Sustainable materials and solutions to individual polybags used in the retail-industry

Marcus Malmsjö

Master's Thesis 2018
Environmental and Energy Systems Studies
Department of Technology and Society
Faculty of Engineering at Lund University

Lunds universitet
Lunds Tekniska Högskola

Sustainable materials and solutions to individual polybags used in the retail-industry

Marcus Malmsjö

Master's Thesis

June 2018

Dokumentutgivare, Dokumentet kan erhållas från	Dokumentnamn
LUNDS TEKNISKA HÖGSKOLA vid Lunds universitet Institutionen för teknik och samhälle Miljö- och energisystem Box 118 221 00 Lund Telefon: 046-222 00 00 Telefax: 046-222 86 44	Examensarbete Utgivningsdatum 14 juni 2018 Författare Marcus Malmsjö

Dokumenttitel och undertitel

Hållbara material och lösningar till individuella polybags som används i detaljhandeln

Sammandrag

Den här avhandlingen ger en förståelse och överblick av möjligheterna och utmaningarna för en hållbar användning av individuella polybags i detaljhandeln. Detta genomfördes genom en kvalitativ analys som inkluderade litteraturstudier, semi-strukturerade intervjuer och e-mejl korrespondens. Ett material som används vanligtvis för individuella polybags är fossil-baserad LDPE plast och denna förpackningslösning bidrar till en ökning av fossil-baserat plastavfall. Hållbara material och lösningar som kan bli implementerade för individuella polybags är därför viktiga, och dessa ska kunna vara applicerbara i en cirkulär ekonomi. Försiktighet ska tas angående bioplaster, som ofta är sedda som ett ”grönt” materialval. En tydlig kommunikation och märkning angående bioplaster behövs för att kunna användas på ett hållbart sätt. Material som bio-baserad LDPE och återvunnen LDPE kan användas som hållbara material alternativ till den konventionella individuella polybagen. Lösningar som reducerar användandet av material och själva förpackningslösningen ska prioriteras, och det kan göras genom tunnare polybags, mindre polybags, eller använda vikning- och knyt tekniker som skulle kunna eliminera användandet helt. Mekanisk återvinning ska föredras för individuella polybags när denna ses som avfall, och återvinning i slutna loopar genom återtagande och samlande är hållbara lösningar som skulle kunna implementeras. I Kina borde ett pappers-baserat material alternativ undersökas för individuella polybags som används för online-handel, där företagen inte har kontroll över plastavfallet. Detta på grund av att Kina har ett underutvecklat avfallssystem och är en stor bidragande faktor till läckage av plast i naturen. När detta material undersöks är det viktigt att diskutera eventuella avvägningar angående energi- och vattenanvändning, föroreningar, avfalls alternativ och nedskräpning.

Nyckelord

Individuella polybags, hållbarhet, cirkulär ekonomi, plast, bioplast, förpackning, detaljhandel, plaståtervinning, avfallshantering, Kina

Sidomfång	Språk	ISRN
70	Engelska, Svensk Sammanfattning	ISRN LUTFD2/TFEM--18/5133--SE + (1-70)

Organisation, The document can be obtained through	Type of document
LUND UNIVERSITY Department of Technology and Society Environmental and Energy Systems Studies Box 118 SE - 221 00 Lund, Sweden Telephone: int+46 46-222 00 00 Telefax: int+46 46-222 86 44	Master thesis Date of issue 14 June 2018 Author Marcus Malmsjö

Title and subtitle

Sustainable materials and solutions to individual polybags used in the retail-industry

Abstract

This thesis provides an understanding and overview of the opportunities and challenges to enable a sustainable use of individual polybags used in the retail-industry. This was done by conducting a qualitative analysis including literature reviews, semi-structured interviews and e-mail correspondence. A common material choice for individual polybags is the fossil-based LDPE plastic and this packaging solution contributes to an increase in fossil-based plastic waste. Sustainable materials and solutions that can be implemented for individual polybags are therefore important, and these should be applicable in a circular economy. Caution should be taken regarding bioplastics, which often is interpreted as a "green" material choice. A clear communication and labelling regarding bioplastics is required to enable a sustainable use. Materials as bio-based LDPE and recycled LDPE can be used as sustainable material alternatives for the conventional individual polybag. Solutions that reduces the use of material or packaging solution should be prioritized, and this can be done by thinner polybags, smaller polybags or by using folding and tying techniques that possibly could eliminate the use entirely. Mechanical recycling is the preferred end-of-life option for individual polybags and closed loop recycling by re-take and collection systems could be applied as a sustainable solution. In China a paper-based material alternative should be looked into for individual polybags used for e-commerce, where the companies has no control over the package. This is due to that China has an underdeveloped waste management system and is a large contributor of plastic leakage into nature. When this material is evaluated it is of importance to discuss trade-offs concerning energy- and water consumption, pollution, end-of-life options and littering.

Keywords

Individual polybags, sustainability, circular economy, plastic, bioplastic, packaging, retail-industry, plastic recycling, waste management, China

Number of pages	Language	ISRN
70	English, Swedish Abstract	ISRN LUTFD2/TFEM--18/5133--SE + (1-70)

Preface

This thesis was written in collaboration between the technical consultant company ÅF and The Faculty of Engineering at Lund University. The thesis came up because ÅF have clients within the retail-industry that has seen problems with the amount of fossil-based plastic waste generated in the industry, but also the problems with plastics ending up in nature. A possible contributor to these problems are the individual polybags, which will have continuing growth especially due to the growing e-commerce within the retail-industry. Therefore would sustainable materials and solutions to individual polybags be of interest to these clients.

I would like to thank all my supervisors during this period, who has helped me with questions, thoughts and feedback along the way. The aim of the thesis was not defined at first, and as it is a wide and complex area it was difficult to determine what to aim for. But with discussions and communication between me and my supervisors a defined aim was determined.

Thanks to Lars J. Nilsson and Ellen Palm, my supervisors at the division of Environmental and Energy System Studies of the Department of Technology and Society, Lund University. You have given me the opportunity to dig deeper in the world of plastics and also attending STEPS Annual Meeting, which was much appreciated.

Thanks to Stina Tang, my supervisor at Supply Chain Management, ÅF for giving me the opportunity to write my thesis at ÅF and taken me under her wings by providing me with her experience and knowledge. I have been given the opportunity to meet many interesting people at the Stockholm-office and attending events as well as meetings regarding biomaterials and sustainability. I would also like to thank Carolina Togård, ÅF for providing me with information, contacts and her knowledge within this area. I would also like to thank the Packaging Development team at the Malmö-office where I have spent the majority of my time during this period. They have taking care of me and providing me with opportunity to attend interesting events as well as space at the office and good company.

Abstract
This thesis provides an understanding and overview of the opportunities and challenges to enable a sustainable use of individual polybags used in the retail-industry. This was done by conducting a qualitative analysis including literature reviews, semi-structured interviews and e-mail correspondence. A common material choice for individual polybags is the fossil-based LDPE plastic and this packaging solution contributes to an increase in fossil-based plastic waste. Sustainable materials and solutions that can be implemented for individual polybags are therefore important, and these should be applicable in a circular economy. Caution should be taken regarding bioplastics, which often is interpreted as a "green" material choice. A clear communication and labelling regarding bioplastics is required to enable a sustainable use. Materials as bio-based LDPE and recycled LDPE can be used as sustainable material alternatives for the conventional individual polybag. Solutions that reduces the use of material or packaging solution should be prioritized, and this can be done by thinner polybags, smaller polybags or by using folding and tying techniques that possibly could eliminate the use entirely. Mechanical recycling is the preferred end-of-life option for individual polybags and closed loop recycling by re-take and collection systems could be applied as a sustainable solution. In China a paper-based material alternative should be looked into for individual polybags used for e-commerce, where the companies has no control over the package. This is due to that China has an underdeveloped waste management system and is a large contributor of plastic leakage into nature. When this material is evaluated it is of importance to discuss trade-offs concerning energy- and water consumption, pollution, end-of-life options and littering.

Terminology

ABS	-	Acrylonitrile butadiene styrene
Bio-PE	-	Polyethylene based on biomass
Conventional plastic	-	Plastic that is mainly used today, i.e. fossil-based
GHG	-	Greenhouse gas
HIPS	-	High Impact Polystyrene
HDPE	-	High-density Polyethylene
LCA	-	Life Cycle Assessment
LDPE	-	Low-density Polyethylene
LLDPE	-	Linear low-density Polyethylene
PA	-	Polyamide
PBAT	-	Polybutyrate adipate terephthalate
PBS	-	Poly(butylene succinate)
PCL	-	Polycaprolactone
PE	-	Polyethylene
PET	-	Polyethylene terephthalate
PHA	-	Polyhydroxyalkanoates
PLA	-	Polylactic acid
PP	-	Polypropylene
PS	-	Polystyrene
PTT	-	Polytrimethylene terepthalate

Table of Contents

1. Introduction

Plastic packaging used today is almost entirely based on petroleum, and the transition from conventional plastic packaging to packaging that are based on renewable resources and possibly biodegradable, as some bioplastics or paper, is a topic that is increasingly discussed in the packaging industry. It has especially increased a lot during the past few years, even among the general public, and a great factor to this is an increase in knowledge about the large amounts of plastic littering, especially the marine littering, which harms the environment and animal life. Animals can mistake the plastic waste for food which can result in accumulation of plastic parts in their intestines which can eventually kill them. Other negative impacts are that they can be poisoned due to toxins and additives released into their tissue or that they get tangled up in the plastic which make them immobile. If the littering rate is continued as it is presently, the oceans will carry more plastic than fish by 2050 (UN Environment 2017). Even though there are several materials that could replace the conventional plastic which could be better for the environment if released into the nature, the action of plastic littering should never be encouraged. This is a possible rebound effect when choosing a biodegradable packaging alternative, especially for bioplastics, because of the possible perception by the general public that the package will biodegrade anyways in natural environments. Therefore clear communication to the public is important, e.g. labels and symbols of how to discard a package in a sustainable way. It is not only the material that is important from an environmental perspective, but also well-functioning waste management, re-use and recycling systems. These are areas that are challenging to answer for the near future and reports by World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company (2016) and the EU-directive by European Commission (2018a) demonstrates the importance of the latter alternative, i.e. the circular economy. When considering packaging materials based on renewable resources, an example of a challenge is which type of renewable resource for packaging material to use and which of these that are the most sustainable alternative from an environmental perspective. One thing that is certain is that industries, companies, organizations, politicians and the whole society must work together towards the same goal to make the packaging industry as sustainable as possible and with that a more sustainable planet.

A plastic packaging solution that produces great amounts of plastic waste and which companies within the retail-industry are looking into reducing or finding sustainable alternatives to is the individual polybag. This packaging solution is increasing in use, mainly due to the growing e-commerce in the retail-industry and with that, the control of the plastic waste is held by the customers and not the companies. The individual polybag is used in the retail industry to protect garments and other products during transportation to maintain the quality of the products, which is good from one point of view. But, this also results in negative environmental aspects as vast amounts of petroleum-based plastic waste which could end up in nature because of littering, but also a continuation of fossil fuel depletion. A sustainable material, reduction of utilization and a sustainable waste management solution to the petroleum-based individual polybag will hopefully reduce the plastic waste as well as reducing the plastic littering and leakage into the oceans. These strategies are needed to be realized to take a few steps towards a circular economy and create a more sustainable solution for the petroleum-based individual polybag. This will enable taking a few steps towards a more sustainable packaging industry and therefore it is essential to continue to do research and analysis in the area.

1.1 Aims and Objectives

The aim of this thesis is to provide an understanding and overview of the opportunities and challenges to enable a sustainable use of individual polybags. Materials, solutions that can reduce the amount of plastic used and solutions that can reduce the entire use of the individual polybags are aspects that are taken in consideration. The materials and solutions should also be able to be applied in a circular economy and therefore possible waste management solutions regarding the individual polybag is of interest. An additional aim is to evaluate if a different approach regarding strategies towards sustainable individual polybags should be utilized in a country with an underdeveloped waste management system compared to a country with a developed waste management system. Therefore the waste management system as well as the utilization of circular economy and bioplastics within China is analyzed. When comparing to a country with a developed waste management system, a comparison is done with Sweden.

Objectives:

- To analyze different materials that can be applied to the individual polybag and in a circular economy.
- To analyze possible solutions to reduce the packaging material for the application of the individual polybag and if less utilization of the individual polybag is possible.
- To analyze possible recycling and waste management streams for the individual polybag.
- To analyze the utilization of bioplastics, the waste management system and circular economy in China. This is connected to if a different strategy towards sustainable individual polybags should be utilized there in comparison with a country that has a developed waste management system, as Sweden.
- To analyze the views regarding individual polybags, bioplastic- and conventional plastic packaging as well as the waste management of these from three different sectors: companies within the retail-industry, waste management and recycling sector and independent consultants/scientists.

1.2 Delimitations

This thesis limits itself to the environmental aspects of sustainability and circular economy for packaging alternatives that could be an alternative to the conventional individual polybag used in the retail-industry. It will have its focus on findings of sustainable materials and solutions for the usage of the individual polybag in the retail industry which can be applied in a circular economy. This thesis provides an overview and therefore there are no detailed analyses of the objectives. The findings regarding China are limited to waste management, bioplastics and circular economy. China is compared to Sweden if not pointed out otherwise.

2. Methodology

2.1 Qualitative analysis

This thesis uses a qualitative analysis as methodology, which is often said to be subjective. This is due to the data that is collected is interpreted by the researcher, and the meaning with interpretation in a qualitative analysis is for the researcher to contribute with a general view of a phenomenon, in this thesis: sustainable materials and solutions to individual polybags (Hedin 2011; Alvehus 2013).

Within the borders of a qualitative analysis there are several approaches that can be used. Observations, interviews, diaries and case studies are all within these borders, resulting in less use of numbers, but numbers can still be used to complement the results and findings (Hedin 2011). Therefore it is not set that if a qualitative analysis is used, quantitative elements will not be present. Examples of this in this thesis is when numbers are used from literature, e.g. recycling rates or production data, which is then regarded as quantitative data. This quantitative data can be of interest for a researcher using a qualitative analysis and therefore will a “qualitative analysis” be dependent on the goal of which the researcher has with the study or project, and with that use several different variations as approach. The data that is collected in a qualitative analysis can be divided into primary data and secondary data, this depending on who has collected the data. The primary data is empirical material that has been collected for the specific research, e.g. interviews, observations or by using a poll. The secondary data is the empirical material that has been collected from another research or study, but is used in the actual research that is undergoing (Alvehus 2013).

This thesis uses semi-structured interviews and e-mail correspondence to collect primary data and literature reviews from scientific reports, reports from non-governmental organizations, news articles and reports made by companies for collection of secondary data. The semi-structured interviews are divided into three categories based on the sector the interviewee has his/hers profession. The questions that are asked is slightly modified to the specific sector. The key remarks from this data are found in chapter 5.1-5.3, and for a more detailed information see chapter 10, Appendix. The primary data is collected from:

1. Representatives from a company within the retail-industry that uses individual polybags as well as public information regarding companies within the retail-industry using individual polybags.
2. Representatives from a company within the waste management and recycling sector.
3. Scientists or consultants within the area of plastics, bioplastics, packaging, recycling or sustainability.

