from the pulped material and because the test went well, 1,8 tons of B1.1 board was sent to Company D. The Company D's pulper capacity was little under 5 tons thus 36 % of the pulped material was B1.1 board and other material was quite clean ordinary sorted office paper (2.05 in the European standard EN 643) and multi printed paper (3.10 in the European standard EN 643) which are company's typical raw material in its production. The recycling test was done while the company was running the normal production. Repulping time was approximately 15 minutes, the water was 50 °C and there were no chemicals were added to the pulper. The raw material, which was pulped at the test, is presented in Figure 11.

**Figure 11.** Raw material going to pulper. B1.1 board are the B1 sheets and other material is shredded ordinary sorted office paper.

At first, there were some bigger material parts floating around the pulper. Those parts were approximately 4 $cm^2$ and the parts consist multiple layers of sheets. It is possible that the material form, B1 size sheets, caused these parts since the material was packed in compact form. However, the material was able to disintegrate in 15 minutes thus were no bigger parts left at the end but nonetheless, the barrier formed relatively long barrier ribbons. In the pulper, the barrier layer came off from the board and pivoted around itself forming ribbons. The ribbons went to reject and they were removed from the pulper. One of the ribbon is presented in Figure 12.

**Figure 12.** Barrier ribbon where other waste is attached.

The barrier ribbons were no problem for Company D’s process because the reject percentage was almost same in this recycling test. Company D’s typical reject rate is approximately 10 %. However, the barrier layer took some of the fibres to reject but according to Company D, that is not a problem since the fibre yield was still good. Company D is interested to take dispersion coated barrier board to their raw material in its continuous production. This recycling test gave a really good result since Company D’s facility has not been designed for extrusion coated board but the pulper was able to repulp dispersion coated barrier board. However, the next step would be to test if other form than B1 sheets would be better to repulped and if post-consumer waste could be used as well as a raw material. Also, it should be tested how much dispersion coated barrier board there can be in raw material in relative to other raw material.

### 3.3.4 Summary and conclusion of the recycling tests

According to laboratory tests made in PTS, Aalto University, Michigan University and Darmstadt University, all the board grades are either recyclable or partly recyclable. When comparing A boards and B boards, it can be concluded that even tough A boards had more pigments and barrier compared to boards’ weight, the reject rates were bigger with B boards. Therefore, A board grades are more easy to recycle than B board grades. This also means that the hypothesis was not correct which also means that the pigments and barriers are not functioning in the same way at the recycling test. The share of the pigments and barrier are affecting in the recycling test results in significant way.

The recycling tests made in different companies' laboratories are presented in Table 8. Only one company, Company B, has resulted the board as non-recyclable and other one, Company C, as partly recyclable. In two companies' laboratory tests, the board has been rated as recyclable. Only Company C has made production scale tests and that tests' result was good since the B1.1 board was repulped with other materials without any problems.

**Table 8.** Companies' recycling test results.

| Board | Tester | Scale of the test | Result |
|---|---|---|---|
| B1.1 | Company A | Laboratory | Recyclable |
| | Company B | Laboratory | Non-recyclable |
| | Company D | Laboratory | Recyclable |
| | Company D | Production | Recyclable |
| B1.3 | Company C | Laboratory | Partly recyclable |

According to Tables 5, 6 and 8, the dispersion coated barrier board are all recyclable in some processes and fibre yield is good. Dispersion coated barrier boards cannot be recycled in every processes since they need longer disintegration time than some board materials.

These test results also showed that laboratory tests are not comprehensive. Board can be rated as recyclable in the test laboratory with the PTS Method RH 021/97 but it cannot be recycled in typical RCF facilities, such as PE coated board. PTS Method RH 021/97 and Voluntary Standard measures only one type of pulping scenarios and therefore, production scale tests in the real RCF facilities in production scale tests are crucial when wanting to prove the recyclability and repulpability of a fibre-based product.

# 4 RECYCLING LEGISLATIONS AND PRACTICES

Kotkamills is currently operating in every continent. However, the most important market area for Kotkamills is Europe. Therefore, two European countries were chosen for this study for closer investigating and those countries are Finland, and Germany. Since both countries are currently part of the European Union, they have to obey EU legislations and directives which are also the basis of their national legislations. Because of the national legislations, Finland and Germany have differences in their legislations and municipal waste practices. For example, they have different targets in the waste amounts and different recycling systems as well as waste management practices.

When Kotkamills' dispersion coated barrier board product is used, it becomes waste such as every other packaging. The EU waste hierarchy for all waste is presented in Figure 13.

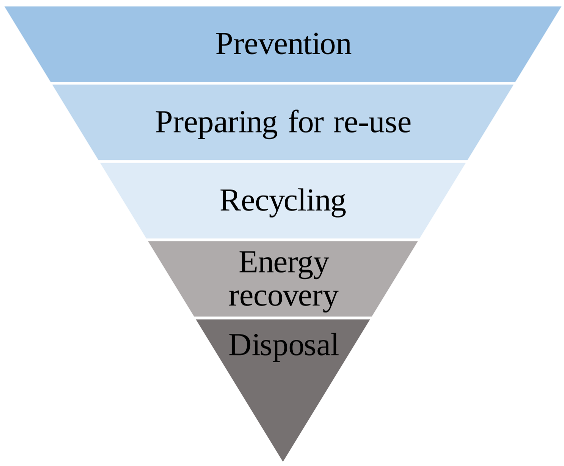


**Figure 13.** The EU waste hierarchy (2008/98/EC 2008).

The best option for dispersion coated barrier board products is recycling from the EU waste hierarchy. When the business is about making the product, the waste cannot be prevent and since there can be interactions with food, products cannot be re-used as they are. Therefore, the third best option of the waste hierarchy is the best for the products made from dispersion coated barrier board. After recycling, the options are energy recovery and disposal. Disposal of the product should always be considered as a last option because it is waste of a material which can be recycled or recovered.

Kotkamills’ dispersion coated barrier board products are typically packaging and therefore, the European Parliament and Council Directive 94/62/EC on packaging and packaging waste is important. The Directive came into force in 1994 and it forms the basis for packaging legislation in EU countries. The Directive has four amending Acts which are Directives 2004/12/EC, 2005/20/EC, 2013/2/EU and 2015/720/EU. The directives seek to harmonizing management practices of packages and packaging waste by prevent or reduce environmental impacts of the packages and ensure the functioning of the internal market. In the directives, there are determined basic requirements for packaging and how they can be manufactured in a safe and hygienic way which minimizes weight and volume and environmental impacts of the packaging. (94/62/EC 1994.)

The directives also imply the producer responsibility principle and set out measures and requirements for the prevention, re-use and recovery of the packages and packaging waste in EU countries. The prevention of the packaging waste production is the first priority. After that the directives promote recycling, re-use and energy recovery and the final disposal should always be the last solution. (94/62/EC 1994.) The directives have set the paper and board (fibre) recycling target to 60 % based on weight (2004/12/EC 2004). The EU parliament and council have proposed that the recycling target for paper packaging will 75 % for 2025 and the target will be increased in 2030 to 85 % (EUWID 2017, 2).

In order to meet the requirements of the directives, member states are taking necessary operations which has led to Green Dot System implementations. Green Dot System is about packaging waste management system which is popular in the Central and Western Europe. Nowadays Green Dot System is used for example in Germany, France, Spain, Austria and United Kingdom. However, in the United Kingdom, the Green Dot System is licensed for those organisations who are wishing to have an emblem so it is not obligatory. (Pires 2011, 1039–1040; Baughan & Evale 2004, 1.)

To identify the material of a packaging, packaging placed on the market may be labelled. The marking shall be clear and visible and even if the packaging is opened, the marking shall be easily legible. (518/2014 2014.) However, using a recycling symbol is optional since a recyclable claim can be done also otherwise (EN 14021 2016, 52). Universal recycling symbols have been created for the identification. There are different recycling symbols for different use. Figure 14 presents three different recycling symbols on the market. The first symbol on the left is a recycling symbol for generic material. The second and third symbols are called Mobius Loop. The symbol indicated that a product or packaging can be recycled. However, Mobius Loop does not indicate that the product or packaging will be accepted every recycling collection systems. (Recycle Now 2018.)

**Figure 14.** The recycling symbol for generic materials and white and black Mobius Loop (Recycle Now 2018).

Typically, the first symbol is combined with more precise information about the material. Thus, there can be a number inside the symbol which states the plastic grade. If the material is paper or paperboard, there are letters "PAP" below and a number inside the symbol indicating certain type of the material. Corrugated board is marked as PAP 20 and other cartonboard as PAP 21. Paper is PAP 22. (518/2014 2014.) There are own markings for combination of different materials, such as paperboard with metal is C/PAP 80 and paperboard with plastic is C/PAP 81 if there are more board than other material. Otherwise, it would be for example C/PE 81 if there is more PE than board. (Suomen Kuitukierrätys Oy 2018, 2.) Material of the packaging should be easy to identify with the symbol and a consumer knows how the packaging should be recycled.

It is possible to find other symbols in paperboard packaging as well and three of them are presented in Figure 15. The first symbol does not tell anything about the material of the packaging but it tries to educate a consumer for not littering the environment. The second is an international symbol for material which is food safe so the material can be interactions with food (1935/2004/EC). The last symbol is the Forest Stewardship Council's (FSC) logo. The logo is used for product made from wood which is from well managed forest which has certified in accordance with the rules of FSC. (Recycle Now 2018.)


**Figure 15.** "Do not litter" recycling symbol, food safe symbol and FSC symbol (Recycle Now 2018; 1935/2004/EC).

Because of the recycling labels and symbols, consumers have more information about recycling the paper or paperboard products. Symbols in Figure 14 and 15 are free to use when the company can prove that their product follows the rules and fulfils the demands of the symbols.

There are some organizations and bodies which are gathering information from the paper and paperboard business. CEPI comes from words Confederation of European Paper Industries and it e.g. follows and updates the recycling and utilization rates of the paper and paperboard annually. There are 18 countries in CEPI. 17 of them are EU member states and one of them is Norway. Finland, Germany and United Kingdom are all CEPI members. (CEPI 2018b.) The utilization of paper and paperboard for recycling in 2017 is presented in the Figure 16.

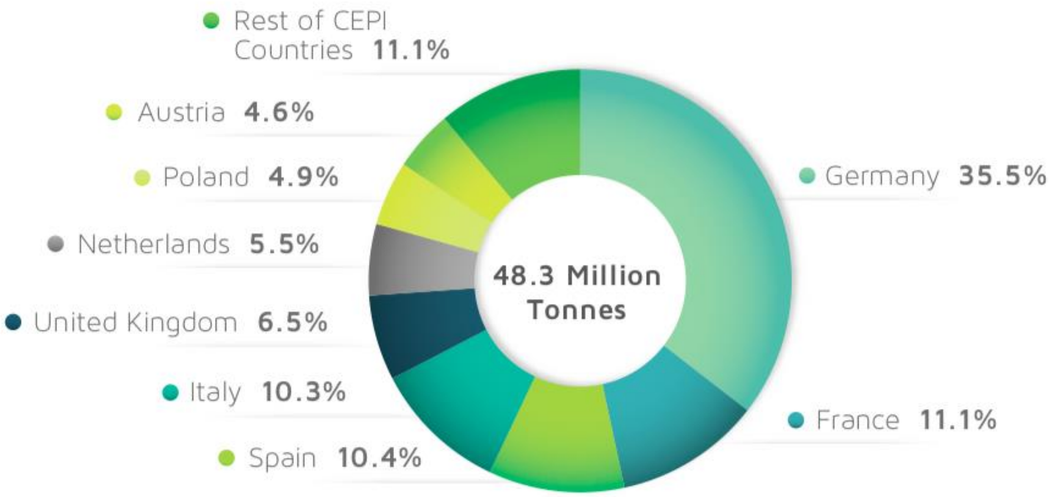


**Figure 16.** Utilization of paper and paperboard for recycling in CEPI countries in 2017 (CEPI 2018a, 21).

In 2017, 48,3 million tonnes of paper and paperboard was utilised for recycling in CEPI countries. Germany recycled 35.5 % from that volume which is approximately 17,15 million tonnes, and United Kingdom recycled 6.5 % which is 31,40 million tonnes. In the Figure 16, Finland is a part of "the rest CEPI countries" with other nine member countries. (CEPI 2018a, 21.) The shares can be explained with the bigger population and volume. Also, Finland has a lot of forest and wood and therefore, there is no need to use recovered fibres and they can export the recovered fibres to other countries. Germany and France do not have a lot of forest to use in paper and board making and therefore, they need to utilize recovered fibres.