These different categories gives an understanding of the challenges, opportunities and strategies regarding plastic packaging, bioplastics and the individual polybag from three different perspectives.

2.2 Literature reviews

Literature reviews is conducted in this thesis to acquire an understanding of the research topics that the thesis will take in consideration. It also gives a basis of what has been done as well as being done in these topics, which then forms the basis for future research in the area (Cronin, Ryan & Coughlan 2008).

2.3 Semi-structured interviews

When conducting research there are three main types of interviews that are used: structured, semi-structured and unstructured. In this thesis the semi-structured research interview is used and this is chosen due to greater flexibility than the structured interview but also more organized than the unstructured interview. The semi-structured interviews allow the interviewer or interviewee to a greater open discussion when answering the questions and enables the interviewer to conduct follow-up questions to the response. It will consist of some key questions which will give an exploration of different areas during the interview (Gill, Stewart, Treasure & Chadwick 2008). This thesis includes interviews by physical meetings and telephone meetings.

3. Background

3.1 Individual Polybags

An individual polybag is a common transport packaging solution in the retail industry and is often regarded as an industry standard. These are used to pack every single product individually and protect them during transportation, both locally and globally. As the retail-industry continues to grow, as well as the e-commerce, this type of packaging solution will most likely increase heavily in use. This packaging solution results in great amounts of fossil-based plastic waste, but as mentioned, it also protects the products efficiently during transportation. This is important to take in consideration if choosing to discard the use of an individual polybag, because a damaged product will most likely result in a greater negative environmental impact than using an individual polybag.

Four similar individual polybags can be seen in figure 1 below, all of them are used for e-commerce in Sweden but from four different companies. As can be seen in the figure, three of the polybags have a written text and two symbols. The text is similar on all the three which warns about letting children play with them and the risk of suffocation, some in several languages. One of the symbols is the three arrow recycling symbol, the one to the right in figure 1a, with a number and text marking which kind of plastic that the bag is made of. The other symbol is “der Grune punkte”, to the left in figure 1a, which marks that the package is connected to the waste management system and that the producer takes its responsibility that the package is discarded properly. The individual polybag in figure 1d has no ink at all, i.e. no text or symbols.

Figure 1. Four similar but different individual polybags used by four different retail companies. In 1a, 1b and 1c there are clear texts warning about that the bag is not a toy and from suffocation. The recycling symbol for LDPE and “the Grüne punkte” is clearly shown. In 1d, there are no texts or symbols at all (photo: Marcus Malmsjö).

A majority of these bags used today are petroleum-based and made from low density polyethylene (LDPE), which is a grade of polyethylene made from the monomer ethylene. The low density arises from the branching in the polymer chain, which result in a less efficient packing of the polymer chains in comparison to for example high density polyethylene (HDPE) which has more efficient packing of the polymer chains, see figure 2 below. LDPE has properties as lightweight, flexibility (even at low temperatures), tear strength, tensile strength, impact strength and transparency, but also chemical resistance. As tear strength is a measurement of how a material is able to resist tearing, tensile strength is a measurement of how well a material resists tension and impact strength how well a material can withstand a suddenly applied load, these are properties that is preferable when garments and products should be protected during transportation (Sen & Raut 2015). The properties of LDPE will keep them intact and in shape even if a lot of movements and impacts happen during transportation. The chemical resistance will protect the products if exposed to chemicals and solvents, but also water and oil. As it is transparent it will provide a visual recognition of the product inside the individual polybags and this can be used to ensure that the correct product and color is put in the individual polybag.

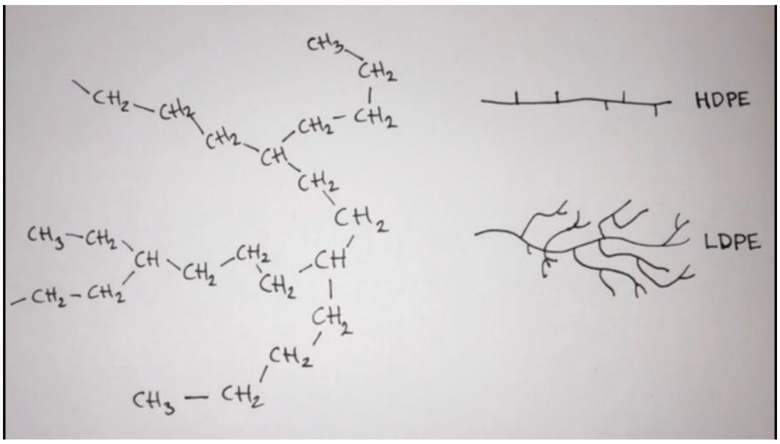

Figure 2. The chemical structure of PE (left) and two grades of polyethylene, HDPE and LDPE (photo: Marcus Malmsjö).

LDPE is used to a large extent in today's society for various applications but mainly for flexible films, containers and plastic bags, and in numbers it is estimated that 500 billion to 1 trillion plastic bags are consumed each year worldwide (Sen & Raut 2015). Conventional LDPE is petroleum based and therefore this plastic material is contributing to the depletion of fossil fuel resources as well as it is a non-biodegradable material in nature. Regardless to this, LDPE is chosen as the material for this packaging solution and this is chosen due to its many properties mentioned above that is required for this application. The properties of LDPE will efficiently protect the garments and other products from scratches, moisture and other damages during transportation. As for moisture, it is also important that it does not stay captured within the plastic barrier which then could harm the products. Therefore, some individual polybags have small holes to give circulation of air and let the moisture to escape, some individual polybags will also have moisture absorber bags within the bag to absorb the moisture if present (Company 2).

The individual polybags reaches retailers where the polybag is discarded when unpacking the products, but it will also reach the customer directly when e-commerce is used. For the latter case it means that the customer is responsible for how the individual polybag is discarded, which creates an uncontrollable waste stream for the company using the individual polybags as packaging solution. These transportation streams will together, especially with the growing e-commerce market, result in vast amounts of individual polybags that are used and this could have several negative effects on the environment. These negative effects can be greenhouse gases released into the atmosphere during production or if it ends up in landfills, incineration or nature. An environmental impact that is being debated frequently today is the plastic littering, especially in marine environments, which harms the environment since it can take several hundreds of years for conventional plastics to be fully degraded and during this time the plastic can harm the environment and the animals living there. Some negative aspects of this are: The plastics can be mistaken as food, animals can get stuck which can make them dysfunctional and they can release toxins and additives that pollutes the water and which can later find its way back to humans when consuming marine animals as food. Therefore, a more environmental friendly solution is required for this packaging solution. Possible solutions could be materials from renewable resources or with recycled content, biodegradable materials, a well-functioning waste management with effective collection and recycling of the polybags or minimizing the usage of the package or the amount of plastic material. These solutions are embedded in a circular economy, which is most likely the best sustainable strategy that can be utilized in the packaging industry.

3.2 Materials based on renewable resources and the environmental impact

There are several materials that can be produced from renewable resources which can be applied for packaging solutions and these materials can have several different characteristics and properties. Materials based on renewable resources is part of a circular economy and enables a decoupling from fossil-resources. Paper has a great utilization in the packaging industry and is a material produced from renewable resources, but as the properties of plastic packaging is required in many packaging applications a lot of research has been and is being done to produce plastics from renewable resources, which will then be regarded as bioplastics. Paper are made from wood fibres which is a renewable resource, but bioplastics can be derived from several different renewable resources, as starch, sugar cane, cellulose and vegetable oils. Another “renewably sourced” plastic that is interesting for the future plastic market is the greenhouse gas-based plastic. To produce these plastics greenhouse gases as carbon dioxide or methane gas are captured and the carbon is used as feedstock for production of plastics through a chemical process. This technology has newly been commercially scaled and is still not a large segment on the market. These plastics has potential as environmental friendly plastics due to their contribution to reducing the amount of greenhouse gases in the atmosphere (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

When choosing a sustainable packaging solution it is not always certain which material that is the most sustainable. Some aspects to take into consideration are if the package is produced from renewable resources and if these are sustainably grown, if the material is able to be recycled and used again for a similar application, how much energy and resources that are used during manufacturing as well as the extent of released emissions and pollution. The likelihood of being discarded properly or recycled at end-of-life is also important to consider (EcoEnclose n.d.). To measure the environmental impacts, from cradle to grave or cradle to gate, of different materials a Life Cycle Analysis (LCA) is an important tool and this can be used when comparing the environmental impact from for example fossil-based plastics, bioplastics and paper. When using the LCA methodology it is important to take in consideration that a LCA conducted in similar areas can have different assumptions, delimitations and other aspects that may lead to different results and conclusions. Therefore it is important to considering all aspects, be critical and discuss trade-offs when determining the most environmental friendly material. The potential environmental impact from different materials used in shopping bags has been published by different stakeholders through the years and the bags evaluated has similarities to possible materials used for the individual polybag. Therefore are these LCAs of interest regarding individual polybags as well.

3.3 Bioplastics

A plastic material that is perceived as a bioplastic should either be bio-based, biodegradable or both bio-based and biodegradable. This is the definition of bioplastics according to European Bioplastics e.V. (2018), see figure 3 below. According to European Bioplastics e.V. (2018) bioplastics have the same or similar properties as conventional plastics and can offer better functionalities, reduced carbon footprint or additional waste management options as organic recycling.

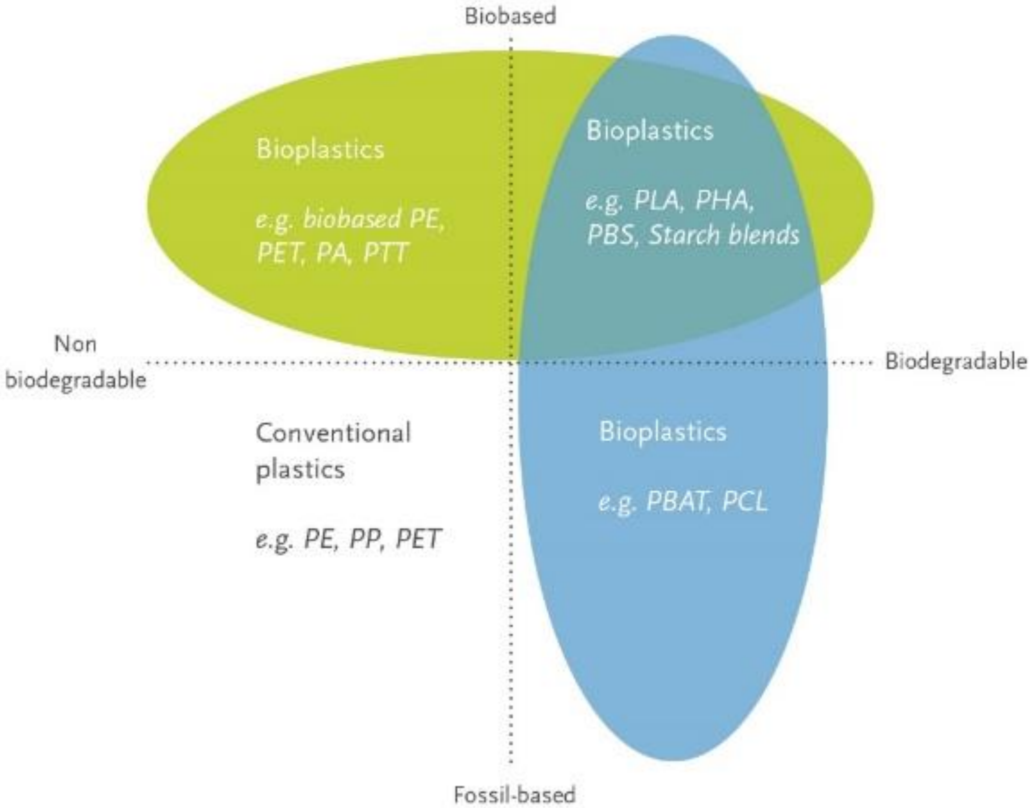

Figure 3. Definition of bioplastics: it should either be bio-based, biodegradable or both bio-based and biodegradable (European Bioplastics e.V. 2017b).

Bioplastics can be implemented in several different segments and products in the society today and the global production capacity of bioplastics by market segment in 2017 can be seen in figure 4. It can be seen that a great majority of all bioplastics produced are used for flexible and rigid packaging solutions, almost 60 %, and therefore this is a segment of importance for bioplastics (European Bioplastics e.V. 2017b).

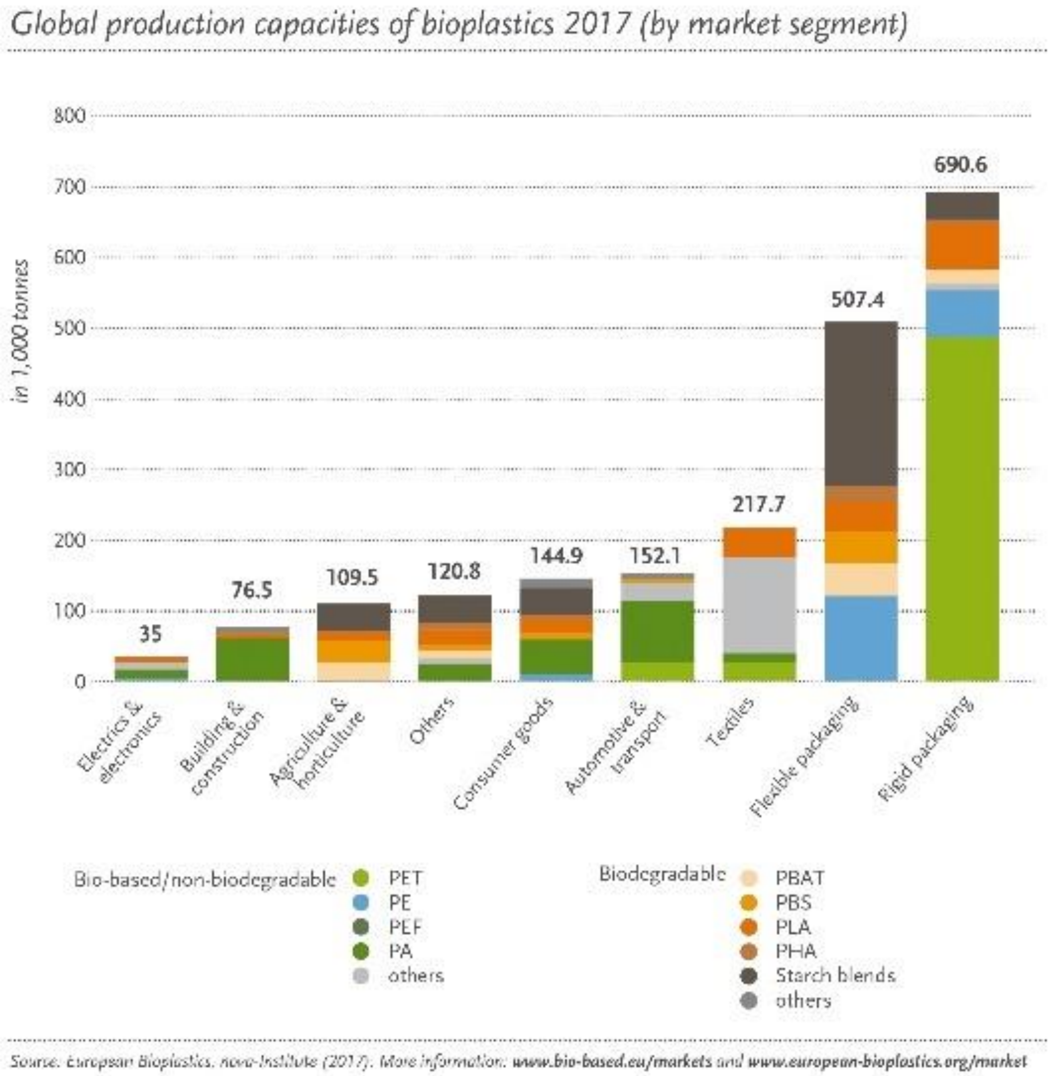

Figure 4. The global production capacities of bioplastics 2017 (by market segment), almost 60 % is used for flexible and rigid packaging (European Bioplastics e.V. 2017a).

Bioplastics can be divided into sub-groups, and this is important to be able to find the best possible application for the specific characteristics that separates them. This is because when using bioplastics for packaging an issue is to distinguish how the bioplastic waste should be handled. An important aspect to take into consideration is that labelling and clear messages of the type of bioplastic exist on the packages. This enables a greater communication to the user of the package which will better understand how to discard the bioplastic waste. If this is not clear there is a higher risk that it will end up in a less environmental friendly end-of-life as incineration or landfills, or even worse, in the nature, instead of a more environmental friendly end-of-life as mechanical recycling or organic recycling. To reach an environmental benefit from utilization of bioplastics a well-functioning waste management is required, which can handle the waste in a sustainable way.

In the present packaging sector, there are several bioplastic alternatives that can be used, but they still represent a small fraction of the total packaging sector, about 1 % (European Bioplastics e.V. 2017a). There are great possibilities for growth of bioplastics in the packaging sector, but there are also challenges and barriers to overcome to utilize them to a greater extent in this segment. An important aspect to take into consideration is that the bioplastic that is used should be applicable in a circular economy.

European Bioplastics e.V. (2017a), that represents the bioplastics industry in Europe, has estimated the present global production capacity of bioplastics and also made a forecast for the next few years, see figure 5 below. From the figure it can be seen that bio-based/non-biodegradable plastics have a greater global production capacity in 2017 and will still have the greater global production capacity in 2022. The forecast also shows that the global production of biodegradable plastics will have a percental increase compared to the bio-based/non-biodegradable in the time-period between 2017-2022, but they will still have a lower total global production capacity.

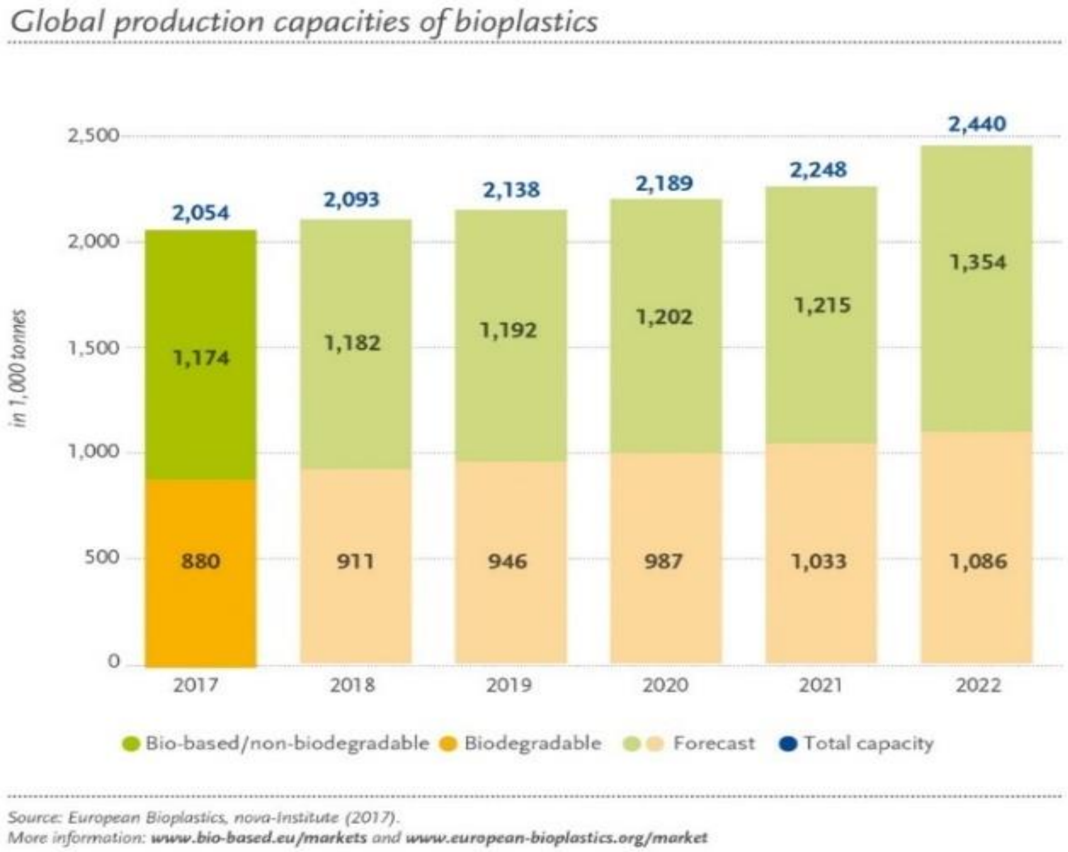

Figure 5. The global production capacity for bio-based/non-biodegradable plastics and biodegradable plastics in 2017 and forecasts for 2018-2022 (European Bioplastics e.V. 2017a).

Bioplastics are produced all over the world with a total of 2.05 million tonnes globally, but this is still small amounts compared to the total global plastic production which reached 335 million tonnes in 2016. The global production capacities of bioplastics by region in 2017 can be seen in figure 6 and Asia clearly has the greatest production capacities of bioplastics with over 50 % of the globally produced bioplastics. Europe is also a major hub for the bioplastics industry where also research and development is ranked highest (European Bioplastics e.V. 2017a; PlasticsEurope 2017).

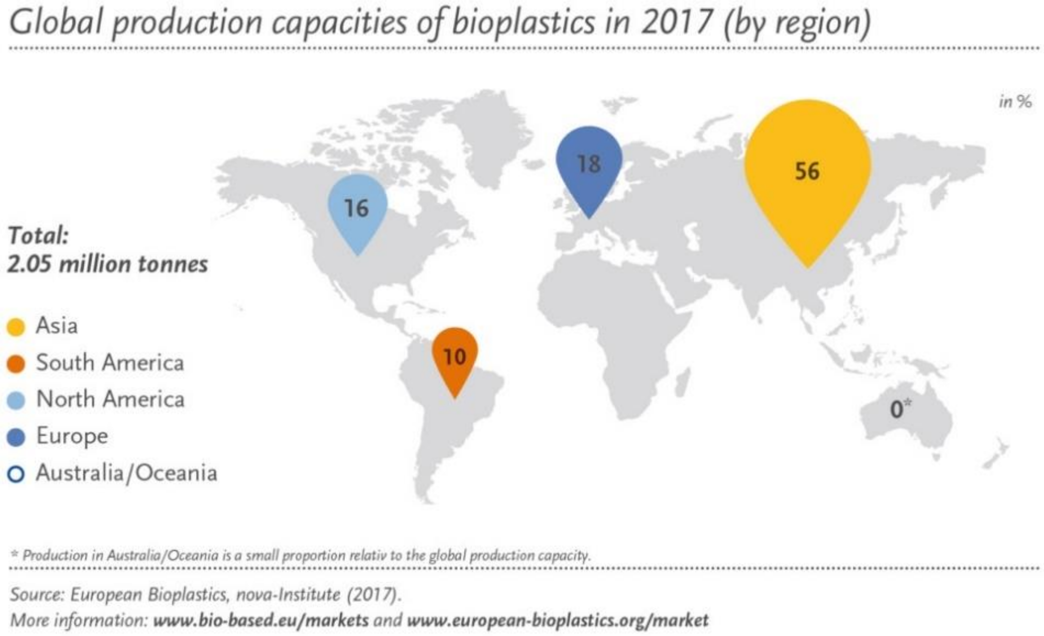

Figure 6. The global production capacities of bioplastics in 2017 (by region) (European Bioplastics e.V. 2017a).

3.3.1 Bio-based- and greenhouse gas-based plastics

A bio-based plastic is partly or fully based on biomass and can be either biodegradable or non-biodegradable, whereas a greenhouse gas-based plastic is produced from greenhouse gases. A bio-based non-biodegradable plastic is referred to as a "drop-in" bioplastic if it has the same properties, chemical structure and recyclability as the fossil-based counterpart. This enables a possibility of a direct substitution of the conventional plastic alternative with no concern of other properties or waste management. The "drop-in" bioplastics has the greatest production capacities among bioplastics today and make up around 56 %, which mainly consists of bio-based PE, PET and PA. The bio-based plastics can be based on several different feedstocks which can be divided into four generations of feedstock (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016) :

1st generation: Examples of these feedstocks are sugar cane, corn and wheat, i.e. carbohydrate rich plants that can be used as food or animal feed.

2nd generation: Examples of these feedstocks are cellulose (non-food crops), corn stover and waste vegetable oil (waste materials from 1st generation feedstocks), i.e. biomass from plants that are non-edible or not suitable for animal feed production.

3rd generation: This generation of feedstock is represented by biomass derived from algae. This has its own category due to its higher growth yield than both the 1st and 2nd generation feedstocks.

4th generation (in a biofuel context): Feedstock from greenhouse gases as methane gas (CH_4) and carbon dioxide (CO_2).

Production of bioplastics from biomass that can be used for food and feed, i.e. the 1st generation feedstock, has been debated for several years due to aspects of starvation in several parts of the world. An estimation by European Bioplastics e.V. (2017a) concluded that 0.016 % of the total agricultural area globally was used for the production of bioplastics, whereas 97 % was used for food and feed. Even with a growing bioplastic market, the land-use would increase to 0.021 % by 2022 according to estimations. This is still a small part of the total land-use and not competing with the use of biomass for food and feed. The generations of feedstocks to come will require more research as well as making it economically feasible to be commercially scaled. This will enable a future bioplastic market that hopefully is non-competing with the food- and feed industry.

The 4th generation feedstock, the greenhouse gas-based plastic, is relatively new in the plastic industry and not rigorously defined, but can have great potential for the future since it can be "carbon negative", i.e. uses more carbon than what is released into the atmosphere. A company named Newlight Technologies has been in operation since 2003 and has come up with a technology that captures the potent greenhouse gas methane, mainly from landfills, and processes it into polymers by using a biocatalyst derived from micro-organisms (Plastics Magazine 2012; World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

To ensure and communicate that a plastic packaging is bio-based there are organizations that can provide certifications and labelling based on an EU standard "CEN/TS 16137:2011 Plastics – Determination of biobased carbon content". Two labels that communicates bio-based content can be seen in figure 7 below, which is provided by the international testing, inspection and certification company TÜV AUSTRIA Group (acquired Vinçotte 2017) (left) and the German certifier DIN CERTCO (right) (European Bioplastics e.V. 2017b).

Figure 7. Two labels that communicates certification of bio-based content. Provided by TÜV AUSTRIA Group (left) and DIN CERTCO (right) (TÜV AUSTRIA Group n.d..; DIN CERTCO n.d..).

3.3.2 Biodegradable plastics

Biodegradable plastics can be both bio-based or fossil-based and these can have a great diversity of the environment a certain plastic is biodegradable in. Different environments can be an industrial composting facility, home compost, natural soil or marine and water environments. According to European Bioplastics e.V. (2017b) "Biodegradation is a chemical process during which microorganisms that are available in the environment convert materials into natural substances such as water, carbon dioxide, and compost (artificial additives are not needed)." and this process is very much dependent on the surrounding environment. The biodegradation process of biodegradable polymers is dependent on several factors, the first order structures (molecular weight, molecular weight distribution, chemical structure), the surface conditions (hydrophilic and hydrophobic properties, surface area) and the high order structurers (melting temperatures, glass transition temperature, crystallinity, modulus of elasticity and crystal structure) (Tokiwa, Calabia, Uqwu & Aiba 2009). Humidity, presence of microorganisms and oxygen are also important factors that affect the effectiveness of biodegradability (Van der Oever, Molenveld, Van der Zee & Bos 2017).

To enhance performance and reduce costs it is not that uncommon that fossil-based and bio-based biodegradable polymers are combined to form blends (Song, Murphy, Narayan, & Davies 2009). See table 1 below for some examples of biodegradable plastics and examples of end-of-life possibilities.

Table 1. Examples of biodegradable plastics and examples of end-of-life possibilities (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016; Accinelli et al 2012; UNEP 2015).

Biodegradable plastic	Bio- or fossil-based	Industrial compostable	Biodegradable in marine environments	Mechanically recyclable (technically)
PLA	Bio	Yes	No	Yes
PBAT	Fossil	Yes	No	No
PBS	Fossil	Yes	No	Yes
PHA	Bio	Yes	In some aquatic environments. Uncertainty, more research is required.	Yes
Starch-blends	Bio	Yes	In some aquatic environments. Uncertainty, more research is required.	No

Compostable bioplastics is a subgroup of biodegradable plastics that requires a certain environment (temperature, microorganisms, oxygen etc.) to be fully biodegraded, and which can be divided further into two groups: industrial compostable and home compostable. The home compostable (can always also be industrial compostable) do not need the same controlled environment as industrial compostable plastics, but the timeframe of the biodegradability can be longer (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016). To consider a bioplastic packaging as an industrial compostable packaging, it should fulfill the requirements of certain standards which define compostability. ASTM 6400 is an standard used in USA, EN 13432 in Europe and ISO 17088 is an international standard. The European standard EN13432 requires 90 % biodegradation after six months and at least 90 % disintegration after twelve weeks and therefore has "requirements for packaging recoverable through composting and biodegradation". For biodegradable packaging which are designed for anaerobic digestion and industrial composting, this is the standard to use. It also includes tests on the content of ecotoxicity and heavy metals. An example of a label that ensures that the plastics are biodegradable and compostable is The Seedling label, see figure 8. The international testing, inspection and certification company TÜV AUSTRIA Group and the German certifier DIN CERTO offers not only a certification process for bio-based content, but also for biodegradable and compostable plastics, this to ensure that the qualifications needed for the plastic to be biodegradable and compostable are fulfilled. This labelling fulfills the EN13432 standard (European Bioplastics e.V. 2017b). It is important that industrial compostable bioplastics are not mixed with or mistaken as home compostable due to that they will, as mentioned, not be degraded properly in such conditions. Therefore clear labelling of which environment that it biodegrades in is required to ensure proper discarding of the "compostable" plastic (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

compostable

Figure 8. Illustrates The Seedling, a reliable label for composability of biodegradable plastics. The certification process which enables the usage of this label is offered by TÜV AUSTRIA Group and DIN CERTCO (European Bioplastics e.V. 2017b)

Some biodegradable plastics will biodegrade in the presence of oxygen (aerobic digestion) and will not biodegrade in facility's where no oxygen is present (anaerobic digestion) which can make it problematic for the waste management companies. The anaerobic digestion facility's has the purpose of producing biogas which then is regarded as a renewable power production. Therefore it is important to know which kind of facility's that the biodegradable plastic are meant to end up at when regarded as waste (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016). The use of biodegradable plastics are often found in applications where biodegradability can be a key advantageous feature, as short service life applications. This can be in applications as shopping bags, films and bottles in food packaging, agriculture mulch films and convenience food disposables. But, to reach the maximum environmental benefits of biodegradable plastics, they will still need the appropriate waste management as collecting the post-consumer waste and be locally composted according to Song et al. (2009).