The European Commission proposed new rules to target ten disposable and single-use plastic products in May 2018. The rules would be EU-wide and together with abandoned finish gear, these disposable plastic product are constituting 70 % of all items which are marine litter. Consumption reduction will affect food containers and cups for beverages and the extended producer responsibility will be taken into use in all of the European countries. Other items in the list are for example cotton bud sticks, cutlery, plates, straws, packets, wrappers and lightweight plastic carrier bags. (2018/0172.) This proposal opens even more business opportunities to barrier coated paperboards in Europe.

Recycling legislations and practices of Finland and Germany are shortly presented in following chapters. The chapters are focusing to the most important legislations, biggest players in the recycling sector and typical costs of the practices.

## 4.1 Finland

Finnish waste legislation is based on EU's current waste legislation (Rinki 2017, 8). The EU directives on packaging and packaging waste were implemented in Finland's national legislation with a government decision in 1997 (92/1997) and government decree in 2005 (817/2005). The current government decree on packaging and packaging waste is from 2014 (518/2014) and it includes all the possible packaging materials, such as paper and paperboard (fibres). The legislation on packaging and packaging waste was updated because the Waste Act (646/2011) of Finland was also updated and the most important update was to transfer the responsibility of packaging waste to packers and to producers of packaged products.

In Finland, the recycling rate target for fibres was at first 53 % by weight by producer but it was increased to 60 % in 2002 (Rinki 2018b) which was the same in EU directives (92/1997). In 2005 and 2016, the recycling target was increased again. First to 75 % (817/2005) and currently it is 80 % (518/2014). Finland has exceed its fibre recycling target every year thus the target may be have been too low. Recycling of the fibres have been increased steadily from 2001 and in 2015, the recycling rate were 112 % (Rinki 2018b). Table 9 presents recycling rates from 2007 to 2015.

**Table 9.** Recycling rates of fibres from 2007 to 2015 in Finland (Rinki 2018b).

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|
| Recycling rate [%] | 88 | 93 | 95 | 96 | 97 | 99 | 98 | 101 | 112 |

The recycling rate can be over 100 % because packaging waste is considered to be the same as the packaging placed on the market. In 2015, there were approximately

250 100 tons of paper and paperboard placed on the market and there were approximately 279 100 tons of recycled paper and paperboard. Recycled paper and paperboard includes recycling in the Finland as well as foreign countries. (Pirkanmaan ELY-keskus 2017.)

Reuse rate is the amount of refilled packaging divided by the amount of total use of fibres. Finnish Packaging Recycling RINKI Ltd's packaging data shows that in Finland, the reuse rate has varied from 3 % to 8 %. In 2014, the rate was 8 % but in 2015, the rate was only 3 %. (Rinki 2018b.) Recovery rate can be defined as the amount of paper and paperboard packaging waste which is divided by the number of packaging which are placed on the market. Recovery target of paper and board was 75 % in 2015 and the rate was 132 %. When converting the reuse rate as tons, the amount is almost 8 600 tons. (Pirkanmaan ELY-keskus 2017.)

### 4.1.1 Recycling practices

The responsibility of packaging waste belongs to packers and producers of packaged products and they can fulfil their producer responsibility in three different way. The producer can join a producer organisation or submit an application to the Pirkanmaa ELY Centre for registration in the producer database. In the last option, the producer has to ensure that the producer responsible is taken care of with collection, recycling and waste management. The final option is to establish a producer organisation with other producers. If the producer is not obeying the law and fails with the producer responsibility, Pirkanmaa ELY Centre may impose a default a fine to the producer. (Ympäristö 2018.)

Finnish Packaging Recycling RINKI Ltd (Suomen Pakkauskierrätys RINKI Oy) is a producer organisation which was founded in 1997. It was previously known as the Environmental Register of Packaging PYR Ltd (Pakkausalan Ympäristörekisteri PYR Oy) and it is a non-profit service company. (Rinki 2015.) RINKI is owned by Finnish industry and retail trade. In the beginning of 2018, RINKI took a new trademark into use and built new infrastructure for public municipal solid waste sorting points. The RINKI trademark in a product communicates the company’s corporate responsibility and bears its producer responsibility for packaging. A company can use the trademark in their packaging, website, advertises and other marketing purposes. (Rinki 2018a.) The RINKI trademark is presented in upper left corner in Figure 17.

RINKI is managing post-consumer waste in regional collection points which can also be called recycling points, recycling stations or take-back points. The company has over 1 850 eco take-back points for paperboard, glass and metal packaging which makes infrastructure of eco tack-back points quite comprehensive. The take-back points are presented in Figure 17. The recycling points of RINKI are organized by the municipalities or municipal waste management authorities. Also a producer can organize a recycling point where a consumer can bring their sorted waste. In the recycling points, there must be collected at least one type of recyclable or recoverable waste. Depending on the municipality and the take-back point, there can be separated collection container for corrugated board and packaging cartons for liquids such as milk and juice cartons. (Rinki 2018b; Rinki 2018c.)

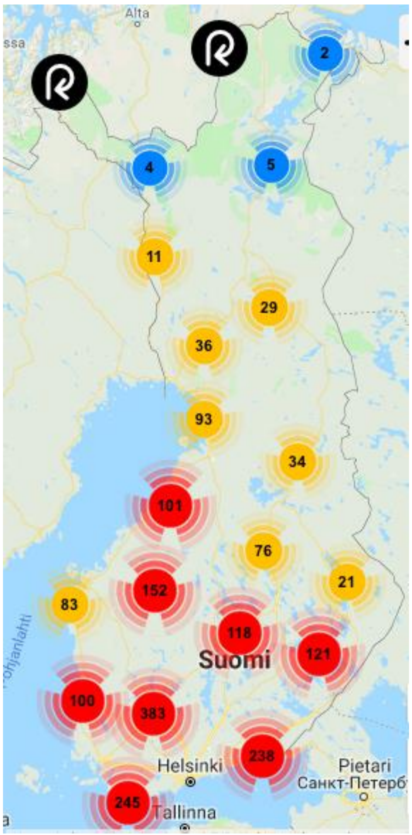


**Figure 17.** RINKI's take-back points for post-consumer waste in Finland (Rinki 2018d).

RINKI has thousands of member companies which ensure that those member companies can implement their producer responsibility easily and efficiently. RINKI's tasks include producer identification, invoicing and customer service. For example the company is marketing producer organisations' and its own services to companies which are interested to producer responsible. RINKI also collects packaging data, registers and reporting, collects and recycles consumer packaging as well as communicate and lobbying. This means that the company maintains the producer register, reports to producer organisations as well as designs and implements the packaging waste collection infrastructure. (Rinki 2018c.)

RINKI cooperates with different waste management organisations in Finland. When RINKI is managing just the eco tack-back points, those management organisations are managing where the material is going from the take-back points. Examples from those organisations are Paperinkeräys Oy and Suomen Keräystuote Oy, which are collecting paper, and Lassila & Tikanoja Oyj and Paperinkeräys Oy which are collecting board as well. (Rinki 2017a, 6.) Those companies typically use baler to make the recovered paperboard more compact form and sell the bales to the companies which are using recovered fibres as their raw material. Recovered paper and paperboard is typically utilized in newspaper, paperboard and tissues in Finland (Seppälä et al. 2005, 68).

RINKI’s eco take-back points are for post-consumer material and they are used by regular consumers or small entrepreneurs. Bigger organisations, companies and industries are making the contract about the collection of the recovered material directly with the waste management organisation, such as Paperinkeräys Oy (Suomen Kuitukierrätys Oy 2017a). Fibre waste of these organisations or industries can be either pre-consumer or post-consumer waste. However, they are handled the same way. First, the fibre-based packaging are collected to the container. Then the material is taken to waste management facility where the material is baled with a baler. A driver of the waste management company who collects the container decides which board grade the material is. Finally, the waste management company sells the material to the companies which are using the recovered fibres. (Jussila 2018; Olander 2018.)

### 4.1.2 Costs of recycling

The board of Suomen Kuitukierrätys Oy has decided recycling fees of the fibre packaging for 2018. Organisations and companies which are producing packaging have to pay the fee due to the producer responsibility. (Suomen Kuitukierrätys Oy 2017b.) If the organisation or company is a member of RINKI, RINKI will collect a customer fee based on the last year packaging statics (RINKI 2017b). The fees of different materials are presented in Table 10. RINKI does not collect any registration fee thus the customer fee presented in the Table 10 is the only fee which a producer needs to pay.

**Table 10.** The producer responsibility fees for different board material in Finland (Suomen Kuitukierrätys Oy 2017b).

| **Packaging material** | **Fee [€/tonne]** |
|---|---:|
| Liquid carton packaging | 96,00 |
| Cartonboard and paper packaging | 52,00 |
| Corrugated packaging | 9,50 |
| Industrial fibre packaging | 14,50 |

For example, when a cartonboard mill is producing cartonboard, it will not pay the fee from the produced material but the packaging where a reel is packed. Since the reel is packed industrial fibre packaging, it has lower fee than what the material of the reel is. When a converter is producing a packaging out of the reel, the converter is paying the producer responsibility fee from the cartonboard packaging.

Companies need to sort their waste and their contract with the waste management company is determining the waste fee. The fee can vary depending on the company, the size of the container and emptying frequency. For example, in Helsinki, HSY takes from 3,55 to 6,96 € for emptying 240–800 litre container depending on how many containers there are and the emptying frequency. HSY takes 4,47 € for emptying one container every four week and 4,97 € for emptying once per week. All the prices are including the container. (HSY 2018.)

In Finland, citizens living in detached houses are typically using take-back points of RINKI and people living in apartment buildings, are using take-back point of the building. Finnish are encouraged to recycle their waste and therefore, RINKI's take-back points are free to use. However, the waste management company, which is collecting the waste from the take-back point, is not operating for free because the operations are paid by RINKI. (RINKI 2018b.) The take-back points of apartment buildings are not free, since a board of the apartment has to make a contract with a waste management company just like companies (HSY 2018). Therefore, the fee is the same as with the companies but since it is divided with all the people owning an apartment in the building, the fee is not big.

The waste management companies are selling the recovered paperboard for the companies which are using the paperboard as a raw material in their production. Waste management company determines which European standard board grade the recovered material is. For example, recycling fibre plant may pay 180 €/t from EN 643 standard grade 2.11.00 which is board with plastic layer, and 260 €/t from EN 643 standard grade 3.13.00 which is white unprinted multiply board. (Koskenheimo 2018.)