Biodegradation in marine environments can be vastly diverse due to the broad spectrum of differences in marine environments throughout the world. Temperature, presence of microorganisms and where in the water the plastic is located (on the surface etc.) are few examples of factors that affect the biodegradation. As mentioned, there are existing standards and labelling for biodegradation in for example an industrial composting facility, but for biodegradation of plastics in marine environments there are currently none available. But, as the measurement of marine biodegradation is an important aspect for biodegradable plastics, there are a few projects undergoing for standardization at ISO and ASTM level (European Bioplastics e.V. 2016a).

A plastic that is referred to as “oxo-plastic”, “oxo-degradable”, “oxo-fragmentable” or “oxo-biodegradable” is a plastic that is fossil-based with additives that initiates fragmentation if exposed to for example heat or UV-radiation. The fragmentation is faster than conventional plastic in an open environment, but there is no evidence that they will biodegrade fully in a time that is reasonable in most environments and therefore they are not suited for long-term use, composting or recycling. These plastics have no beneficial effects on the environment, but can instead be harmful for both the environment and the recycling industry. The fragmented plastics can be contributing to the accumulation of microplastics in marine environments. They should be avoided in all applications according to, and based on several conclusions by, scientists, experts and governmental institutions (European Commission 2018b; World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

3.4 Sustainable packaging, sustainable plastics and circular economy

Many companies, organizations and people in general today is using the word “sustainability” or “sustainable development”, but it is important to define the meaning with this term to understand in what context it should be applied. The World Commission on Environmental and Development published a report known as the *Brundtland report* or *Our Common Future*, that introduced the concept of sustainable development and described how it could be achieved. According to World Commission on Environment and Development (1987) the definition of Sustainable Development is:

“1. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:
the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.”

When defining a sustainable packaging one can summarize it by saying that for all packaging materials, there should be closed loop systems. By utilizing this system it will most likely result in an environment friendly system for the packaging life cycle. The definition of sustainable packaging can be further fractionated into several criteria’s which will outline a framework for actions towards sustainable packaging and these are according to Sustainable Packaging Coalition (2011):

“Sustainable packaging:

A. Is beneficial, safe & healthy for individuals and communities throughout its life cycle
B. Meets market criteria for performance and cost
C. Is sourced, manufactured, transported, and recycled using renewable energy
D. Optimizes the use of renewable or recycled source materials
E. Is manufactured using clean production technologies and best practices
F. Is made from materials healthy throughout the life cycle
G. Is physically designed to optimize materials and energy
H. Is effectively recovered and utilized in biological and/or industrial closed loop cycles”

An essential part of a sustainable future for packaging is that a circular economy is applicable for the packaging solution. A foundation that has the aim of accelerating the transition to a circular economy was founded in 2010 and goes by the name *Ellen MacArthur Foundation*. A report about a new plastics economy was published by World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company (2016) which outlines a rethinking for the future of plastics (by examples from the plastic packaging value chain) and strategies towards a new plastic economy.

In a circular economy the value-preserving of a material is of importance. Preserving the value of plastics can be done by recycling them and using the recycled plastic for new products. This process is unfortunately not the case for most of the plastics today, in Sweden 16 % of all the plastic that falls out of use is recycled into “new” materials (Material Economics 2018). This low number is mainly because of three reasons: plastic that is not sorted but handled as waste for incineration, plastic that is sorted but is used for energy recovery and plastic that is sorted away in the recycling process. To send the plastic for energy recovery (incineration) is better than sending it to landfills, but by doing so and not mechanically recycling it, the value of the recovered energy is worth less than 10 % of the plastic original value. There is a value-loss when the plastic has been mechanically recycled as well, then it is valued to 50-60 % of virgin plastic in general. This value-loss is due to loss in quality and a low demand for recycled plastics (Material Economics 2018).

The principal of the circular economy is defined by World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company (2016) as:

“The circular economy is an industrial system that is restorative and regenerative by design. It rests on three main principles: preserving and enhancing natural capital, optimizing resource yields, and fostering system effectiveness.”, see figure 9 below for a visual outline of a circular economy.

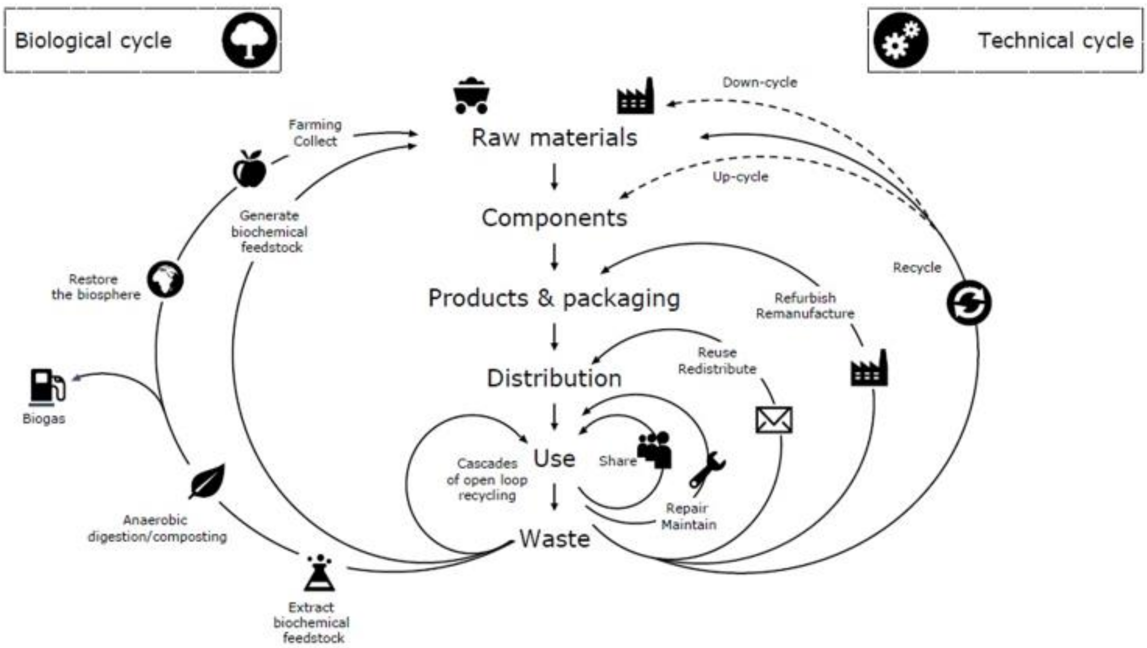

Figure 9. Visual outline of a circular economy made by ÅF, adapted from World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company (2016).

As the waste management is an important part of a circular economy it is of importance to understand the struggles that the waste management companies are facing when introducing new materials in the waste streams. Implementing new materials in the packaging industry, e.g. some bioplastics, likely need separate waste streams to reach the positive environmental impact that they are meant to fulfill. This is not something that is an easy fix, the waste management companies have been developing the systems that are utilized today for decades, and these systems are still not perfect. fore, it is important to have a continuing dialogue with all the actors in the value chain to reach the best possible environmental friendly solution and create a well-functioning circular economy for plastics (Company 11; Company 12; Consultant/scientist 1).

The waste management of plastics today is diversified across the world and if a circular economy should be considered, recycling and re-use are two aspects that are important. Plastics are mainly recycled by a mechanical recycling process which means that they are separated, shredded into tiny parts and then washed, which later can be re-processed into new plastic products. A negative aspect of this recycling process is that the plastic cannot be recycled infinitely, which is because the polymer chains that the plastic consists of are shortened and disoriented, which will result in loss of properties. But there could be a solution to this; there are a few companies that use a chemical recycling process which could enable infinite recycling of plastic. In this process the polymer chains are processed back to its initial building blocks, the monomers, or another chemical feedstock. This process is still energy demanding and is not economically viable, but with innovation and incentives this can have potential as an alternative for recycling of plastics, especially mixed plastic waste. By using this process the dependence on virgin building blocks for plastics will decrease, which means that the plastics industry would not be contributing to the depletion of fossil fuel-resources and greenhouse gas emissions in the same extent. When considering the mechanical recycling, two separate loops can be used, the closed loop and the open loop. The closed loop is the most value-preserving loop because it will cycle the materials into the same applications and therefore keep the quality of the materials at the same level as before, i.e. up-cycled. The open loop is in place for materials with degraded quality, e.g. if quality is lost when mechanical recycled, and these materials is used for applications with lower demands, i.e. down-cycled (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

By outlining strategies towards a circular economy for plastics and ensuring minimal negative environmental impact, the European Commission (2018a) has formulated “A vision for Europe’s new plastics economy”, which proposes strategies towards a circular economy for plastics in Europe. According to The European Commission (2018a) the way forward is by turning the vision into reality, not only by nation and regional authorities, but also by the industry and this is done by:

- “Improving the economics and quality of plastics recycling”;
- “Curbing plastic waste and littering”;
- “Driving innovation and investment towards circular solutions”;
- “Harnessing global action”.

Plastic production, plastic consumption and the end-of-life of plastics are areas where challenges exist in the EU today, but these are also able to be turned into opportunities and with that a competitive European industry. If this strategic vision is embarked through the whole value chain it could provide job opportunities, spur the transition towards a circular economy, provide the society with a safer and cleaner environment as well as spur growth and innovation (European Commission 2018a). The ending words in European Commission (2018a) concludes the importance of collaboration and working towards a common goal to reach a circular plastics economy in the future: “The Commission therefore calls on the European Parliament and Council to endorse this strategy and its objectives, and calls on national and regional authorities, cities, the entire plastics value chain, and all relevant stakeholders, to commit to resolute and concrete action”.

Sustainable Development and Sustainable Packaging has been defined, but the definition of Sustainable Plastics is not clearly outlined. A research programme funded by Mistra, a Swedish research foundation, is called STEPS – Sustainable Plastics and Transition Pathways. The programme has outlined a starting point in the programme: “A transition to a more sustainable plastics system involves an increase in the resource and material efficiency of plastics consumption, a significant increase in the reuse and recycling of plastics, a shift to new plastic additives with low environmental and health impacts, and a switch to renewable feedstock”. These sustainability aspects of the starting point are illustrated in figure 10 below (Palm & Svensson Myrin 2018).

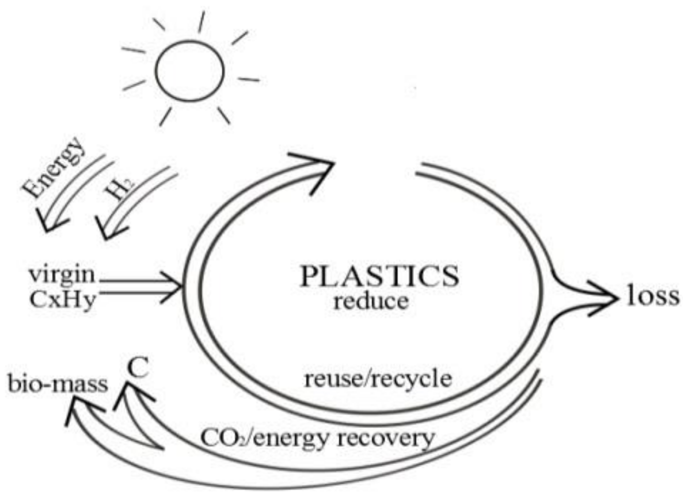

Figure 10. A sustainable plastics system with the aspects of renewable feedstock, reuse/recycle and waste management (Palm & Svensson Myrin 2018).

4. Findings

4.1 Sustainable individual polybags

The definition of sustainable packaging by Sustainable Packaging Coalition (2011) and circular economy by World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company (2016) as well as the starting point outlined in the STEPS programme, is taken into consideration when researching sustainable materials and solutions that could be applied in the case of individual polybags.

4.1.1 Sustainable materials

The plastic material that is mainly used for individual polybags in the retail industry is LDPE, and this is because it fulfills the properties required for this application. The industry standard for this packaging solution as it is today will therefore require similar properties as LDPE to ensure that the garments and products are well protected during transportation. Paper is also evaluated due to its common use in packaging solutions.

A material that has been reaching greater utilization in the plastics and packaging industry in recent years is the bioplastic, bio-PE, i.e. bio-based PE. This is a material made from renewable resources and this could be a material alternative to the petroleum-based LDPE individual polybag. The bio-PE can be made as a bio-LDPE grade and has exactly the same chemical structure as the petroleum-based LDPE which will give the exact same properties as flexibility and tensile strength etc. Due to this the bio-LDPE can be integrated directly in an existing waste management infrastructure that recycles LDPE and it has the same recyclability as the conventional petroleum-based LDPE, i.e. 100 % recyclable and is therefore regarded as a “drop-in” plastic (Braskem n.d.). From a material and waste management perspective the choice of using bio-LDPE would enable a smooth substitution from the conventional LDPE individual polybag to a bio-LDPE individual polybag. The bio-LDPE can be made from sugarcane or corn starch which are two examples of renewable resources and are 1st generation feedstocks. The main global supplier of bio-PE is the Brazilian petrochemical company Braskem and are calling their product I’m Green^{TM} Polyethylene and have HDPE, LLDPE and LDPE in the I’m Green^{TM} Polyethylene portfolio, see figure 11 below for an overview (Braskem n.d.). Braskem is using ethanol derived from sugarcane as the raw material when processing it into bio-LDPE and the entire life-cycle (as farming, processing of ethanol etc.) has to be taken into consideration when concluding if this is a sustainable material choice. Therefore a Life Cycle Assessment (LCA) has been made on Braskem’s I’m Green Polyethylene by external companies that specializes in conducting LCAs for the sustainable energy and materials industries. The LCA study was done with the aspect of cradle-to-factory, i.e. that end-of-life is excluded, and the Global Warming Potential (GWP_{100}) impact, which presents the greenhouse gas emissions. A comparison between Braskem’s fossil-PE and bio-PE was done, which concluded that for the bio-PE the emissions are negative and for the fossil-PE the emissions are positive. The GWP_{100} impact was +1.83 kg CO2e/kg fossil-PE and -3.98 CO2e/kg bio-PE. A major reason for this is that the sugarcane “removes” carbon from the atmosphere in the form of CO_2, which is still fixed in the polymer after the processing steps (E4tech, LCAworks, Macedo, I. & Seabra, J. 2013).

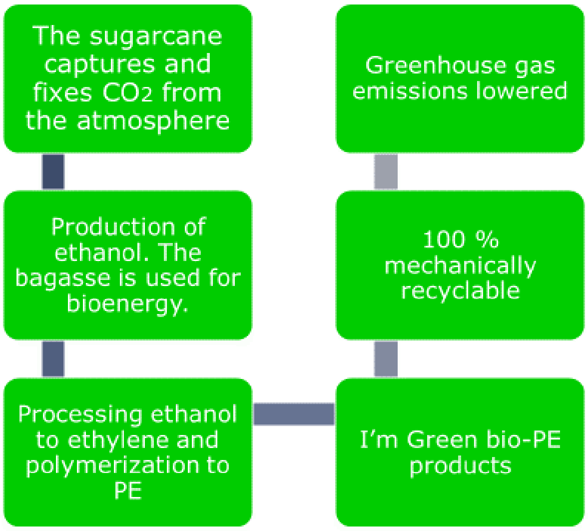

Figure 11. An overview of the process and the environmental benefits of I'm Green™ bio-PE products by Braskem. Done with inspiration from Braskem (n.d.).

The ethanol that is derived from sugarcanes and is processed into LDPE can also technically be derived from cellulose fibers, i.e. from trees, which will then be processed into ethylene and then PE by the same process. This gives an additional renewable resource and will enable possibilities of greater amounts of biomass for the production of bioplastics, but the process of deriving ethanol from cellulose is still not commercialized. There are several companies collaborating in a project called "Närodlad Plast" that evaluates the opportunities and challenges regarding forest-based plastics (SEKAB n.d.).

Another renewable sourced material alternative that is used to a great extent in the packaging industry is paper. Paper is made from cellulose fibers and is therefore from a renewable resource. It is biodegradable in industrial composting and natural environments, and recyclable in municipal waste streams. But, there are other aspects to take in consideration as well. There are LCA studies concluding that a conventional plastic bag has a lower environmental impact than a paper bag, and others concluding that a paper bag has a lower environmental impact (Overcash 2007; Dahlgren & Stripple; The Danish Environmental Protection Agency 2018). A LCA by Overcash (2007) concludes that the PE bags has lower environmental impacts than a compostable plastic bag and a paper bag with 30 % recycled wood-fibres. The study does not address the littering issue, but it can be used to debate if it is an acceptable trade-off when considering the overall environmental issues. Another LCA study of grocery carrier bags by The Danish Environmental Protection Agency (2018), also not considering the effects of littering, concluded that LDPE carrier bags provide the overall lowest environmental impacts if reuse is not considered. With this said, there is a LCA study concluding that a paper based bag has a lower environmental impact. Dahlgren & Stripple (2016) compared the climate impact of four different shopping bags: BillerudKorsnäs bag (paper bag made from virgin fiber), recycled paper bag (85 %), recycled LDPE bag (50 %) and renewable LDPE bag (made from sugarcane in Brazil). The conclusion was that the global warming potential for the BillerudKorsnäs bag had a lower impact compared to the other bags. The main reason for this is that the mill where they are produced uses high amounts of biofuels and excess energy which is used internally at the mill. The end-of-life in this study was not taken in consideration.

When determining if paper is a more environmental friendly material than plastic, it is important to take all environmental aspects into consideration, e.g. production, transportation and end-of-life. There can be environmental trade-offs to consider when determining if plastic or paper should be chosen as material, as biodegradability in natural environments. For the application of the individual polybag it also requires to have properties that protects the garments and products during transportation. Paper do not have the same tear strength or impact strength as plastic, as well as paper is water absorbing (Nesic & Seslija 2017). These lacking properties can result in that the products gets harmed during transportation which likely will have greater negative impact on the environment compared to using an individual polybag. A study by Cohen (2014) also concluded that paper mailers instead of using the conventional individual polybag did not sufficiently protect the products, not even in the logistics system in a distribution center, which then potentially could be harmed. The study also concluded that a damaged product would result in a far greater negative impact on the environment than producing and using an individual polybag. According to Company 1, a global company within the retail-industry, their individual polybags have to be transparent for their logistics systems, and if conventional paper is used, the transparency is lost. But, there are paper-based alternatives that provides a certain degree of transparency, which possibly can be enough to fulfill the requirements. Company 2, a global company within the retail-industry, is evaluating a tissue-bag, i.e. a paper-based bag that resembles tissue-paper but has stronger mechanical properties, for the application of the individual polybag for e-commerce. If this is a success in case of protective properties, a thorough LCA study should be done to evaluate the overall environmental impact.

A solution to the possible problem of lack in properties needed to protect the products by using paper could be to use a material that is based on wood fibers but has the same strong protective properties as plastic. This product is called Paptic and has production in a pilot plant for the time being, but is working towards an upscaling to industrial scale. This material has been developed to help companies work towards fighting the marine plastic waste problem, see figure 12 below for examples of products made by Paptic. The material is based on wood from certified forests and is therefore from renewable resources, biodegradable and recyclable. The material also includes man-made bio-based fibres as well as additives that often are used for paper manufacturing. The properties of this material has higher stretchability than paper, and higher tensile stiffness than plastics which will give a high impact resistance. The tensile strength will also result in that the material will maintain its shape when loaded and not lose it as easily as a plastic film. When this material was compared to kraft paper and LDPE with 10 % recycled content in a LCA, the results showed that the Paptic material is more environmentally friendly than the other two materials in the aspect of carbon footprint (Paptic Ltd 2018). Lost transparency can however be an issue if using Paptic for the application of individual polybags.

Figure 12. Examples of products made of Paptic material (photo: Paptic).

A material alternative that have resembling properties of LDPE is the bioplastic polybutyrate adipate terephthalate (PBAT), which is a biodegradable plastic. It has wear and fracture resistance, high elasticity and resistance to water and oil, but relatively low tensile strength though. This polymer is used for the product Ecoflex® by the German chemical company BASF (Niaounakis 2015). This plastic is fossil-based, but due to its biodegradability it is regarded as a bioplastic. PBAT is compostable according to the EN13432 standard (industrial composting) and therefore requires certain environmental properties to biodegrade properly and in a certain time-frame (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

A bio-based and biodegradable plastic material group called polyhydroxyalkanoates (PHAs) can potentially be a material alternative. Newlight Technologies, that produces plastic from greenhouse gases, have a bioplastic product that they are calling AirCarbon PHA. This is a thermoplastic material which is produced from oxygen in air and hydrogen and carbon from methane emissions. The AirCarbon PHA can be rigid or flexible by using different PHA grades (modified with additives) and is meant to compete with oil-based plastics as HDPE, LDPE, LLDPE, PP, HIPS and ABS (Plastics Magazine 2012: World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016). Among the class of biodegradable plastics, PHA has the most promising biodegradable properties. It biodegrades in both anaerobic and aerobic conditions, and has been found to be degradable in soil and lake- and marine water. These environments is required to have high microbial activity for PHA to degrade (Sashiwa, Fukuda, Okura, Sato & Nakayama 2018: Ong, Chee, Sudesh 2017). As marine environments and conditions are greatly diverse throughout the world, it is not calculable enough to ensure that biodegradable plastics will degrade fully. With this said, biodegradable plastics, PHA included, are not a solution to marine litter (Van der Oever 2017; UNEP 2015).

Another bioplastic that has been commercially utilized and extensively researched during several years is polylactic acid (PLA). This is also a bio-based and biodegradable plastic that possibly can be used for the application of the individual polybag. The mechanical properties can vary for PLA and soft and elastic plastics can be obtained, this is determined by chosen crystallinity when processed. In addition to this it can be processed into transparent, high-modulus and high strength polymers (Farah, Anderson & Langer 2016). PBAT could also be blended with PLA to reach different properties and reduce costs, as well as including bio-based content (Shahlari & Lee 2012). Considering recycling, PBAT can technically be both mechanically recycled and organically recycled (industrial composting). If it is mechanically recycled it needs to be held dry during the process, due to that PLA is sensitive to hydrolysis, and it will degrade strongly in presence of moisture at higher temperature (50 ºC) (Cefur 2016).

A bio-based (to some extent) and biodegradable alternative that could be applied in the case of the conventional individual polybag is a packaging solution from TIPA, which is a packaging company from Israel. They provide a packaging solution that according to them has "excellent mechanical properties" and is a re-sealable flapped bag that is possible to use for transporting garments, see figure 13 below. This packaging alternative is both industrial compostable according to EN13432 and home compostable according to certification "OK compost Home", and is available with 20-30 % bio-based content (TIPA 2017). Home composting should however be considered as a complementary solution to industrial composting and anaerobic digestion (European Bioplastics e.V. 2015).

Figure 13. A re-sealable flapped bag that is bio-based (to some extent) and biodegradable, provided by TIPA. (photo: Yoram Aschheim)

An overview of the presented material alternatives for the application of the individual polybag is seen in table 2 below. The advantages and disadvantages are presented, as well as if the material is made from a renewable resource.

Table 2. Material alternatives to the conventional individual polybag and its advantage as well as disadvantage.

Material	**Renewable resource**	**Advantage**	**Disadvantage**
Bio-LDPE (bioplastic)	Yes	Same properties and mechanical recyclability as conventional LDPE. Lowered greenhouse gas emissions compared to conventional LDPE. From renewable resource.	As for biodegradability and littering, it will not change anything due to the same characteristics as conventional LDPE.
Paper	Yes	Biodegradable in natural environments, organically and mechanically recyclable. From renewable resource.	Can lack in protective properties. LCA studies shows that the environmental impact can be greater compared to conventional plastic. Lost transparency.
Paptic	Yes	Biodegradable and mechanically recyclable. Properties that resemble to both plastic and paper. A LCA study show that it has a lower carbon footprint and use of fossil fuels compared to competing flexible packaging materials.	Not commercially used and uncertainty of the exact composition and production. Lost transparency.
PBAT (bioplastic)	No	Biodegradable in industrial composting. Resembling properties to LDPE.	Not mechanically recyclable. No waste management infrastructure for biodegradable plastics. Fossil-based.
PHA (bioplastic)	Yes	Can be made by using carbon from greenhouse gases. Can technically be both mechanically recycled and organically recycled (biodegradable in industrial composting, anaerobic digestion and home composting). Biodegradable in some aquatic environments. From renewable resources.	Uncertainty in which aquatic environments it biodegrades properly. No waste management infrastructure for biodegradable plastics.
PLA (bioplastic)	Yes	Can technically be both mechanically recycled and organically recycled (biodegradable in industrial composting). From renewable resources.	The mechanical recycling can be problematic. No waste management infrastructure for biodegradable plastics.
TIPA (bioplastic)	To some extent (20-30 %)	Biodegradable in industrial composting and home composting. "Excellent mechanical properties".	No waste management infrastructure for biodegradable plastics. Home composting should be regarded as a complementary to industrial composting and anaerobic digestion. Bio-based to only 20-30 %.

4.1.2 Recycled content

The LDPE plastic can be mechanically recycled and the recycled LDPE resin can technically be used again to produce new plastic products. The utilization of recycled content for packaging solutions is increasing and this due to its environmental benefits of not depending on virgin plastic material, i.e. no further contribution to fossil fuel resource depletion, and also curbing CO_2 emissions. If all the global plastic waste would be recycled it would have potential energy saving measured up to 3.5 billion barrels of oil per year according to estimates. Even though these environmental benefits, there is still a weak demand for recycled plastics, about 6 % of the total plastics demand in Europe (European Commission 2018a). The market for recycled plastics is described as a catch-22, i.e. the producers claims that they cannot get hold of recycled plastics that is high enough quality, transparency and traceability, and the companies selling the recycled plastic claims that there is no demand for most of the recycled plastic or no willingness to pay for upgrading that will increase the quality (Material Economics 2018). Increasing the demand and further utilizing recycled plastic content in packaging solutions is important strategies towards a circular economy within the plastics and packaging industry. This will keep the material in the loop and creates value once again, see figure 9 in section 3.4.

A barrier for a greater utilization of recycled content for individual polybags are the quality of the recycled plastic which can be affected by contamination, smell and lost transparency. The price of recycled plastics are also a barrier, it is lower than virgin plastic with an average of 50-60 %, but still seems to be too high for companies to find incentives to buy. The risk of getting a low quality plastic resin or enough supply is too high compared to paying not that much extra for virgin plastic resin which has a known level of quality (European Commission 2018a; Material Economics). These are problems mainly from a post-consumer recycling stream, which are when the plastic has been used by consumers and are then collected for recycling, often by municipal waste management companies. The post-consumer recycling stream increases the probability of contamination from other fluids, chemicals and materials, which can result in a decrease in quality of the material. There is also a pre-consumer recycling stream, which is when the plastic waste is collected for recycling from the industries, as for example spill in the production process. This stream is more homogenous and can be controlled to a greater extent which will give a higher quality for the recycled plastic resin. Another problem with mechanical recycling of plastics is that the polymer chains in the plastic material are shortened or degraded in some way when undergoing the recycling process. When processing a new individual polybag the quality of the recycled plastic resin needs to reach the demands and mechanical properties that the individual polybag needs to fulfill, i.e. tensile strength, tear strength etc. When the quality of the recycled plastic does not fulfill these requirements, it will often need to be mixed with virgin plastic material to ensure that the plastic fulfills the requirements and properties. Another possibility to reach the properties required in the product is to use an excess of recycled plastic material (no virgin material). The disadvantage of this is that it requires more material, and with that the weight and size is increased (Ragaert, Delva & Van Geem 2017; Company 10; Company 11). It can also be difficult to reach the desired high volumes of recycled LDPE that is of high quality, transparent, and with no smell or contaminations for conversion into individual polybags. As mentioned, the retail-industry is growing and especially e-commerce, therefore sufficient continues supply of high quality recycled LDPE is required. Some companies within the retail-industry has implemented recycled plastic content for their master polybags and recycled content is especially getting more common for shopping bags, both within retail and supermarkets. This is a good sign of a growing market for recycled plastics and hopefully a step away from the catch-22 phenomenon.

4.1.3 Less material and usage

If less plastic material can be used for the individual polybag, but still retain its protective properties, it would reduce the amount of plastic waste. A solution to this is to implement as thin polybags as possible, but with retained required protective properties. Another solution proposed by Cohen (2014) is to utilize more sizes of the individual polybags, which can be better fitted to a specific product. This will reduce the problem of using larger polybags (more material) than needed to fulfill its purpose, i.e. over packaging. Cohen (2014) also proposes to implement folding and packaging guidelines when the product is about to be packed in order to reduce the size of the individual polybags, which results in using less plastic material, see figure 14 below.

Figure 14. Folding guidelines of garments can reduce the required size of the individual polybag and result in less used plastic material. A shirt is here folded to a smaller size than it "normally" is when packed in an individual polybag. Done with inspiration from Cohen (2014) (photo: Marcus Malmsjö).