## 4.2 Germany

Germany's Duales System Deutschland (DSD), which is also sometimes called as Green Dot System, is the most popular packaging waste system. It was the first Green Dot System and it was applied in 1991. The system has spread to other European countries and it was one of the reasons why EU adopted the Packaging Directive in 1994. Germany's municipal waste management is completed by the Duales System which is based on the German packaging ordinance. The ordinance rests on the act named "Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal". The act takes into respects current EU directives for packages' return and disposal. (Der Grüne Punkt 2018a.)

Green Dot is a symbol on a packaging which tells to consumer that the organisation has paid for recovery, sorting and recycling of the packaging to a qualified national packaging recovery organisation. However, the Green Dot symbol on the packaging does not mean that those things will be happen but there has been a financial contribution towards them. In Germany, it tells that the packaging belongs to the Duales System during the consumption phase. DSD is based on the idea that privately organised channels which are providing a service to collect all the primary packages from the consumers. At the same time, service providers are ensuring that the packages are undergoing a material-specific recycling process. Currently, the green dot symbol is used in 29 countries and it is worldwide protected trademark.

(Pires 2011, 1038–1039; PRO Europe 2018.) The Green Dot label is presented in Figure 18.

**Figure 18.** The Green Dot symbol (PRO Europe 2018).

The Duales System takes care for the operations defined by the packaging ordinance, such as registration, sorting, and recycling of the packaging. The system facilitates both the manufacturers' and the sellers' responsibility for ensuring that the recycling process proceeds easily across all distribution chains from the packaging manufacturer to the store. All the export companies in the Germany's market area has to obey the Germany's legislation. (Deutch-Finniche Handelskammer 2018.)

New German Packaging Act (Verpackungsgesetz) will be implemented in 1st January 2019 and it will replace the current German Packaging Ordinance. The Act will apply for all distributors which are placing their packaging into commercial circulation in the German market. Thus it affects national producers and importers as well as online dealers. (Der Grüne Punkt 2018b.) The new act will have further ecological requirements than the earlier ordinance. The recycling target rates are being updated in the new packaging act and a central office for co-ordinate dual systems and their competition is being established by the law. Also a bidding process for collection service contracts will be enhanced by increasing transparency. (Cole 2017.)

Current target for paper and paperboard recycling is 70 % in Germany. However, with the new Packaging Act, Germany has set a target for the 2019 and 2022. The first target is to increase the recycling rate by 15 % to 85 % and by the end of 2022 the recycling rate will be 90 %. (Der Grüne Punkt 2018b.) According to German Pulp and Paper Association VDP (2015), the overall recycling rate of paper and paperboard packaging was 99 % in 2015. At the same year, the recycling rate of corrugated board was 108 % and folding box board was 89 %. The recycling rates have been almost the same between 2009 and 2014.

Table 11 presents paper and board production in Germany between January and May in 2018. The production amounts are divided in different materials.

**Table 11.** Production of paper and board in Germany from January to May in 2018 (VDP 2018a).

| **Material** | **Production [tons]** |
|---|---|
| Graphic papers | 3 263 000 |
| Paper and board packaging | 4 989 000 |
| Sanitary and household papers | 627 000 |
| Paper and board for technical and other special uses | 616 000 |
| **Total** | **9 495 000** |

Germany produced 9,5 million tons of paper and board in total from January to May in 2018. From that production, 5,0 million tons were paper and paperboard packaging. At the same period in 2017, the same number was 4,9 million tons thus the production of the paper and paperboard packaging was increased with 2.8 %. The paper and paperboard packaging was the only sector which production was increased over 1 % from the 2017 period. From January to May in 2018, total deliveries of German paper mills were 5,0 million tons and 1,7 million tons were for domestic deliveries and 2,5 million tons were exported. (VDP 2018a.)

### 4.2.1 Recycling practices

Germany’s waste management practices are almost same as in Finland. However, when Finland has only one operating producer organisation, Germany had ten in February 2017 (Reclay Group 2017, 4). Currently, there are nine dual systems in Germany (BellandVision 2018). Der Grüne Punkt, which was the first dual system in the Germany and worldwide, is the market leader (Der Grüne Punkt 2018c) and the second biggest dual system is BellandVision GmbH. BellandVision is a subsidiary of one of the largest waste management company in Germany, SUEZ

Deutschland GmbH. The parent company of SUEZ is also operating in France. (BellandVision 2018.)

The customers of the dual systems are manufacturers and distributors (Reclay Group 2017, 5) and since there are many operating dual systems in the market, they have to compete for the customers. Therefore, dual systems can offer several different kind of services. Der Grüne Punkt is offering several services, such as take-back systems, recycling system designed for plastic waste, design for recycling, trading and logistics and suppliers. BellandVision is offering almost the same services, such as billing service, invoicing software, letter of representation, weight of the packaging, $CO_2$-limate certificate (BellandVision 2018).

Figure 19 presents how the dual system works. The dual system connects manufacturers, collection, sorting and preparation and recycling by making contracts with every organisation and facility. The dual system monitors that the material will be recovered and sorted and the recycling goes as planned.

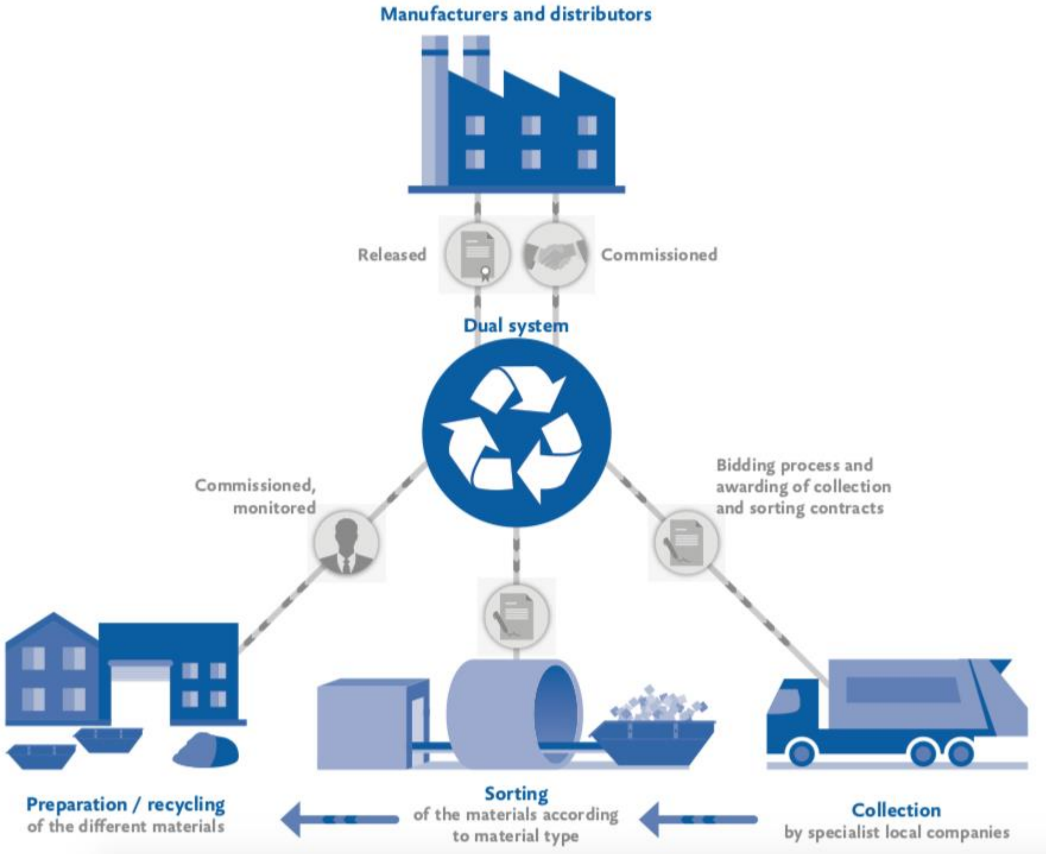


**Figure 19.** The idea of the dual system (Reclay Group 2017, 6).

The dual systems and disposal companies of the municipal are invited to tender for the collecting practices by municipalities. The citizen of the municipality then can get bins for free or pay a deposit from the bins. Households have different colour coded bins for different material and for example, a blue bin for paper, paperboard, newspapers, magazines, waste paper, paper bags etc. fibre-based products (How to Germany 2018). Since blue bins are mainly the right waste type (fibres), it goes to direct supply to the paper mill which are using recovered paper as a raw material. However, all of the fibre based material is not recovered straight from the blue bins due to the human errors or incapability of sorting thus other part of the recovered fibres are coming from the sorting facilities. (BellandVision 2018.)

Companies need to invite the different dual systems to tender for their waste management. Companies have to sort their waste in different containers and a dual system, which the company has made a contract with, is collecting the container. (BellandVision 2018.) When households are collecting all the fibre waste in the same bin, companies can sort their waste with more care. Depending on the waste, which a company is producing, there can be for example, a container for corrugated board and cartonboard. Typically, big grocery stores like Lidl collect corrugated board, which is in European standard 643 1.04.00, in separate container and other fibre-based products to other container.

### 4.2.2 Cost of recycling

In the beginning, Der Grüne Punkt had a monopoly. After the market was opened to other dual systems and competition, the prices and fees have decreased (Reclay Group 2017, 5). However, blue bins, where households are recycling their fibre wastes, have always been free to use. In current years, the waste management and producers' responsibility fees have had some fluctuation. When comparing the producers' responsibility fee in last two years, the total paper and paperboard fee has increased gradually as well as the fee of case materials (VDP 2018b).

Company needs to pay a dual system fee to cover their producer responsibility. The dual system fee is paid to the dual system which the company has a contract with. However, if a company wants to use the green dot trademark for paper or paperboard, the cost is 3,00 €/tonne. (Der Grüne Punkt 2018a.) The same price for composite paperboard, which is a paperboard covered with plastic layer, is 13,00 €/tonne and for plastics it is 17,00 €/tonne (PRO Europe 2017, 18).

According to BellandVision (2018) the manufacturers' responsibility fee for paper and paperboard can vary between different dual systems. For example, one dual system takes less than 70 €/tonne from paper and paperboard and if the paper or paperboard is coated with plastic which is 5 % from the weight of the paper and paperboard, the fee is more than 500 €/tonne. In this case, the plastic layer includes also bioplastics such as PLA. Nevertheless, a company named Use Pac (2018) which is a partner of Veolia dual system has different fees for the materials. According to Use Pac, the manufacturers' responsibility fee for paper and paperboard is 160 €/tonne and for paper and board covered with plastic layer, the fee is 1150 €/tonne. However, all of these fees depends on the volume of the material.

According to EUWID (2018, 1–3) there have been poor availability of many paper and paperboard grades in Germany in the beginning of 2018. Therefore, paper and paperboard merchant and waste management organisations have been able to sell their paperboard with more expensive price. This has increased the prices of paper and paperboard in the German market.

# 5 RECYCLING SCHEME OF BARRIER COATED BOARD

The waste hierarchy which is presented in European law 2008/98/EC and Figure 13, and which is implemented in Finland and Germany, enhance prevention of the waste. However, if the waste cannot be prevented, it should be re-used or recycled. Since Kotkamills' dispersion coated board cannot be re-used as it is, the best option is recycling. Used packages made from Kotkamills' dispersion coated board is a good raw material for new products since the board is made from valuable fibres which can be reused. Also the dispersion coating is more easily to recycle than extrusion coating as the chapter's 3.3 recycling tests proved.

Circular economy has been enhanced in the communities and therefore, the recycling practices have become more available and the recycling has been made relatively easy for customers. Also, the customers have become more aware of the recycling possibilities and the reasons why they need to recycle their waste. Because of the practices and the knowledge, more fibre waste has been and can be recovered and recycled. However, due to the limitations of the recycling, all fibre products cannot be recycled or recovered.