A solution to reduce or even eliminate the usage of the polybags is by a special folding and tying technique of the garments. The outdoor apparel company prAna is using a solution like this, and which has reduced their usage of polybags with 74 %. This is done by folding the garments in a certain way for a specific garment and tying the garments with a strong, grass-like material called raffia ribbon, which is made from strips of the raffia palm tree (Caputo 2016). The raffia ribbon may not have a protective property, but it holds the garments together. See figure 15 below for recreation of prAna's folded garments tied with a raffia ribbon, but in this figure, a similar material to raffia-ribbon is used. A solution like this is promising to enable a minimal usage of the package and should be analyzed if possible to implement, but there can be difficulties. For global companies in the retail-industry with large volumes that are transported all over the world, this solution can have difficulties to be implemented. The reason for this is due to that the garments and products needs to be well protected during transportation which can be in many different environments when transported in a global scale. The logistics of transportation and packing guidelines can also differ between companies within the retail-industry, which can result in that this solution is applicable in some systems but not in other systems (Company 1). The risk of a destroyed or harmed product at arrival will have a greater negative environmental impact than using an individual polybag (Cohen 2014).

Figure 15. Recreation of prAna's folded garment tied with a raffia ribbon-like material (photo: Marcus Malmsjö).

Using master polybags is a solution that is already used to some extent today by companies in the retail-industry. The meaning with master polybags are that several products or garments are transported in one large polybag to retailers instead of individually packed. If this can be utilized even more it could reduce the amount of used plastic material and result in a reduction of plastic waste. Packing the products for e-commerce in a master polybag should be evaluated by the retail-companies as a possibility when a delivery is destined to the same destination. There is an example of a company using plastic banderols, polyband, to transport assortments together to the retailers, which also reduces the plastic material used as well as plastic waste, see figure 16 below.

Figure 16. Polybands, used to pack assortments for transportation to retailers. Sometimes used instead of the conventional individual polybag (photo: Company 2).

A possible sustainable packaging solution that would decrease the amount waste generated can be to use re-usable and durable containers for transporting garments and other products. If this could be a new industry standard it would create a far more sustainable supply chain (Szaky 2014). A similar solution as this is already implemented to some extent in the retail-industry when garments and products are transported to retailers from distribution centers. They are then transported in re-usable and durable grey totes, see figure 17 below. But, the polybags and polybands are still not discarded until they reach the retailers according to Company 2. The possibility of discarding the polybags at the distribution centers should be evaluated, which will give greater collection volumes at one location, the distribution center, which in turn reduces additional transportation of the plastic waste.

Figure 17. An example of a re-usable and durable container for transporting products from distribution centers to retailers, a grey tote (photo: Company 2).

4.2 Waste management

There are different end-of-life options when the individual polybags have been used and are regarded as waste. The choice of where it ends up can be depending on where in the world it has its end-use and which bin the end-user discards it in. Landfill, incineration, industrial composting, anaerobic digestion, mechanical- and chemical recycling are some options of waste management where the individual polybags can end up when taking care of by waste management companies in a global perspective.

4.2.1 Mechanical- and chemical recycling

The individual polybags are, as mentioned, mainly made from LDPE and this polymer is recyclable and therefore have a post-use value. Besides reduce and re-use, recycling is the best possible strategy in a circular economy. There are two types of recycling processes that exist in the technical recycling industry today, but it is mainly one that is used commercially and globally, the mechanical recycling. This process has been used for several years and is relatively cost-effective and energy-efficient as well as the most value-preserving loop. The other option is the chemical recycling process, which is not commercially scaled because it is still energy demanding and not that cost-effective compared to mechanical recycling. The chemical recycling is still promising though, and has great potential if the process becomes more economically viable to use (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

The mechanical recycling process has several steps:

1. Sorting and separating of the different plastics. There are both manual sorting and automated sorting used in the industry today. Near Infrared (NIR) spectroscopy is an example of a commonly used automated sorting method to separate the plastics. It is an optical sorting technology which can detect which kind of polymer it is by analyzing the reflection spectrum.
2. Washing the plastics to remove contaminants
3. Grinding the plastics into small flakes which later can be further reprocessed into a granulate
4. The granulates are further converted into new plastic products

This recycling process is not applicable to all plastic waste. Heterogenous and contaminated plastic waste, or multi-layered plastics are few examples that probably will end up in incineration or landfills. This is because of not being able to be separated or washed properly in the mechanical recycling process. Therefore it is not economically or technically feasible to use the mechanical recycling process for this kind of plastic waste.

The chemical recycling is a promising alternative for this contaminated and heterogenous plastic waste, and this could be used as feedstock for the production of valuable chemicals and fuels as well as new polymers. The chemical recycling can be further divided into two paths, monomer recycling (building blocks for new plastics) and feedstock recycling (fuels and other chemicals), and these are ideal methods for preserving limited resources and also protecting the environment from non-degradable waste (Ragaert, Delva & Van Geem 2017; World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016). There are several companies using chemical recycling methods today, and some examples are listed in table 3 below.

Table 3. Examples of companies using chemical recycling methods for plastics.

Company	**Which type of material that is chemically recycled? Feedstock/monomer recycling? (Country)**
Bin2Barrel	Plastics that is polluted and not suitable for mechanical recycling. Feedstock recycling. (Netherlands)
Carbios	Polyesters (PET, PLA etc.) and polyamides, which then are used for plastic bottles, packaging and films. Monomer recycling. (France)
Enval	Plastic aluminum laminates. Feedstock recycling. (United Kingdom)
Enerkem	Non-recyclable municipal solid waste. Feedstock recycling. (Canada, United States)
Ioniqa Technologies	PET bottles, textiles and carpets. Monomer recycling. (Netherlands)
Plastic Energy	"Dirty" non-recyclable plastic waste. Monomer and feedstock recycling. (United Kingdom, Spain)
Recycling Technologies	End-of-life plastics that are destined for landfills or incinerators, as laminates and contaminated packaging. Feedstock recycling. (United Kingdom)

The common challenges are that the processes are energy demanding and costly to separate colorants and additives. Better catalysts are also required to reach higher yields and making the process economical viable to use. There are mainly four different processes for chemical recycling regarding plastic waste: Hydrogenation, chemolysis, pyrolysis and gasification. The different methods are shortly described in table 4 below (Cefur 2016).

Table 4. The main four processes of chemical recycling regarding plastic waste, and a short explanation of the process (Cefur 2016; World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

Process	**Short Explanation**
Hydrogenation	The plastic waste is heated together with hydrogen gas. This will break down the polymer into hydrocarbons in liquid form. These can later be used as raw materials for processing new polymers.
Chemolysis	The plastic will break down to monomers in a chemical solvent. The solvent is then removed and the monomers consisting of hydrocarbons can be used for processing new polymers.
Pyrolysis	Mainly used for "plastic to fuel", i.e. energy recovery rather than material recovery. Decomposes the polymer into hydrocarbons by using heat in the absence of oxygen and presence of a catalyst. The result is a blend of hydrocarbons, similar to oil, which can be both liquid or gas. After purification the hydrocarbons could be used to produce new plastic materials.
Gasification	The plastic waste is heated in a controlled anaerobic environment and results in the production of carbon monoxide and hydrogen. The gas blend can be refined into methanol which can be a possible raw material for the production of new materials.

The individual polybags should be destined for the mechanical recycling stream in first hand when regarded as waste, this due to that it is a mono-material, can be collected as homogenous plastic waste and that it is the most value-preserving alternative. The disadvantage is that the polybags cannot be recycled infinitely when using mechanical recycling, which the possibility is when using chemical recycling. By using mechanical recycling an additional advantage compared to chemical recycling is that energy and costs are saved by not requiring the step of re-polymerizing the monomers into polymers once again. See figure 18 below for a flow scheme from raw materials to end-of-life for plastics as well as to which stage in the flow scheme the two recycling technologies processes the plastic waste back to.

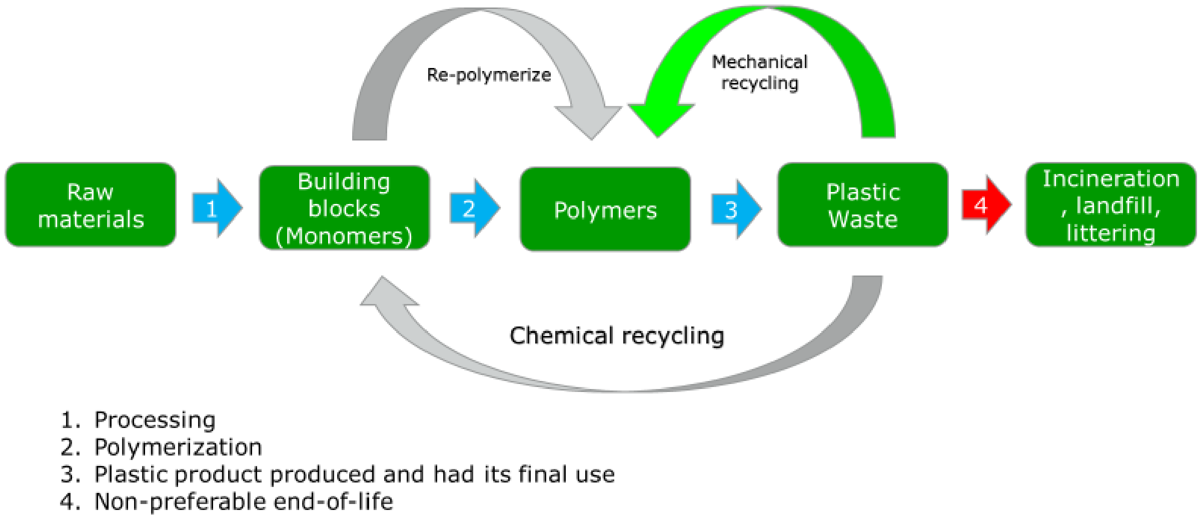

Figure 18. A flow scheme and overview from raw materials to end-of-life for plastics. It is also shown to which stage in the flow scheme the two recycling technologies processes the plastic waste back to.

To ensure an increased recyclability for a packaging solution it is of importance that the design of the package is considered. This will not only impact the recyclability, but also how it can incorporate plastic that already have been recycled. The individual polybags are a mono-material packaging solution which is positive from a recyclability perspective due to that no separation of different plastic layers is needed and in addition to this it is also a mono-material plastic, which means that the polymer is built up by one kind of monomer, ethylene. This results in that the sorting facilities will easier and more effective sort this kind of polymer. Plastics packaging with multiple layers of different polymers will most likely be sorted out and end up for incineration (Ragaert, Delva & Van Geem 2017). Another aspect to take in consideration is that there is often a text and other stamps on the individual polybags, as for example the symbol indicating which kind of plastic it is. This could either be a water-based ink or solvent-based ink. To have an efficient and more environmentally friendly recycling process it is better that the ink is water-soluble according to Company 11. An overview of the advantages and disadvantages of mechanical- and chemical recycling can be seen in table 5 below.

Table 5. An overview of the advantages and disadvantages of mechanical- and chemical recycling.

	Advantage	**Disadvantage**
Mechanical Recycling	• Most value-preserving. • No need for re-polymerization (see figure 18 above). • The recycled plastic resin can be converted directly into new plastic products.	• Limited number of recycling cycles. The polymer is degraded to some extent in every cycle. • Often requires an efficient sorting and washing process for mixed plastics. • Risk of contaminations.
Chemical Recycling	• Possibility for mixed and dirty plastics. Less demanding of sorting. • Less sensitive to contamination. • Can be used to produce additional feedstock as fuels and other chemicals.	• Demands a lot of energy compared to mechanical recycling. • Often not economically feasible. • Need of re-polymerization (see figure 18 above).

4.2.2 Bioplastic waste management

If a bioplastic would be used as material choice to the LDPE individual polybag there should be different streams for the collection of the bioplastic waste. In general, there are two pathways for the waste management of bioplastics, one pathway that is meant for industrial composting or anaerobe digestion processing, i.e. for biodegradable plastics. Then there is one pathway that is meant for mechanical recycling or production of renewable energy, i.e. the bio-based "drop-in" plastic, see figure 19 below (European Bioplastics e.V. 2016b). Some bioplastics can technically be put in both streams, the bio-based and biodegradable plastic polylactic acid (PLA) is one of them. The mechanical recycling stream will though result in a decrease of its mechanical properties after a few cycles due to its thermal degradation. These bioplastics are still not that utilized and low volumes of these plastics end up in the mechanical recycling stream. Therefore there are still no economic incentives to sort out these and be mechanically recycled. But, as PLA has two possible recycling opportunities, mechanical recycling (technically, not commercialized) and organic recycling (both for aerobic and anaerobic conditions), it could have an edge in the bioplastic market from a waste management point of view in the future (Farah, Anderson & Langer 2016; Cefur 2016).

Figure 19. Two separate collection streams for bioplastics, one for mechanical recycling (left) and one for organic recycling (right) (European Bioplastics e.V. 2016b)

The biodegradable plastics utilized today do not have separate collection streams in a general municipal waste stream and this makes it problematic for the general public to determine how to discard this kind of plastic in a sustainable way. Is it meant for industrial composting, anaerobic process or home composting are questions that are not easy to answer by the general public. Biodegradable plastics will not automatically lead to a reduction or be a solution to the marine littering and the negative environmental aspects that they cause. Experimental studies done by Accinelli, Saccà, Mencarelli & Vicari (2012) concluded this by observing a biodegradable plastic bag in marine ecosystems, the starch/PBAT blend Mater-Bi™ . This had a slow rate of degradation in these marine environments, but for compost and soil it had an rapid deterioration. A biodegradable plastic that is marked as compostable is therefore not equal to biodegradable in marine environments. UNEP (2015) concludes two important things regarding this: “On the balance of available evidence, biodegradable plastics will not play a significant role in reducing marine litter” and that some evidence has shown that consumers will more likely discard a biodegradable item inappropriately.

4.2.3 Re-take and collection

Pre-consumer plastic waste and post-consumer plastic waste is often used to distinguish between plastic waste collected from industries (pre-consumer waste) and plastic waste collected from consumers (post-consumer waste). The two streams where the individual polybags initially are discarded will now be referred to as the “pre-customer” and “post-customer” waste stream. The “pre-customer” waste stream refers to the individual polybags that are discarded when products are unpacked at the retailers, and the “post-customer” waste stream which refers to the individual polybags that reaches the customers directly when using e-commerce. These two different streams affects how well the collection and recycling efficiency will be, as well as the end-of-life of the individual polybags, see figure 20 below for an overview of the two separate streams. When considering the pre-customer waste stream a possible solution, that is utilized to some extent already in the industry, is to collect and bale the individual polybags and master polybags at the retailers which then can be further transported and recycled at recycling facilities. The polybags can possibly be recycled in a separate stream (if the volumes are large enough) and will likely give a good transparent quality recycled LDPE, which then can be used again to produce new individual polybags. To reach an economically feasible mechanical recycling in closed loops of individual polybags, it would require sourcing of sufficient and stable volumes (Vlugter 2017; Company 11). This will likely require collaborations within the retail-industry, but also with the waste management and recycling companies. An example of an existing collaboration like this is the outdoor apparel company The North Face that has a polybag recycling program in collaboration with the international recycling company TerraCycle. The polybags that reaches the retailers is collected and sent to TerraCycle which according to them will "recycle them into fun and innovative products" (TerraCycle n.d.).