Because the dispersion coated barrier board has designed for consumer packaging and there may be interactions with organic material, such as food, the recycling is not as easy as recycling clean paper and paperboard. There cannot be any food waste in the recycled material because EN 643 standard prohibits it. For example, the study of Aarnio and Hämäläinen (2007, 619) showed that the fast food industry's waste is disposed of in the landfills even though it has high recoverability in 2007. The reasons has been for example, insufficient waste management practices and unsuitable waste management solutions. Therefore, fast food chains would need new innovations to waste sorting and managing.

When choosing the grade for recovered paperboard, the end user, such as the companies, which use recovered board fibres as their raw material, affect lot to the board classification. The final products may need certain type raw material which can contain for example, only certain amount of different adhesives or refined mechanical pulp. Therefore, it is understandable that the companies can affect to the classification and the raw material which they are using. There is not a strict cartonboard grade for dispersion coated barrier board yet which for example, plastic coated board has. However, it is proved with the recycling tests that the dispersion coated barrier board can be repulped and recycled more easily than plastic coated board so dispersion coated barrier board does not have to be categorised to the same grade as plastic coated board.

The recycling scheme was done as a cooperation with partners which are operating in different fields of the recycling scheme. A convertor, RINKI, a dual system company, waste management company, end users and RCF facilities have affected recycling scheme. RINKI and the dual system company helped to target the recycling scheme operations for Finnish and German markets.

## 5.1 Recycling scheme

The basic recycling scheme is the same in Finland and Germany even though, the recycling practices differ from each other. Therefore, the recycling scheme is presented first as it is and only after that, the differences between Finland and Germany markets are introduced in their own chapters. A rough recycling scheme for both pre- and post-consumer material flows are presented in Figure 20. The rough recycling scheme presents only Kotkamills' dispersion coated barrier board flows and it does not take into account all the possible options and flows but the most significant material flows.

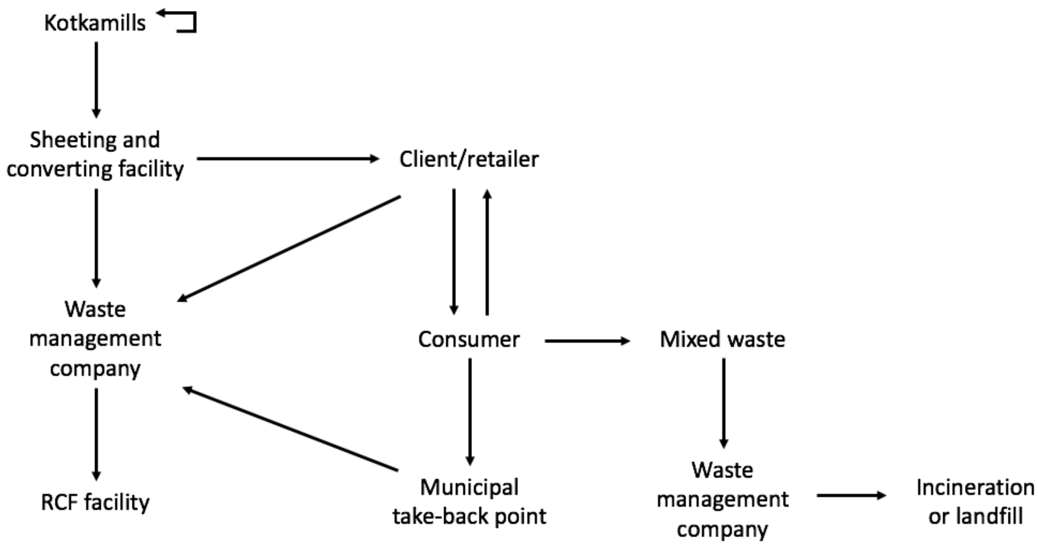


**Figure 20.** A rough recycling scheme for pre- and post-consumer material flows.

The rough recycling scheme, presents the most valuable and significant material flows. However, there are some material leakage in the real life. For example, if the sheeting and converting facility mix different board grades so there is plastic coated, dispersion coated barrier board and uncoated board waste in the same container, the container may be send to incineration plant if there is not a RCF plant which can utilize plastic coated board. Also a client or retailer may sometimes have to throw the dispersion coated barrier board waste away, for example if the packaging's inside content is spoiled somehow. In that case, typically the whole packaging is recycled as it is in the incineration plant. It is also possible that a consumer is throwing the packaging into the nature.

The rough recycling scheme can be divided to pre- and post-consumer waste flows. The pre-consumer waste is produced in the production, before a final consumer is in touched with the product. Consumers are producing post-consumer waste. First the pre-consumer waste and cash flows are presented and after that the post-consumer waste and cash flows are investigated. Material flows are presented with black arrows and cash flows with blue arrows.

Kotkamills is producing material for their clients' needs. Kotkamills' clients are typically retailers. And when the cartonboard is produced there will always be some broke. That broke can be recycled directly back to the mill's own process. The finished cartonboard leaves from the mill in reels which are first going to sheeting and converting facility. When the cartonboard is sheeted and converted, it is sent to the client. However, clean cutting waste is produced from sheeting and converting and depending on how heavily the cartonboard is printed, it can be recycled as EN 643 standard paperboard grade 3.11.00, 3.12.00 or 3.13.00. After sheeting, there will be white unprinted multiply cartonboard (3.13.00) and from converting, the material is either white heavily printed multiply cartonboard (3.11.00) or white lightly printed multiply cartonboard (3.12.00).

If the cartonboard is somehow contaminated or it is mixed with some plastic coated cartonboard, it cannot be recycled as 3.11.00–3.13.00 paperboard grades. However, if the container consist only cartonboard or other fibre waste, it can be classified as 1.01.00, 1.02.00 or 5.02.00 paperboard grade and recycled in RCF facilities which utilize that paperboard grade. If the cartonboard is mixed to normal mixed waste, such as household waste, the cartonboard cannot be recycled and therefore, it is incinerated, composted or landfilled depending on a country and a city. The waste management company is collecting the waste from the sheeting and converting facilities and transporting it to the RCF facility.

It would be also possible to utilize the waste from sheeting facilities if the sheeting is done in the production line which has the same quality demands of the cleanness as in Kotkamills production line. This means that the production line and the storages needs to obey the Commission regulation 2023/2006/EC which guarantees that the waste is totally clean so it can be recycled back to dispersion barrier production. However, there should be large amount of the waste so there would be financial benefits from the arrangement. Every time when a reel is sheeted, first layers as well as final layers of the reel are reject. The first layers are taken off since there can be some quality flaws from transporting or packaging. The last layers are reject because when the cartonboard is bent too much, there can be cracking on the surface of the cartonboard. Therefore, first and last layers cannot be utilized for final products.

Cash flows are presented with blue arrows in the recycling scheme. Client pays for Kotkamills for the material and Kotkamills pays to sheeting and converting facility for their work. Kotkamills is producing the material in reels, sheeting facility is making the reels into the right size sheets and converting facility is converting reels or the sheets into the final products. Sheeting and converting facilities need to pay a waste management company to have a containers for the wastes and the waste management company sells the waste to the RCF facilities as a raw material. Figure 21 shows the pre-consumer material and cash flows.

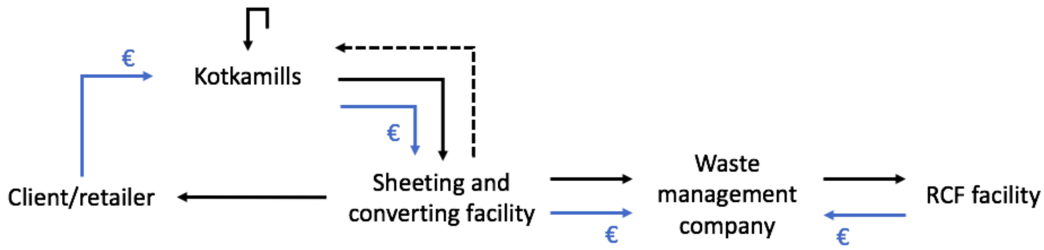


**Figure 21.** Material and cash flows of pre-consumer waste.

There are different post-consumer material flows depending on the client and the retailer since in the post-consumer side of a recycling scheme, the dispersion coated barrier board can be used for example, in big fast food chains and coffee shops or small, local and independent coffee shops or work places or households. However, Kotkamills' client gets their products from converting facility. The convertor send the products to the client or retailer which fills them with their own products and which a consumer buys. When the consumer uses the product for example, in the cafeteria or restaurant, the client or retailer have to arrange the waste handling. This means that the retailer has to inform the customer of the recycling and make a contract with a waste management company of the waste handling. The waste management company rents a container to retailer and empties it as agreed. The waste management company then classifies the waste as is EN 643 standard grades and sells it to RCF facility.

In the big chains for example, used cups can be collected into their own recycle bin away from the other waste. Also, other products can be collected to their own bins. However, in this way, there is a lot of trust for customers and consumers since in many places customers need to do the sorting by themselves. Like mentioned in chapter 2.6, packaging material, which contains impurities, such as organic matter, cannot be recycled so customers need to sort their waste based on this rule. For example, cups, which has only been in contact with liquids, can be recycled but wrappings, which have a lot of mayonnaise on them, cannot be recycled. Therefore, some part of the dispersion coated barrier board waste is lost from the recycling scheme since the cartonboard, which contains organic matter and other impurities, have to be thrown to mixed waste from where they end up to the incineration or composting plants or landfills.

The Figure 22 presents the material and cash flows of a retailer, which products are used inside the restaurant, so the retailer has to take care of the produced waste.

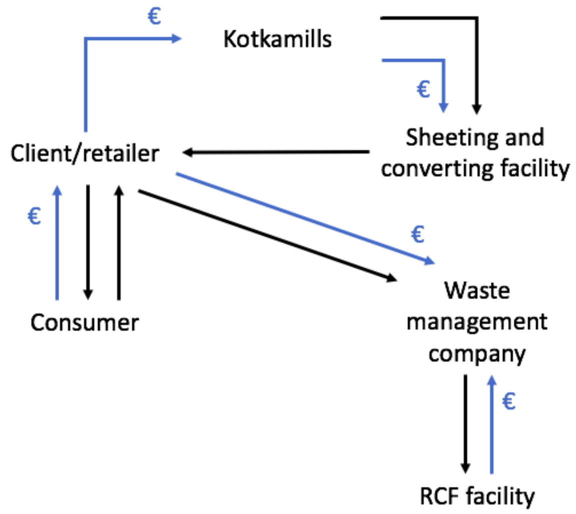


**Figure 22.** Material and cash flows of big chain's post-consumer waste which is produced in the restaurant.

Many retailers are already collecting OCC to a separate container because they are recycling OCC packaging where cups and wrappings etc. are packaged. Therefore, the easiest way would be to recycle the dispersion coated barrier boards in the same flow so the retailer would not need another container for the dispersion coated barrier board waste. The easiest way of recycle the dispersion coated barrier board waste in the restaurants would be to collect the dispersion coated barrier board into the recycle bins made from OCC. Therefore, the whole recycle bin with the waste inside can easily be thrown to the container which a waste management company collects and sells to RCF facility.

Kotkamills has made a test version of a recycle bin for cups. The recycle bin was approximately 80 cm high, and 30 cm wide and deep. There was nine holes on the bin so there will be nine cup piles inside the recycle bin. The test version of the recycle bin is presented in Figure 23.


**Figure 23.** The test version of a recycle bin.

Depending on size of cups and how compact and dense piles they are making inside the recycle bin, one full cup stock includes 82–88 % cups and 12–18 % of corrugated board based on weight. Regular 8 oz coffee cup of Kotkamills weights approximately 6,8–7,2 grams and 8 oz cup with two double layer weights 10,4 grams. Due to the double layer of board, the cups will not piled up as compact as regular cups and there are more air between the cups. Therefore, cup stock has room only for approximately 500 cups with double layer when the same cup stock can include from 1 000 to 1 200 regular cups with one basic layer.

However, some of the packaging are sold in the supermarkets and other grocery stores and due to the nowadays consuming habits, many consumers prefers takeaway option more than staying in the restaurant. Therefore, there is another recycling scheme for post-consumer waste. When a consumer has used the product inside the packaging, the packaging becomes a packaging waste. The waste can be recycled as any other paperboard waste if the packaging is clean from the organic matter and other impurities. In this scenario, the consumer can take the packaging waste to the municipal take-back point where the waste management company collects the waste and sells it forward to RCF facility. However, if the paperboard is not clean, it have to be thrown to mixed waste which the consumer pays itself. Waste management company collects the mixed waste from the kerbside and transport it to incineration or composting plant or landfill.

Typically, when the dispersion coated barrier board ends up to the households, the board is recycled with paper or another paperboard types such as liquid carton which has plastic layer on the paperboard. Therefore, the material, recycled paperboard, is going to recycling centre where the paperboard waste may be cleaned and sorted with different technologies. Some recycling centres may be able to sort brown OCC, paper and plastic coated paperboard separately. In this scenario, the paperboard continues to a RCF facility with the paperboard grade which the recycling centre has chosen. However, in many cases, the paperboard, waste which has collected from the households, is transported straight to the RCF plants which can utilize plastic coated paperboard.

The second post-consumer recycling scheme is presented in Figure 24. The waste is turning from pre-consumer waste to post-consumer waste after the consumer has been in touch with it.

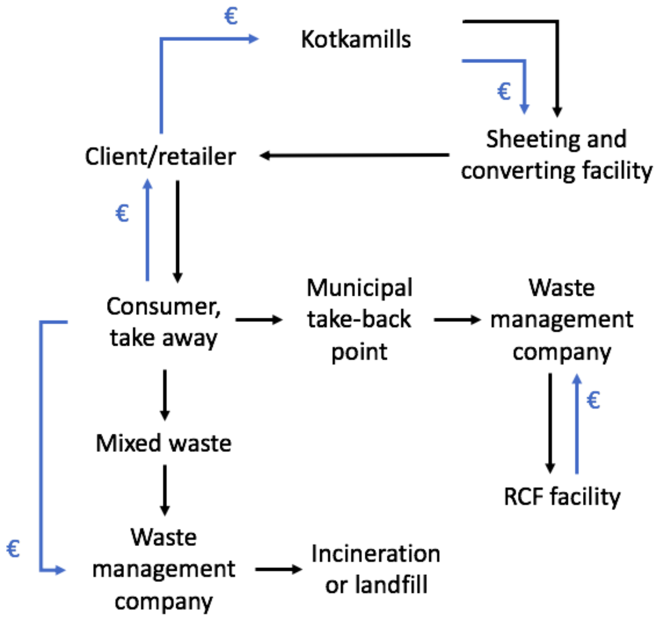


**Figure 24.** Material and cash flows of big chain's takeaway and other post-consumer waste.

### 5.1.1 Case Finland

The Kotkamills' dispersion coated barrier board can be classified only certain type paperboard grade in EN 643 standard. For example, the Kotkamills' dispersion coated barrier board cannot be classified as newspaper, magazine, graphic paper or office paper. However, the most typical EN 643 standard paperboard grades, which Kotkamills' dispersion coated barrier board can be classified in Finland, are presented in Table 12.

**Table 12.** The most typical EN 643 standard board grades in Finland.

| **Code** | **Name** | **Origin** |
|---|---|---|
| 1.03.00 | Boxboard cuttings | Sheeting and converting facility |
| 1.05.00 | Ordinary corrugated board (OCC) | Organisations, supermarkets |
| 3.11.00 – 3.13.00 | Different white multiply board | Sheeting and converting facility |
| 5.02.00 | Mixed packaging | Households |

Sheeting and converting facilities are producing boxboard cuttings as well as multiply board cuttings. The EN 643 board grade 1.03.00 includes all other board cuttings except plastic coated board and corrugated material and 3.11.00–3.11.13 include multiply board cuttings with different printings. Organisations and supermarkets are collecting OCC as EN 643 standard grade 1.05.00 in Finland and households' paperboard waste is classified as 5.02.00 which is mixed packaging. Since 1.05.00 grade can contain 10 % other packaging paper and paperboard, small amount of dispersion coated barrier board can be recycled with that grade. That 10 % is enough in restaurant and fast food chains since there is produced a lot more container waste than dispersion coated barrier board waste. In Finland, RINKI and the waste management companies are handling the collecting and recycling of the paper and paperboard. The rough recycling scheme with the recycling fibre codes is presented in Figure 25.

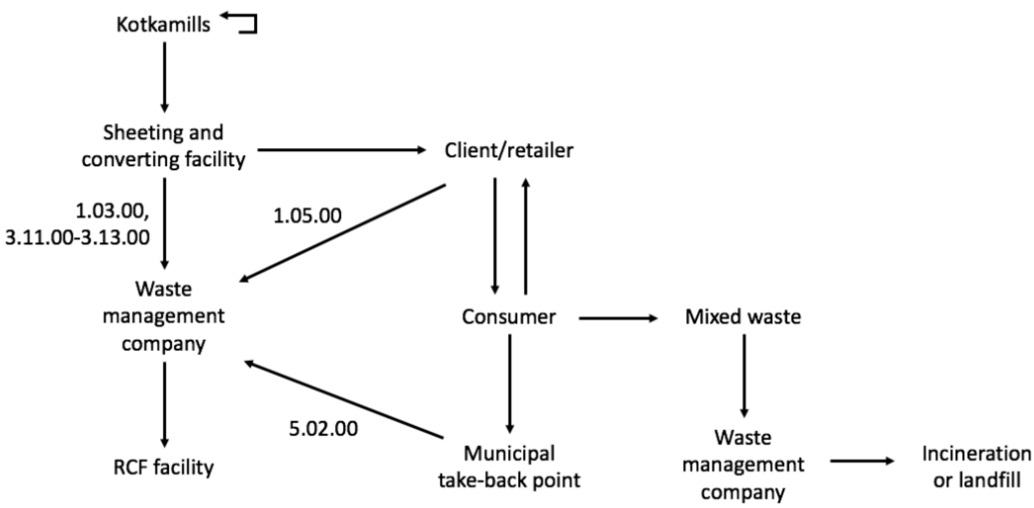


**Figure 25.** The rough Finnish recycling scheme.

All the materials in different board grades can be utilized in different processes and products. Therefore, different RCF facilities are buying different board grades. Also some RCF facilities cannot utilize for example, mixed packaging waste because their processes are not designed for large amount of impurities such as plastic and metal. In Finland, recycling centres do not typically sort or clean paper and paperboard waste which means that the material is transported straight to the RCF facility from the collecting point.

### 5.1.2 Case Germany

Germany uses slightly different EN 643 standard grades than Finland. Sheeting and converting facilities in Germany are classifying the paperboard cuttings in the same method as in Finland but pre-consumer waste is classified in different grades. The most typical EN 643 standard paperboard grades, which Kotkamills' dispersion coated barrier board can be classified in Germany, are presented in Table 13.

**Table 13.** The most typical EN 643 standard board grades in Germany.

| Code | Name | Origin |
|---|---|---|
| 1.02. | Mixed paper and board | Households |
| 1.03.00 | Boxboard cuttings | Sheeting and converting facility |
| 1.04. | Corrugated paper and board packaging | Supermarkets |
| 3.11.00 – 3.13.00 | Different white multiply board | Sheeting and converting facility |

In Germany, households are collecting all the fibre based material in the same recycling bin as mentioned in chapter 4.2.1. That means, there are different kind of paper and paperboard mixed so the recycling centre needs to sort and clean the fibre waste. Supermarkets are collecting used corrugated paper and paperboard packaging which is classified as 1.04. in Germany. That grade needs to include at least 70 % of corrugated material and the rest can be other paperboard or paper packaging and therefore, it is easy to combine dispersion coated barrier board waste with OCC waste in Germany. Compared to grade 1.05.00 which Finland is collecting, the 1.04 has lot more impurities. Organisations are collecting used corrugated kraft II which is classified as board grade 4.03.00 but that board grade cannot be mixed with FBB.

The rough recycling scheme with the recycling fibre codes used in Germany is presented in Figure 26. In Germany, the dual systems are handling the collection and recycling of the fibre based packaging waste.

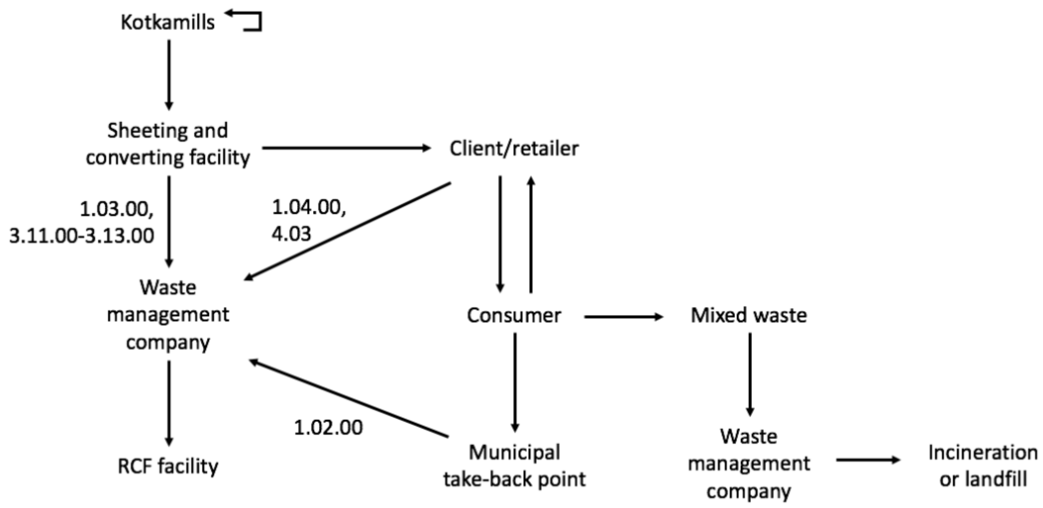


**Figure 26.** The rough German recycling scheme.

In Germany, small dual systems and disposal companies of the municipal can sell their recovered paper and paperboard to traders. In Finland, there are no paper and paperboard traders. Those traders buy the material from the waste management companies and sell it to the RCF facilities. That is an extra step between the waste management company and RCF facility. However, due to the traders, the RCF facilities have always a possibility to buy a raw material that they need for their production and waste management companies have always a place to sell their recovered material.

## 5.2 Functionality of the recycling scheme

As mentioned earlier, the recycling schemes do not take into account all the possible waste flows and therefore, they are quite simple. They present the most significant as well as the most valuable material recycling flows for Kotkamills' dispersion coated barrier board. Therefore, they do not present lost or small flows thus the recycling schemes are not an absolute truth of the dispersion coated barrier board recycling. However, the recycling schemes are functional since they have been done with a cooperation partners, which are currently operating in the market areas, and all the flows and waste management practices are currently used.