When considering the post-customer individual polybags which are growing in volumes due to the increase in utilization of e-commerce, it is important to understand that the responsibility is almost entirely put on the customer of how the individual polybags are disposed. How the customer choses to dispose the individual polybag will likely be based on how many sorting alternatives there are in the municipal waste management, but also how well the customer understands where and how it should be discarded. This is where the responsibilities from companies using the individual polybag as a packaging solution comes in. It is important for the companies to provide information and communicate to the customers how the polybags should be discarded in the best possible and sustainable way. This can be by using text or symbols on the polybags, but also through their marketing channels and retailers.

A collection and re-take system for the post-customer individual polybags can be a promising solution to ensure that they are handled in a sustainable way and that the control of the individual polybag is put in the hands of the companies. A re-take collection system service at local retailers or distribution centers can be a good solution if the companies communicate well to the customers and they know that this is possible as well as a sustainable choice. This can create a willingness from the customers to discard the individual polybag in a sustainable way. An example of this can be found in the study by Cohen (2014), which investigated the usage of polybags used by the retail-company Patagonia, they give the opportunity to their customers to send the polybags that has reached them by e-commerce back to the retailers. To reach even more willingness to return the individual polybags to the retailers or sending it to distribution centers could be to give the customers bonus-points or a voucher if a certain amount of individual polybags has been returned. The bonus points or voucher could then possibly be used in the store as a payment method. In a study by Singh & Cooper (2017) a sustainable business model was proposed for plastic shopping bag management in Sweden which resulted in reducing the environmental footprint compared to the current plastic shopping bag use and disposal. In the business model they propose to take a fee for the usage of the plastic bag, refunding the full fee when the customer returns the bag to the store and which then can be collected and recycled into new plastic bags. This is a good example of strategies towards a closed loop system and enables the waste management and recycling companies to collect a homogenous plastic waste stream that can give high quality recycled plastic. A proposed model for a re-take and collection system regarding individual polybags, referred to as "IP" in figure, used for both e-commerce and to retailers can be seen in figure 20 below. This is illustrated with inspiration and data regarding shopping bags from the shopping bag business model made by Singh & Cooper (2017).

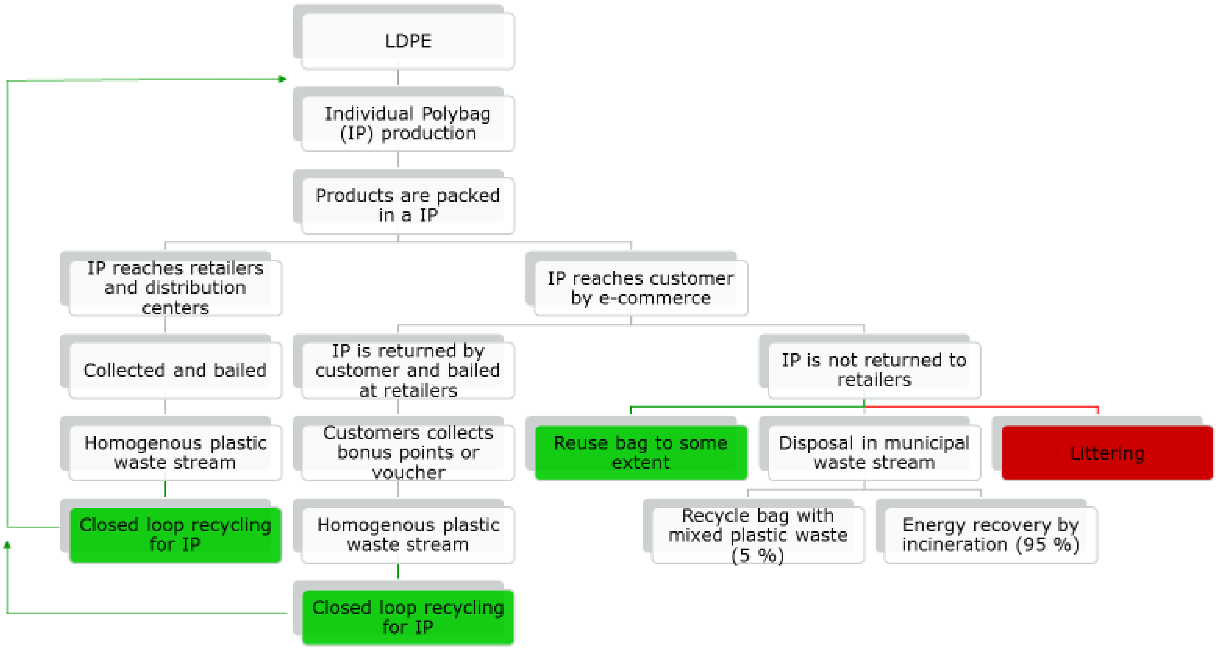

Figure 20. A re-take and collection system for individual polybags (IP) for the two streams they are used in. Done with inspiration and data from shopping bag business model by Singh & Cooper (2017)

By creating incentives for costumers, as giving bonus-points, the willingness will likely increase to return individual polybags to the retailers or distribution centers for mechanical recycling in closed loops. This could increase the amount of collected and recycled polybags, especially for the ones used for e-commerce. This could also provide awareness to customers that they can make a sustainable choice when discarding an individual polybag. There are existing examples of companies that have implemented successful and promising collection or pawn systems to increase the recycling of plastic bags, see table 6 below:

Table 6. Companies that have utilized collection/pawn systems for plastic bags, and how it works.

Company	**How it works?**
PantaPåsen	Utilized a digitalized pawn-system at recycling stations that companies can be connected to. When the customers pawn the plastic bag at the recycling station they will get money back by scanning a code on the bag with an app on the phone. Tested in Sweden (PantaPåsan n.d.).
Hemköp	Pawn Hemköps-plastic bag at Hemköps supermarket destined for recycling and you get 1 SEK withdrawn from your total amount. Tested in Sweden (Hemköp n.d.).
Netto	Pawn Netto-plastic bag at Nettos supermarket destined for recycling and you get 1 DKK back. Tested in Denmark (Netto n.d.).
The North Face	The retailers collect polybags and send it to TerraCycle for recycling (TerraCycle n.d.).

4.3 China – different approach regarding sustainable individual polybags?

With an increasing global market within the retail-industry and especially the increase in e-commerce, the usage of individual polybags will also increase on a global scale. With this said, it is important to understand that there are several differences between countries regarding industrial development, waste management, utilization of sustainable materials within the packaging and plastics industry and circular economy in general. Some of these differences can be found when comparing China and Sweden, but should this result in a different approach regarding sustainable individual polybags?

The plastic consumption is part of a growing consumption in China, which is not only the largest producer of plastic materials, 29% of the world's total production, but also has a plastic consumption that is greater than all the European countries combined (PlasticsEurope 2017).

4.3.1 Circular economy and waste management

China was an early adopter of the concept of circular economy and the central government of China proposed a national policy in 2002 towards a sustainable development and a circular economy. This has been implemented and further developed in several pilot areas in China (Su, Heshmati, Geng & Yu 2013). This will enable them to tackle the pollution and other environmental problems in the country, but also improve the efficiency of materials and energy use. Circular economy is an area that has been utilized in different perspectives, and McDowall, Geng, Huang, Barteková, Bleischwitz, Türkeli, Kemp & Doménech (2017) propose several differences in the perspective of circular economy between China and Europe. China has an approach to enable a circular economy which is reflected by a greater concern of industrial production, pollution, water, and place. The circular economy policy is therefore set as a wider response to the rapid growth and industrialization and the environmental challenges that follows. The conception of circular economy in Europe has an environmental scope that is more narrow, and has its main focus on waste and resources. Two main differences in the conception of circular economy in Europe compared to China are that the aspect of pollution is regarded in a little extent, as well as the circular economy policies are also including the economic terms as resource efficiency potential to spur the competitiveness. Both regions can learn from each other, and a greater mutual understanding of the circular economy concept will enable greater collaboration possibilities between these great regions on our planet (McDowall et al. 2017).

The main end-of-life for solid waste in China are landfills, approximately 60 % of the solid waste ends up there according to Zhang Pin[1], who works in China for Purac, a Swedish company that focuses on solid waste treatment. This can be compared to Sweden where 0.7 % of the total household waste was destined for landfills in 2016, and it is only allowed to send waste there that cannot be treated in any other way. Sweden is mainly using the other waste management methods, incineration (waste to energy) (48.5 %), mechanical recycling (34.6 %) and organic recycling (16.2 %) (Avfall Sverige 2017). According to Zhang Pin[1], China is moving in the right direction though, for example many incinerators where built in 2017 and about 35 % of the solid waste was incinerated that year. In addition to this composting and anaerobic digestion facilities, i.e. organic recycling, are becoming more utilized, especially for food waste, manure and sludge. Incineration is not a solution in a circular economy due to

[1] Zhang Pin, works for Purac Environmental System Co,. Ltd in Beijing, China. Purac is a Swedish company that focuses on water- and solid waste treatment. E-mail correnspondance, Mars 14, 2018.

value-loss and greenhouse gas emissions as well as not keeping the materials in a circular system. Mechanical or organic recycling should be prioritized and developed in first hand for a circular economy, but comparing incineration to landfills, it is more environmentally friendly as incineration can give energy recovery (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016).

The domestic plastic waste in China are struggling to create an efficient and advanced collection, separation and recycling. This results in that the majority of plastics will end up in landfills and for incineration. The recycling of plastics in China can be divided into three categories which are: industrial recycling, agricultural recycling and household recycling. The industrial plastic waste recycling stream (pre-consumer) is fairly clean and has a consistent quality which is recycled directly by the producers or by other companies recovering the plastic waste. The situation for the other two categories is different, the agricultural plastic waste is relying on manual recycling and achieves the lowest recycling rate. The household recycling is sorted by the households and is then sold to private collectors, but the majority of the plastic waste that enters the household waste stream will end up in a landfill due to lacking technology and sorting, but also the cheap costs of disposing it that way. There is also a recycling sector that is wide-spread in China, the informal recycling sector. This sector consists mainly of poor and disadvantaged people who collect recyclable plastics from litter bins and landfills which they sell to reprocessing companies. These companies are usually part of the so-called “three non-enterprises” which stands for that there are no rules for operation, no standards for quality and no inspection. This creates an harmful environment for not only the workers but also for the people using the plastic products when reprocessed (Velis, C.A 2014). As Asia stands for more than 80 % of the global marine plastic littering, and China is the largest source of global plastic waste leakage, efficient strategies of collecting plastic waste and preventing plastic leakage into the environment are important to develop (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016; McKinsey & Company and Ocean Conservancy 2015).

On the 1st of January 2018, the Chinese government banned imports of certain plastics that was purposed to be recycled in China. This import of plastics has been an industry in play for many years, and it was estimated that approximately 8 million tons of plastic waste was imported in 2016. This plastic waste has not been homogenous, un-contaminated and non-toxic, which has contributed to a negative impact on the health of the people in China as well as negative impact on the environment. This ban will spur the domestic waste management and recycling companies to create a well-functioning waste management system for the collection and recycling of their own plastic waste. This will not only be spurred in China, but also in the countries that exports the plastic waste, e.g. in Europe (Balke 2018).

4.3.2 Utilization of bioplastics

More than 50 % of the global production of bioplastics are produced in Asia and a large part of the production is situated in China (European Bioplastics e.V. 2017a). The bioplastics produced in China is mainly exported to other countries such as the US, Australia and Europe, since the utilization of bioplastics in China is still fairly small. A barrier to enabling a greater bioplastic market within China is the costs of bioplastics, which is still too high for it to be economically viable for the buyers and possible users within the country. A main driver to a greater utilization of bioplastics in China is encouragement and support from the Chinese government. An example of this is a ban that was determined in June 2008, this ban was on production, selling and usage of conventional plastic shopping bags thinner than 0.025 mm in the whole of China. In addition to this there is a ban of free-of-cost conventional plastic shopping bags, meaning that all supermarkets and shops have to put a price on the bags for people wanting to buy them. This creates incentives for the producers and retailers to look into sustainable alternatives to the conventional plastic bag, were bioplastics could be an alternative (PackWebasia 2014). Some regions have even banned the use and production of conventional plastic bags entirely, as Jilin, a provenance in China, which then could spur other regions to follow and with that a possible greater utilization of bioplastics.

Bioplastics derived from the 1st generation feedstock, which could be used for the food and feed industry can be regarded as controversial as it should in first hand be used to feed the starving people in the world. Despite this, there are several countries in the world where there is an excess of food and much is wasted when not being able to store it. An example of this can be found in China, where there is such a big stockpile of corn in the capital of China, Beijing, that it could feed China’s 1.4 billion people for more than a year. The Chinese government is thinking that the overload of corn could be used to boost the PLA sector by using the corn as raw material and therefore boost the bioplastic market. This will however take money and time to follow through which may not provide a sufficient difference in reduction of the stockpile (Gu & Patton 2017).

According to Company 2, a global retail-company, individual polybags used by the major e-commerce companies in China are using biodegradable plastic as material, often a starch-based alternative. The choice of using biodegradable plastics can be a result of the ban on thin conventional plastic bags by the Chinese government. But, as mentioned earlier, this material is not a solution to the plastic littering due to that the biodegradable plastics that is commercially available today do not have a proper biodegradation in all natural environments. They will likely biodegrade to a greater extent in a shorter time than conventional plastics in natural environments, but the uncertainty of its biodegradation in nature’s many different environments is still high. With an underdeveloped waste management system, it will also increase the likelihood of a non-environmentally friendly end-of-life for the biodegradable plastics used. The rebound effect of using biodegradable plastics, regarding to all countries in the world, is that the action of littering could be presumed as more accepted, because the general public could think that it will biodegrade anyways. The fact that the major e-commerce companies in China are using biodegradable plastics contradicts from the fact that costs of bioplastics are too high for the users in China, as mentioned in PackWebasia (2014).

4.4 Costs

4.4.1 Bioplastics

A major barrier for utilizing bioplastics is the higher price-range in comparison to the conventional plastics and one reason to this is the low price on oil which results in low prices on many products based on oil. This makes it difficult for producers to find the financials required to shift to the usage of bioplastics. The bioplastic-market is growing despite this and it is estimated, as mentioned, by European Bioplastics e.V. (2017a) that the global bioplastics production capacity in 2022 will be approximately 2.44 million tonnes, which in 2017 was 2.05 million tonnes. This is still a small part of the total global plastic production which was 320 million tonnes in 2017. With increasing demand and greater production volumes it will be more economically feasible to produce bioplastics which will most likely result in reductions of the cost. Incentives and directives from governments, as for example carbon taxation, is also an important strategy to accelerate the bioplastic market and reduction of the costs for bioplastics. When the economy of scale of production, the conversion into bio-based products and logistics becomes more efficient and favorable the expectation is that the bio-based plastic prices will drop in the future (Van den Oever et al. 2017).