The biggest challenges of recycling the dispersion coated barrier boards are the impurities of recovered cartonboard as well as consumers' recycling habits. Consumers should realise that a cartonboard, which is contaminated with organic matter, cannot be utilized in the RCF facilities so it cannot be recycled without cleaning. If the consumer cannot clean the board from the impurities, it has to be channelled to mixed waste which is incinerated, composted or landfilled. Also, when consumers start to sort their wastes frequently and with more care, more paperboard and fibres can be recovered and recycled.

Functionality of the recycling schemes have been tested with a post-consumer waste trial which was the first trial made with post-consumer waste. The trial was made in the Kotkamills own RCF facility in August 2018. There were two reasons to make the test. First reason was to see how well consumers were willing to sort their waste and would it be possible to have recycle bins which consist only the right type of waste, B2 board. The second reason was to test if it would be possible to repulp recycle bins, which contains Kotkamills' final products as a post-consumer dispersion coated barrier board waste, in a pulper which is designed for OCC in the normal production. Because of some inconveniences, there was not large amount of test material so the test was done smaller scale than planned.

Tested material was gathered from the coffee rooms and meeting rooms at the Kotkamills' mill area as well as from few events. The material was used products made from different types of B2 board which were collected to a recycle bin made from OCC. Recovered material was quite clean because the products were used only with different liquids and not with food or other organic matter. Because consumer were highly motivated to recycle their waste in this test environment, the recycle bins consist mainly B2 board. However, consumers were not as motivated in the events as in the mill. Some recycle bins consist lot of liquids and other type of products, such as PE coated board, plastic spoons and napkins. This study showed that it is important to motivate the consumer to recycle and give them good and clear instructions to be able to gather recyclable material. The best results were got when there were only one type of product available to use so the products with different coatings were not mixed up.

The repulping test in the RCF facility, was made in two phases. In the first phase of the test, the material feed of the RCF facility was stopped so there were approximately 580 kg of OCC in the pulper. Then four recycle bins were added at once to the pulper. The weight of a recycle bin was approximately 8–9 kg depending on how full the recycle bin was. 82–88 % of the recycle bin's weight was B2 board and the rest 12–18 % was OCC from were approximately 4 % was barrier. Thus there were approximately 585 kg of OCC, 28 kg of B2 board and 1,2 kg of barrier. RCF facility's pulpers were able to disintegrate the material so with this OCC and dispersion coated barrier board relation, the RCF facility was able to disintegrated the post-consumer dispersion coated barrier board waste.

In the second phase of the test, six full recycle bins were thrown on the material feed line of the RCF facility onto the OCC bale. An OCC bale weights typically 780 kg and there were 2 recycle bins on the one bale. Therefore, there were approximately 783 kg of OCC, 14 kg of B2 board and 0,6 kg of barrier. The raw material of the recycling test is presented in Figure 27. The green-white boxes are the OCC cases which contains the different types of B2 board materials.


**Figure 27.** OCC case and used post-consumer B2 board waste on the OCC bales in RCF line.

All the recycle bins were pulped with the normal production and disintegration succeeded and runnability of the material was normal. However, because the material produced in the RCF facility is compressed to 40 % consistency mixed with large amount of other material, the tested material is minimal compared to the amount of other material. Therefore, there was not any difference in the final product even though, some part of the raw material is post-consumer waste made from B2 board.

As a conclusion of the trial, the post-consumer waste of B2 board can be gathered separately and recycled with EN 643 standard grade 1.05 which is ordinary corrugated board and which may already include 10 % other packaging paper or board grade in RCF facility. With this test, it is proved that 5 % of the raw material can be post-consumer B2 board when it is disintegrated in the RCF facility which is designed for OCC. Therefore, it would be possible to collect dispersion coated barrier board waste and OCC waste to same container and recycle it as EN 643 standard grade 1.05.

## 5.3 Benefits of the recycling scheme

It is possible to identify economic and ecological value which can be achieved by using dispersion coated barrier boards instead of plastic coated boards. It is also possible to identify economic and ecological value from the recycling scheme which a retailer or a consumer can get by using dispersion coated barrier board. However, first the dispersion coated barrier boards have to be channelled to certain waste flow. To get the used product made from dispersion coated barrier board to right waste flow, the retailers have to know about the recycling possibilities and consumers have to be informed.

It is proved that Kotkamills’ dispersion coated barrier boards are recyclable in certain RCF facilities and processes and the laboratory test have also given recyclable or partly recyclable status for dispersion coated barrier boards. The partly recyclable status is not a problem for recycling if the dispersion coated barrier board material is combined with another raw material as proved with the production scale tests. Therefore, the dispersion coated barrier boards can be recycled as normal multiply folding boxboard. For pre-consumer waste, that means EN standard 643 grades 1.03.00 and 3.11.00–3.11.13 which are box board as well as multiply board cutting waste. For post-consumer waste, it means that dispersion coated barrier boards can be recycled as any other board.

Economic value is important to the retailers because they need profit to be able to run the business. Nowadays, ecological value is more important to customers and consumers which is why retailers and companies have chosen more ecological options. This trend can be seen also in the packaging industry. There is a demand for easily recyclable packaging without plastics and due to the new legislations and recycling fees, companies can make more income by using those easily recyclable products.

### 5.3.1 Economic benefits

Producing conventional paperboard has almost the same costs despite the mill or the production line. However, dispersion coated barrier board is more expensive than extrusion coated board since polyolefin resins, such as PE coatings, are cheaper than barrier dispersions. Barrier dispersions have been more expensive due to their limited use. However, since the consumption of barrier dispersion are increased, the barrier latexes prices have decreased in 21$^{st}$ century. (Kimpimäki 2008, 62.) Currently, PE-LD, which is the most common polymer in extrusion coating industry, costs approximately 0,60 €/kg (Plasticker 2018) and in 2017, PLA cost approximately 2,10 €/kg in Germany (Plastics Insight 2018). Therefore, Kotkamills' dispersion coated barrier board is more expensive to produce than plastic coated board when the baseboard is approximately the same.

However, Kotkamills uses on-line coating which it reduces costs compare cartonboard which has been coated at off-line coater. Many times on-line coating is cheaper than off-line coating since it produces less waste and there is no need to transfer the material from the production line to the coater. Off-line coater also needs more employees since there has to be own personnel in every machine.

Even though, the dispersion coated barrier board may be more expensive than plastic coated board, retailers in Finland and Germany save a lot of money due to the producer and environmental fees. A paperboard, which is combined with other material, such as plastic or aluminium, incur higher environmental fees than dispersion coated barrier boards. According to Suomen Kuitukierrätys Oy (2017b), if a retailer sells packaging made from plastic coated paperboard, the producer responsibility fee is 96,00 €/tonne in Finland. When using the retailer uses dispersion coated barrier board packaging, the fee is 52,00 €/tonne. Therefore, the retailer's saving would be 44,00 €/tonne.

Retailers' savings are more difficult to calculate for German market. Depending on the dual system the producer responsibility fee can be between 500–1150 €/tonne for plastic coated paperboard and the same fee for dispersion coated barrier board is 70–160 €/tonne (BellandVision 2018; Use Pac 2018). Therefore, the savings are between 360–1080 €/tonne. Also, if the company wants to green dot label on their product, the label is also more expensive to purchase to plastic coated paperboard than dispersion coated barrier board. The saving in green dot label use would be 10 €/tonne when used dispersion coated barrier board instead of plastic coated paperboard (Der Grüne Punkt 2018a; PRO Europe 2017, 18).

When a paperboard is recycled, it costs the same even if it is plastic or dispersion coated. A waste management company or a dual system charges the same amount to all of the board waste from their customers. However, mixed waste is more expensive than paperboard waste and therefore, paperboard waste is profitable to collect separately from the mixed waste. The waste management company or the dual system can then sell the material to companies which use recovered fibres as their raw material. The waste management company or the dual system defines itself which board grade in EN 643 standard the recovered board waste is so they can affect to the price of the waste.

The paper and paperboard market is global and therefore, the market price of the material is almost the same all around Europe. Sorting, cleanness and the amount of recovered material affect the price of the material. (EUWID 2017, 6–9.) According to Koskenheimo (2018), pre-consumer paperboard waste is the most valuable since it is clean so there is only little un-wanted material and non-paper components. The resale cost of a pre-consumer dispersion coated barrier board waste would be approximately 260 €/tonne when plastic coated cartonboard waste would be 180 €/tonne. Corrugated board waste, such as EN 643 standard grades 1.04 and 1.05, are more valuable than mixed paper and paperboard waste.

Dispersion coated barrier board is also easier to repulp than plastic coated board. In RCF facilities, the plastic coated paperboard has to be shredded first and after that the plastic layer has to be removed before the fibres can be transformed into pulp. Separating fibres from plastic typically contaminates the processes in the RCF facility and it needs to be cleaned up more often. This means expenses since more water is needed and the RCF facility cannot be producing the pulp during those breaks. RCF facility also has to take care of the plastic reject and pays for its disposal. Dispersion coated barrier board can be shredded into pieces and transformed into pulp without any extra breaks.

Table 14 presents compares economic values of plastic coated paperboard and dispersion coated barrier board through the recycling schemes. The comparison is general thus the table is valid for both, Finnish and German market.

**Table 14.** Economic value compared with plastic coated and dispersion barrier coated board through the recycling scheme.

| | **Conventional plastic coated board** | **Dispersion coated barrier board** |
|---|---|---|
| Manufacturing | Cheaper | More expensive |
| Producer responsibility fee | More expensive | Cheaper |
| Recycling | Neutral | Neutral |
| Waste management | Less income | More income |
| Repulping in RCF facility | More expensive | Cheaper |

The retailers get economic value out of the producer responsibility fee, since in Finland, a retailer can save 44,00 €/tonne and in Germany, 360–1080 €/tonne depending on the dual system. However, they cannot get economic value out of recycling since the recycling costs the same to plastic coated and dispersion coated barrier board. The retailers, which are using dispersion coated barrier board products instead of plastic coated board products, can also be seen as more eco-friendly. Therefore, the material choices can affect to brand's image in a positive way. It can also bring more customers since there is a wide awareness of the plastic pollution problem.

### 5.3.2 Ecological benefits

Kotkamills' dispersion coated barrier boards give ecological value to retailers and environment. Alliance for the Environmental Innovation and Starbucks have studied how much manufacturing a disposable paper cup with a plastic layer requires raw materials. Manufacturing a 16 oz disposable paper cup needs 33 grams of wood, 4,1 grams of petroleum, 1,8 grams of chemicals, 650 BTU's of energy and more than 3 litres of water. The 16 oz disposable paper cup produces also 109 grams of $CO_2$ emissions. (Love 2017.) A 16 oz cup made from Kotkamills' dispersion coated barrier board would need the same amount of wood, no petroleum, more chemicals, almost same amount of energy but due to the new board machine, manufacturing the board needs less water. Also, Kotkamills has online coating system, which has environmental benefits over off-line coating system, since there is savings in transportation as well as in energy.

Because of the plastic layer, the plastic coated paperboard produces micro plastic into the sea (Andrady 2011, 1597) and when it is landfilled, the plastic layer will not disintegrate naturally (Shah et al. 2008, 256). In RCF facility, when the plastic coated paperboard is pulped, the plastic has to be separated from the fibres. This means extra steps in the repulping and recycling process in the RCF facility. Also, if for example Kotkamills' RCF facility uses raw material which is 50 % of the designed raw material (OCC) and 50 % of plastic coated board, its material feed capacity has to be halved and the reject rate will be doubled. Also, the pulpers has to be cleaned twice more often which consumes more water and energy. If the raw material consists e.g. 90% of OCC and 10 % dispersion coated barrier board, the pulpers can run as designed. However, the production trials showed that there might be slightly more reject than when the raw material consist only OCC.

To be able to achieve the ecological value, the packaging labels and the recycling possibilities has to be made known to every citizens. There are already many different certification and recycling labels on the market and their usage varies between the countries. The most important thing is to use recycling labels which are known and used in the country. By informing consumers with the recycling options and the reasons behind the recycling, they are more willing to recycle and sort their waste. Therefore, there is more material to recover and the need of virgin fibre can be reduced.

# 6 CONCLUSION

Based on the recycling tests, the Kotkamills' dispersion coated barrier board is repulpable and recyclable in the conventional and available RCF processes and pulpers. Therefore, dispersion coated barrier boards can be included in EN 643 standard cartonboard grades, such as 3.11.00–3.11.13 and 1.03. and other grades which are including multiply cartonboards. Because the dispersion coated barrier board is recyclable, the basic recycling labels and symbols can be used with the material. PAP 21 recycling symbol can be used both in Finland and in Germany as a recycling symbol. In Germany, also the green dot symbol can be used if the company has paid the fee. Also, because of the dispersion coated barrier boards' recyclability, the material can be added to available recycling practices and waste flows.

Due to the simplicity of the recycling scheme, it does not take into account that there are different types of RCF facilities which have different processes and there are large scale of the products which are done from recovered fibres. It is proved that in some RCF facilities and processes the dispersion coated barrier board can be recycled. However, since there are many different processes, the repulpability and recyclability have to be tested to certain process and final product. Therefore, more production scale repulping and recycling tests are needed. Nevertheless, the laboratory tests and the two production scale tests have already proved that dispersion coated barrier boards can be utilized as a mix with another raw material, such as OCC and office paper. When the dispersion coated barrier boards recyclability in the certain RCF facility is proved, the material can be channelled to the flow which provide the most ecological and economical value.

To be able to achieve the most desired ecological and economic value out of the dispersion coated barrier board, the consumers need to be educated and familiarized with the recycling practices. Consumers have a lot of power when it comes to recycling since they are the ones which are making the decision to recycle their wastes. It is also crucial that the waste material is easy to identified as recyclable material and it is easy to recycle. By informing consumers with the reasons behind the recycling, they are more willing to recycle and sort their waste.

The next step would be to study how well the PTS and Voluntary Standard methods correlate with the reality. Therefore, it would be beneficial to study different sifter's holes and mesh sizes in various RCF facilities which are currently utilizing multiply cartonboard as their raw material. In the future, more production scale recycling test are also needed so the recyclability can be proved in different processes.

# 7 SUMMARY

Repulpability and recyclability as well as plastic free and more eco-friendly packaging solutions are currently important in the packaging business. Different dispersion coating solutions have been studied but have not been taken into use until recent years. Kotkamills' dispersion coated barrier boards are coated with water-based dispersion barrier is environmental friendly barrier option and the material is also repulpable and recyclable.

Due to the results of the repulpability and recyclability tests made with Kotkamills' dispersion coated barrier board, the boards can be rated as repulpable and recyclable. Thus, the dispersion coated barrier board is suitable to current waste streams. The waste streams as well as waste management practices can vary between countries but because the practices are based on the same principles, there are a lot of similarities as well. The same kind of recycling symbols and labels can be seen in packaging all around the world.

In this master's thesis, the most valuable recycling possibilities of Finland and Germany market areas were recognized with cooperation partners. Those possibilities were converted to recycling scheme which tells in which waste streams the material should be channeled in order to achieve ecological and economic benefits. Based on this master's thesis, the water-based dispersion coated barrier board can be recycled with conventional and available recycled fibre facilities' processes and it is possible to recognize ecological as well as economic benefits in the product's entire life cycle. Economic benefits are for example, saved money from responsibility fees and from easier repulping process and ecological benefits are for example, saved resources since dispersion coated barrier board's coating is not oil-based and it is much more often possible to recycle dispersion coated barrier board than plastic coated board.

# REFERENCES

1935/2004/EC. 2004. Regulation (EC) No 1935/2004 of the European Parliament and of the of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC. L 188, 18.7.2009.

2004/12/EC. 2004. Directive 2004/12/EC of the European Parliament and of the council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste. L 47/26, 18.2.2004.

2008/98/EC. 2008. Directive 2008/98/EC on waste (Waste Framework Directive). Updated 9.6.2016. [www-page]. [Retrieved 25.6.2018]. From: http://ec.europa.eu/environment/waste/framework/

2017/1221. 2017. The Producer Responsibility Obligations (Packaging Waste) (Amendment Regulations 2017. Environmental Protection. [www-page]. [Retrieved 15.7.2018]. From: http://www.legislation.gov.uk/uksi/2017/1221/made

2018/0172. 2018. Proposal for a directive of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment. [PDF]. [Retrieved 8.7.2018]. From: http://ec.europa.eu/environment/circular-economy/pdf/single-use_plastics_proposal.pdf

2023/2006/EC. 2016. Commission regulation 2023/2006/EC on good manufacturing practice for materials and articles intended to come into contact with food. L 384/75. 29.12.2006.

518/2014. 2014. Valtioneuvoston asetus pakkauksista ja pakkausjätteistä. 3.7.2014.

646/2011. 2011. Jätelaki. 17.6.2011.

817/2005. 2005. Valtioneuvoston asetus pakkauksista ja pakkausjätteestä annetun valtioneuvoston päätöksen muuttamisesta. 13.10.2005.

92/1997. 1997. Valtioneuvoston päätös pakkauksista ja pakkausjätteistä. 23.10.1997.

94/62/EC. 1994. European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste. EYV L 365, 31.12.1994.

Aarnio, T. 2006. Challenges in packaging waste management: a case study in the fast food industry. Doctor of Science Thesis. Lappeenranta: Lappeenranta University of Technologies. Yliopistopaino. ISBN 952-214-239-5.

Aarnio, T., Hämäläinen, A. 2007. Challenges in packaging waste management in the fast food industry. Resources, Conservation and Recycling, Volume 52, Issue 4, 612–621 p. Doi:10.1016/j.resconrec.2007.08.002

Andrady, A.L. 2011. Microplastics in the marine environment. Marine Pollution Bullerin 62 (2011) 1596–1605 p. doi:10.1016/j.marpolbul.2011.05.030

Baughan, J. S., Evale, C. M. 2004. The Green Dot System: Promoting Recycling in the European Union. EuroWatch, WorldTrade Executive, Inc, 7–8 p.

BellandVision. 2018. Disposal expertise from one single source: Dual System for the licensing of Sales Packaging. [PDF]. [Retrieved 10.6.2018]. Presentation of BellandVision, got from the company.

Carus, M., Aeschelmann, F., Baltus, W., Carrez, D., de Guzman, D., Käb, H., Philp, J., Ravenstijn, J. 2017. Bio-based Building Blocks and Polymers, Global Capacities and Trends 2016–2021. nova-Institut GmbH, Version 2017-03. 24 p. [PDF].

[Retrieved 14.5.2018]. From: http://bio-based.eu/media/edd/2017/03/17-02-Bio-based-Building-Blocks-and-Polymers-short-version.pdf

CEPI. 2018a. Key Statistics 2017. 32 p. [PDF]. [Retrieved 10.7.2018]. From: http://www.cepi.org/system/files/public/documents/publications/statistics/2018/210X140_CEPI_Brochure_KeyStatistics2017_WEB.pdf

CEPI. 2018b. Members Area. [www-page]. [Retrieved 26.6.2018]. From: http://www.cepi.org/about-us/cepi-members

Cheng, H. Y., Yang, Y.-J., Li S.-C., Hong. J.-Y., Jang, G.-W. 2015. Modification and extrusion coating of polylactic acid films, Journal of Applied Polymer Science, 132(35), 41472 p. DOI: 10.1002/app.42472

Cole, R. 2017. Germany: New Packaging Law Sets New Targets for Packaging Recycling. [www-page]. [Retrieved 6.7.2018]. From: https://resource.co/article/germany-new-packaging-law-sets-new-targets-packaging-recycling-11933

Confederation of paper industries. 2016. How to Recycle. Fact Sheet. Updated: 05/2016. 2 p. [PDF]. [Retrieved 15.7.2018]. From: http://www.paper.org.uk/information/factsheets/How%20to%20Recycle%20May16.pdf

Dahlbo, H., Jouttijärvi T., Koskela, S., Melanen, M. 2002 Paperituotteiden jätehuoltojärjestelmät elinkaaritutkimuksessa. Helsinki: Edita Prima Oy. ISBN 952-11-1241-7.

Der Grüne Punkt. 2018a. Questions and Answers. [www-page]. [Retrieved 8.5.2018]. From: https://www.gruener-punkt.de/en/communication/infocenter/questions-and-answers.html#c3084

Der Grüne Punkt. 2018b. The new German Packaging Act is coming – and it's particularly important for online retailers. [www-page]. [Retrieved 8.5.2018]. From: https://www.gruener-punkt.de/en/services/packaging/german-packaging-act.html

Der Grüne Punkt. 2018c. A Pioneer of Closed-Cycle Economy. [www-page]. [Retrieved 8.7.2018]. From: https://www.gruener-punkt.de/en/company/der-gruene-punkt.html

Deutch-Finniche Handelskammer. 2018. Kierrätys / Duales System. [www-page]. [Retrieved 23.5.2018]. From: https://www.dfhk.fi/fi/saksaan-ja-maailmalle/kierraetys-duales-system/

EN 643. 2014. Paper and board. European list of standard grades of paper and board for recycling. European standard. Approved 3 October 2014. 3rd edition.

EN 13430. 2005. Packaging. Requirements for packaging recoverable by material recycling. Approved 5 May 2004. 36 p.

EN 13432. 2000. Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging. Approved 4 June 2000.

EN 14021. 2016. Environmental labels and declarations. Self-declared environmental claims (Type II environmental labelling). Approved 20 January 2016. 64 p.

Europapier. 2018. Paperboard classifications. Europapier International AG. [www-page]. [Retrieved 16.4.2018]. From: https://www.europapier.com/service/know-how/paperboard-classifications/

EUWID. 2017. EU Parliament and Council reach provisional agreement on circular economy package. Recycling and Waste Management, 26.2017, Volume 23.

EUWID. 2018. The German paper and board market: price hikes for white testliner postponed. Packaging markets, Issue 5/2018

Fibre Box Association (FBA). 2013. Voluntary Standard for Repulping and Recycling Corrugated Fiberboard Treated to Improve Its Performance in the Presence of Water and Water Vapor, U.S.A.

Finnish Forest Industries. 2017. Recycled fibre is a valuable raw material. [www-page]. [Retrieved 5.6.2018]. From: https://www.forestindustries.fi/in-focus/environment-and-sustainibility/circular-economy/recycled-fibre-is-a-valuable-raw-material/

HSY. 2018. Jätehuollon hinnasto 2018. [www-page]. [Retrieved 16.6.2018]. From: https://julkaisu.hsy.fi/jatehuollon_hinnasto_2018.html
Häggblom-Ahnger, U. Komulainen, P. 2006.

Kemiallinen metsäteollisuus 2: Paperin ja kartongin valmistus. 3rd edition. Jyväskylä: Opetushallitus. 279 p. ISBN 952-13-1746-9

ISO 18606. 2013. Packaging and the environment – Organic recycling. Approved January 2013. 1st edition.

ISO N2342. 2001. Universal Multiple Octet Coded Character Set. Date 4.2.2001. 8 p. [PDF]. [Retrieved 1.7.2018]. From: http://std.dkuug.dk/jtc1/sc2/wg2/docs/n2342.pdf

Jussila, V. 2018. Lassila & Tikanoja Oyj. Conversation. 10.4.2018.

Kimpimäki, T. 2008. Dispersion coating. Updated: Lahtinen, K., Avellan, J. In: Kuusipalo J. Paper and Paperboard Converting. 2nd edition. Papermaking Science and Technology, Book 12. Jyväskylä: Fapet Oy. 346 p. ISBN 978-952-5216-28-8.

Kiviranta, A. 2000. Paperboard grades. In: Paulapuro, H. Paper and Board Grades. Papermaking science and technology, Book 18. Jyväskylä: Fapet Oy. 134 p. ISBN 952-5216-18-7.

Komppa, A. 2006. Kuitupohjaisten pakkausmateriaalien raaka-aineet. 25 p. Pakkausalan peruskurssi, II-jakso.

Koskenheimo, P. 2018. Koskenheimo Oy. Conversation. 12.7.2018.

Kotkamills. 2018a. Company. [www-page]. [Retrieved 10.2.2018]. From: http://www.kotkamills.com/en/company

Kotkamills. 2018b. Press releases. [www-page]. [Retrieved 10.2.2018]. From: http://www.kotkamills.com/en/news/pressreleases

Krogerus, B. 2007. Papermaking additives. In: Neimo, L. Paper Making Chemistry. Papermaking Science and Technology, Book 4. Jyväskylä: Fapet Oy. 255 p. ISBN 952-5216-24-0.

Kuusipalo, J., Savolainen, A., Laiho, E., Penttinen, T. 2008. Extrusion coating and products. In: Kuusipalo J. Paper and Paperboard Converting. 2nd edition. Papermaking Science and Technology, Book 12. Jyväskylä: Fapet Oy. 346 p. ISBN 978-952-5216-28-8.

Laakso, A. 2007. Aaltopahvi. In: Järvi-Kääriäinen, T., Ollila, M. Toimiva pakkaus. Helsinki: Hakapaino Oy. 150 p. ISBN 978-951- 8988-41-3.

Lee, T. J., Yoon, C., Ryu, J. Y. 2017. A new potential paper resource; recyclability of paper cups coated with water-soluble polyacrylate-based polymer. Nordic Pulp & Paper Research Journal, 32(1). 155-161 p. Doi: 10.3183/NPPRJ-2017-32-01.

Leppänen-Turkula, A. 1998. In: Savolainen, A. Paper and Paperboard Converting. Papermaking Science and Technology, Book 12. Jyväskylä: Fapet Oy. ISBN 952-5216-12-8.

Love, T. 2017. Germany has come up with the best solution to single-use coffee cups. World Economic Forum. [www-page]. [Retrieved 22.7.2018]. From: https://www.weforum.org/agenda/2017/12/germany-has-come-up-with-the-best-solution-to-single-use-coffee-cups

Lumiainen, J., Harju, K. 2000. In: Paulapuro F. Papermaking Part 1, Stock Preparation and Wet End. Papermaking Science and Technology, Book 8. Jyväskylä: Fapet Oy. 461 p. ISBN 952-5216-00-4

Mansikkamäki, S. 2002. Kartonkipakkaukset. In: Järvi-Kääriäinen, T., Ollila, M. Toimiva pakkaus. Helsinki: Hakapaino Oy. 143p. Updated: M-real Oyj. ISBN 978-951-8988-41-3.

Olander, T. 2018. Pyroll. Conversation. 1.3.2018.

Ovaska, S.-S. 2016. Oil and Grease Barrier Properties of Converted Dispersion-Coated Paperboards. Doctor of Science Thesis. Lappeenranta University of Technologies. Yliopistopaino, Lappeenranta. 92 p. ISBN 978-952-335-009-0.

Pires, A., Martinho, G., Chang, N.-B. 2010. Solid waste management in European countries: A review of systems analysis techniques. Journal of Environmental Management, 92(4). 1033-1050 p. Doi:10.1016/j.jenvman.2010.11.024

Pirkanmaan ELY-keskus. 2017. Pakkaukset ja pakkausjätteet. 2 p. [PDF]. [Retrieved 1.6.2018]. From: http://www.ymparisto.fi/download/noname/%7BC68C61B1-E9B0-46F4-BE13-D4359943C586%7D/119813

Plackett, D. 2011. Biopolymers - New materials for sustainable films and coatings. John Wiley and Sons Ltd. 323 p. ISBN 978-047-068-341-5

Plasticker. 2018. Real Time Price List. [www-page]. [Retrieved 20.7.2018]. From: https://plasticker.de/preise/pms_en.php?kat=Mahlgut&aog=A&show=ok&make=ok

Plastics Insight. 2018. Polylactic Acid Properties, Production, Price, Market and Uses. [www-page]. [Retrieved 20.7.2018]. From: https://www.plasticsinsight.com/resin-intelligence/resin-prices/polylactic-acid/

PRO Europe. 2017. Participation Costs Overview 2017. 44 p. [PDF]. [Retrieved 13.7.2018]. From: https://www.pro-e.org/files/Participation-Costs_2017.pdf

PRO Europe. 2018. The green dot trademark. [www-page]. [Retrieved 2.7.2018]. From: https://www.pro-e.org/the-green-dot-trademark

PTS. 2018. Welcome at Papiertechnische Stiftung. [www-page]. [Retrieved 2.6.2018]. From: https://www.ptspaper.com

Putz, H.-J. 2000. Recycled Fiber and Deinking. Papermaking Science and Technology, Book 7, Göttsching, L., Pakarinen, H. Jyväskylä: Fapet Oy. ISBN 952-5216-07-1.

Rantanen, I. 2014. Blade and Rod Coating of Low Solid Dispersions. Master's Thesis. Lappeenranta: Lappeenranta University of Technologies.

Rinki 2015. PYR is now Packaging Recycling RINKI Ltd. [www-page]. [Retrieved 30.5.2018]. From: https://rinkiin.fi/news/news-releases/pyr-is-now-packaging-recycling-rinki-ltd/

Rinki. 2017a. Vuosikertomus 2016. 16 p. [PDF]. [Retrieved 1.6.2018]. From: https://rinkiin.fi/assets/Vuosikertomus-2016/Rinki-vuosikertomus-2016.pdf

Rinki 2017b. Recycling fees for packaging and RINKI Ltd's registration and customer fees in 2018. [www-page]. [Retrieved 15.6.2018]. From: https://rinkiin.fi/news/news-releases/fees-2018/

Rinki. 2018a. The Rinki trademark communicates corporate responsibility. [www-page]. [Retrieved 30.5.2018]. From: https://rinkiin.fi/news/news-releases/the-rinki-trademark-communicates-corporate-responsibility/

Rinki. 2018b. Packaging statics. [www-page]. [Retrieved 1.6.2018]. From: https://rinkiin.fi/for-firms/packaging-statistics/

Rinki. 2018c. Tasks. [www-page]. [Retrieved 1.6.2018]. From: https://rinkiin.fi/our-operations/tasks/

Rinki. 2018d. RINKI eco take-back points. [www-page]. [Retrieved 5.6.2018]. From: https://rinkiin.fi/for-households/rinki-eco-take-back-points/

Reclay Group. 2017. Packaging licensing made easy. 10p. [PDF]. [Retrieved 7.6.2018]. From: https://www.reclay-group.com/de/images/Content/Presse/broschueren/Reclay_Broschuere_Verpackungslizenzierung_A4_EN_03_2017.pdf

Recycle Now. 2018. Recycling symbols explained. [www-page]. [Retrieved 6.7.2018]. From: https://www.recyclenow.com/recycling-knowledge/packaging-symbols-explained

Shah, A.A., Hasan, F., Hameed, A., Ahmed, S. 2008. Biological degradation of plastics: A comprehensive review. Biotechnology Advances 26 (2008) 246–265 p. doi:10.1016/j.biotechadv.2007.12.005

Seppälä, M. J., Klemetti U., Kortelainen V.-A., Lyytikäinen J., Siitonen H., Sironen R. 2005. Paperimassan valmistus. Jyväskylä: Opetushallitus. 2nd – 3rd edition. 195 p. ISBN 952-13-1142-8.

Suomen Kuitukierrätys Oy. 2017a. Kuitupakkausten lajitteluohjeet yrityksille. 1 p. [PDF]. [Retrieved 6.7.2018]. From: https://asiakas.kotisivukone.com/files/kuitukierratys.kotisivukone.com/Kuitupakkausten_lajitteluohjeet_yrityksille_19_07_2017_V2.pdf

Suomen Kuitukierrätys Oy. 2017b. Kuitupakkausten kierrätysmaksut 2018. [www-page]. [Retrieved 6.7.2018]. From: https://www.kuitukierratys.fi/yrityksille

Suomen Kuitukierrätys Oy. 2018. Kierrätysmerkit ja -ohjeet kuitupakkauksissa. 2 p. [PDF]. [Retrieved 6.7.2018]. From: https://asiakas.kotisivukone.com/files/kuitukierratys.kotisivukone.com/Kierratysmerkit_ja_-ohjeet_kuitupakkauksissa_infosivu_v21_06_18.pdf

Suomen Keräystuote Oy. 2018. [www-page]. [Retrieved 2.6.2018]. From: http://www.suomenkeraystuote.fi/lajittelu/miksi-paperia-kannattaa-kierrattaa/

Tokiwa, Y., Calabia, B. P., Ugwu, C. U. and Aiba, S. 2009. Biodegradability of Plastics. International Journal Of Molecular Sciences, 10(9). 3722-3742 p. ISSN 1422-0067.

Türünç, O., Montero De Espinosa, L., Meier, M.A.R. In: Macromolecular Rapid Communications 01 September 2011, Vol.32(17). 1357-1361 p. ISSN 1022-1336.

Use Pac. 2018. Lizenzrechner. [www-page]. [Retrieved 12.7.2018]. From: https://www.usepac.de van den Oever, M., Molenveld, K., van der Zeer, M., Bos, H. 2017. Bio-based and biodegradable plastics – Facts and Figures. Wageningen Food & Biobased Research number 1722. 65 p. ISBN 978-94-6343-121-7.

VDP. 2015. Papier recyceln. 2 p. [PDF]. [Retrieved 10.7.2018]. From: https://www.vdp-online.de/fileadmin/Datensammlungen/Publikationen/Papierrecyceln.pdf

VDP. 2018a. Statistische Kurzinformation deutscher Zellstoff- und Papierfabriken. 1 p. [PDF]. [Retrieved 10.7.2018]. From: https://www.vdp-online.de/fileadmin/Datensammlungen/Statistik/2018/05_2018_Kurzinfo_Allg.pdf

VDP. 2018b. Producers' Price Index, Germany Basis 2010 = 100. 4 p. [PDF]. [Retrieved 11.7.2018]. From: https://www.vdp-online.de/fileadmin/Datensammlungen/Statistik/2018/en/05_2018_Producers_Price_Index.pdf

Vähä-Nissi, M., Laine, C., Talja, R., Mikkonen, H., Hyvärinen, S., Harlin, A. 2011. Aqueous Dispersions from Biodegradable/Renewable Polymers, VTT Technical Research Centre of Finland, Espoo. TAPPI European PLACE Conference, Volume 1, 170-198 p.

Webster, B. Wake up to a 5p tax on your coffee cup. The Times, 1.11.2017.

Ympäristö. 2018. Tuottajavastuu jätehuollossa. [www-page]. [Retrieved 2.6.2018]. From: http://www.ymparisto.fi/tuottajavastuu