Bioplastics in general is more expensive than conventional plastics and this is often due to that the production and processing of bioplastics is more complex and requires more energy than conventional plastics. PHA is an example of a bio-based and biodegradable plastic that has been produced for many years, but still has too high costs as a barrier to reach commercialization. These high costs are related to the complicated bioprocessing which includes steps as sterilization, separation and slow growth of microorganisms (Chen & Jiang 2017). Bio-PE, which is reaching a greater utilization in the packaging industry is mainly provided globally by the petrochemical-company Braskem and the additional price-level of this bioplastic is +20-40 % compared to the fossil-based PE (Van der Oever et al. 2017).

An overview of the price level in 2016 for some bioplastics mentioned in this thesis provided by Van der Oever et al. (2017) can be seen in table 7 below. The price level in 2016 of some common fossil-based plastics can also be seen to get an overview of the additional costs of bioplastics.

Table 7. The price level in 2016 of some bioplastics and fossil-based plastics in euros/kg (Van der Oever et al. 2017).

Bioplastic	**Price level 2016 (Euros/kg)**
Bio-PE	+ 20 - 40 % to fossil-PE
PBAT	3.5
PHA	5
PLA	2
Starch blends	2-4
Fossil-based plastic	**Price level 2016 (Euros/kg)**
LDPE	1.25 - 1.45
PET	0.85 - 1.05
PP	1.00 - 1.20
PS	1.25 - 1.43
PVC	0.8 - 0.93

4.4.2 Recycled plastics

Barriers to enable growth in the market for recycled plastics are for example quality and sufficient volumes, but also the price level. The recycling process is an expensive and energy demanding process compared to other end-of-life options as landfills or incineration. This results in that the companies which recycles plastics needs to set a price on the recycled plastics to make the industry economically viable. As an example, according to European Commission (2018a) only two-thirds of the recycling business in France are profitable today. It is important for the recycling businesses to scale-up and modernize the recycling plants to make plastic recycling economically viable but still provide high quality recycled plastic resin. There is also a need for greater demands from buyers of recycled plastics to make the recycling companies more willing to recycle greater volumes of plastics. This could also reduce the costs for the overall recycling process and result in lower prices for recycled plastics (Company 11; Consultant/Scientist 1). The value of recycled plastics in general is 50-60 % of the corresponding virgin plastics, and this is due to, as mentioned, the lack in demand on recycled plastics on the market and lack in quality (European Commission 2018a; Material Economics 2018).

5. Key remarks from companies and consultants/scientists

This chapter provides an overview of what the views are on individual polybags, bioplastics, recycling and waste management from three perspectives: representatives from companies within the retail-industry active in Sweden and globally, companies within the waste management and recycling sector active in Sweden, and independent consultants/scientists within these areas active in Sweden with experience abroad. The material is collected by semi-structured interviews, e-mail correspondence and from public information.

An overview is provided below with the key remarks from the three different sectors and more detailed information from the respective company and consultant/scientist is found in chapter 10. Appendix.

5.1 Companies within the retail-industry:

- LDPE is the commonly used material for polybags
- Recycled plastic content has been utilized to some extent for master polybags. At least one company mentions that this recycled content is from pre-consumer plastic waste. Difficulties of using recycled content for polybags is mentioned, and this is due to an unwanted smell.
- Bio-based “drop-in” plastic is mentioned as a possible material alternative.
- Biodegradable plastics are seen as a negative material alternative by some companies. but are being used by others.
- A paper-based material could be a possible material alternative for some companies, but not for others. The possible lack in protective properties, transparency of the material and the uncertainty of if it is better from an environmental point of view are reasons that are mentioned as the negative aspects.
- Reducing their plastic waste and their use of polybags wherever possible is mentioned by several companies.
- A few companies has implemented solutions that reduces the amount of plastic waste and use of individual polybags. Master polybags, thinner polybags, polybands, packing in assortments and eliminating the use of the individual polybag by folding and tying it with raffia are some solutions.
- The requirement of transparency for the individual polybag and minimum protective requirement seems to be diverse within the retail-industry.

5.2 Companies within the waste management and recycling sector:

- Biodegradable plastics can be problematic and harmful for this sector. Needs clear labelling and communication of how to discard them, as well as a separate collection system.
- Bio-based “drop-in” plastics are not a problem, but the uncertainty of the environmental benefits and the communication of what kind of plastic it is to the general public is mentioned.
- The market for recycled plastics is hindered by a low price-level on virgin plastic material and difficulties to reach the same quality as virgin plastic. With incentives and demand, the recycled plastic market can grow.
- LDPE plastic bags could be collected, recycled and be used to produce new polybags. But, it is mentioned that the transparency and quality can be problematic to retain. Blending it with virgin plastic could then be necessary.

5.3 Independent consultants/scientists:

- Bioplastics in general are positive from an environmental point of view. This mainly due to moving away from the use of fossil-resources. The additional costs for production and additional price-level for customers are barriers for a greater utilization.
- Bio-based “drop-in” plastics are in the right direction and can be important for the bioplastic market. A plastic that can be mechanically recycled is in most cases best.
- Biodegradable plastics can be problematic due to that they require a certain environment to biodegrade properly and difficult for the general public to understand how to discard them. But, a positive thing in the long run and a possible ultimate solution for plastics. It is mentioned that they can be good for uncontrollable plastic waste streams that end up in nature, but also that the use of plastics that can be mechanically recycled is in most cases the best option.
- The increase of recycling plastics is important, but there are difficulties to mechanically recycle post-consumer plastic waste. These are often mixed and contaminated.
- The chemical recycling can be a good solution for mixed plastic waste that cannot be mechanically recycled, i.e. a last resort for plastic waste. High costs in the industry is a barrier for the chemical recycling.

There are a few areas where there is consensus between all sectors. Bio-based “drop in” plastics are seen as positive and an increased use of recycled plastics is also an area that the sectors agree on. There are also conflicts between the sectors, and this is mainly related to the biodegradable plastics. Some companies have utilized them and others will not, some say that they may be good for certain applications and others say they can be harmful for waste management and recycling as well as the environment.

6. Discussion

There are several aspects to take in consideration when aiming for sustainable individual polybags, but which strategy regarding materials and solutions is the way forward? A citation by Per Klevnäs, Material Economics (Statens Offentliga Utredningar 2017) states a strategy that this thesis supports and is promising for not only individual polybags, but for all packaging solutions:

"The recycling of plastics needs to be a central strategy, with an increasing share of bio-based plastics as a complement"

With this said, mechanical recycling in closed loops for individual polybags with LDPE as material can be an important next step to support. There are no closed loops in general municipal plastic recycling, and therefore will the polybags be mixed with other LDPE products which can result in a non-transparent colored plastic resin and contaminations that can result in an unwanted smell. With a well-functioning collection system for the individual polybags and other polybags with the same material and transparency used in the retail-industry, an increased homogeneity can be enabled and these problems can be overcome. A system where polybags (both individual and master) are collected at retailers is already applied to some extent among companies within the retail-industry, but this is only for the pre-customer stream. This system can be controlled to some extent, but regarding the individual polybags that reaches customers using e-commerce, the post-customer stream, there is no control. A collaboration between nearby (or possibly global) retail-companies that implements re-take and collection systems can be a possible solution to reach the volumes required to enable a closed loop recycling for polybags. The importance of a closed loop is that the polybags are taken care of and recycled in a sustainable way, which later can be used as material for similar products. This will retain its value, i.e. that the "new" polybags are made from recycled plastic which originate from similar products, which results in no "down-cycling" (Consultant/Scientist 3; Company 2; Company 11). To reach closed loop recycling for polybags, it will most likely require close communication and collaboration between all stakeholders in the value-chain, from the producers of the polybags to the waste management and recycling companies.

The discussion above concerns the material that is mainly used today, LDPE, and the possibility of using recycled LDPE, but there are other existing materials that could be applied for this application as well. From the findings of this thesis, the bio-LDPE is also a promising material alternative. The main reason for this is that it has the same chemical properties as the conventional LDPE, it is based on a renewable resource, it has the same recyclability as conventional LDPE and lowers the overall greenhouse gas emissions. This is a bioplastic and as mentioned in the chapter regarding bioplastics, 3.3, it is important to distinguish the differences between bioplastics. The biodegradable plastics is one sub-group of bioplastics, and the majority of these materials have a biodegradability in a certain specified environment. A biodegradable plastic should therefore not be chosen as a material to solve the plastic littering problem, as it will not biodegrade properly in all natural environments. They should be taken care of in separate collection streams for organic recycling to fulfill its purpose and be properly biodegraded. There is also a risk of lack in knowledge and communication regarding biodegradable plastics, which can result in contamination of the mechanical recycling stream. Until there is a biodegradable plastic that is biodegradable in all natural environments, bio-based as well as mechanical recyclable, this material alternative should not be chosen for the application of individual polybags.

A proposed material strategy towards sustainable individual polybags for the individual polybags that are discarded at the distribution centers and retailers (full control by the companies), can be seen in figure 21 below. This is also regarding to the individual polybags used in e-commerce in a country with a developed waste management system. Using recycled plastic content and complementing it with bio-based "drop-in" plastic can be possible to implement in the present industry. With this said, minimal usage of material and package wherever possible in the chain of transportation should be prioritized. When there is a bio-based and biodegradable plastic that is biodegradable in all natural environments and mechanically recyclable, it could possibly be a material alternative for the individual polybag.

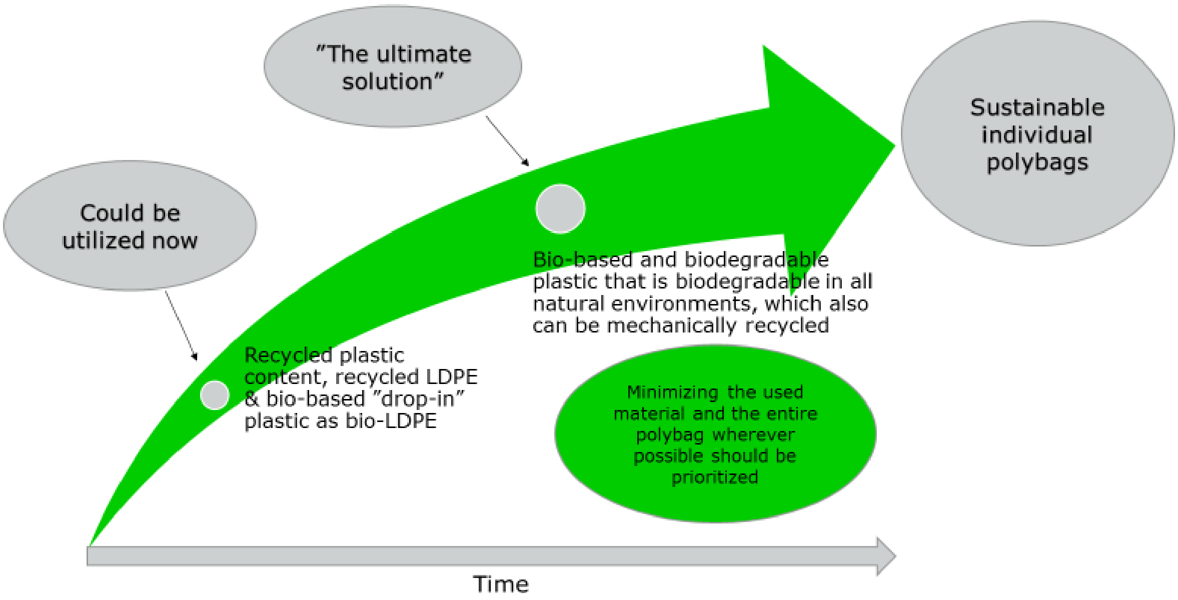

Figure 21. A proposed material strategy towards sustainable individual polybags for the individual polybags that are discarded at the distribution centers and retailers, and the ones used for e-commerce in a country with a developed waste management system.

As mentioned, companies that use individual polybags should prioritize to evaluate possible solutions which can reduce the amount of plastic material used. This could be enabled by for example using as thin bags as possible, implement folding guidelines that require minimal plastic material and making sure that no excess plastic material is used. It is also important to look into how to reduce the usage of the individual polybags wherever possible in the supply chain and also consider the end-of-life scenario, i.e. where will the individual polybag most likely end up. These are strategies towards a sustainable usage of individual polybags, but it is also important to make sure that the chosen packaging solution has the requirements needed to protect the products efficiently during transportation. The proposed material strategy above is determined with the aspect of the required material properties resembling LDPE. But, as mentioned there are companies that have implemented solutions that will not require these material properties, and this enables room for discussion of the required material properties for this packaging solution to safely transport the products.

For the post-customer individual polybag (e-commerce) there is a lack of control for the companies, and with an underdeveloped waste management infrastructure which increases the risk of discarding a conventional individual polybag in a non-environmental friendly way, the material choice is even more important. A material substitution would be a promising strategy to work towards to enable sustainable individual polybags in a country with an underdeveloped waste management such as China for the individual polybags used for e-commerce. Sourcing high quality recycled plastics that can be used is a possible solution and is an important strategy in a circular economy, but as Asia stands for more than 80 % of the global marine plastic littering and China is the largest source of global plastic-waste leakage, a material that biodegrades in nature would be preferable (World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company 2016: McKinsey & Company and Ocean Conservancy 2015). With this said, littering should never be promoted and communication and education is of importance of how to handle plastic waste and waste in general. The plastic littering can be connected to the behavioral patterns of the public, but also the possibilities to discard the waste in a sustainable way. A biodegradable plastic that is proven to be biodegradable in all natural environment, in all or most marine environments does not exist on the market today and well-functioning waste management infrastructure for biodegradable plastics does not either exist. Therefore should biodegradable plastics not be the preferred material alternative for individual polybags in China, or any other place in the world. A paper-based alternative with the necessary properties to protect the products should instead be investigated as a possible material for the application of the individual polybag used for e-commerce in China. By doing so, it is of importance that a LCA study is conducted to ensure possible trade-offs of energy consumption, water consumption and pollution during production of the material, end-of-life possibilities, recyclability and littering. LCA studies have shown that there are conflicts when comparing the environmental impact of a paper bag to a plastic bag, and therefore the trade-offs are important to discuss before choosing a material (Overcash 2007; Dahlgren & Stripple 2016; The Danish Environmental Protection Agency 2018). A material alternative that is paper-based and which has properties resembling plastics can be of interest for the application of the individual polybag for e-commerce in China is Paptic. A LCA study have shown that it has a lower carbon footprint than kraft paper and a lower use of fossil fuels when produced than LDPE with 30 % recycled content (Paptic Ltd. 2018).

The individual polybags discarded at the retailers and distribution centers, i.e. where the companies has full control over them, the same material strategy is proposed as for a country with a developed waste management system. With the circular economy strategy in mind in China as well as the recent ban on importing certain plastic materials destined to be recycled in China, the domestic waste management and recycling sector for plastics will likely have a rapid development. With this said, the companies can communicate and collaborate to make sure that their plastic waste is recycled in a sustainable way.

In figure 22 below, a proposed strategy with the currently used material and a proposed material alternative is shown. This is connected to if there is a developed or underdeveloped waste management system and if the individual polybags is used for e-commerce or to retailers/distribution centers. The proposed strategy concerns the proposed material alternative as well.

Figure 22. Proposed strategy with the currently used material and a proposed material alternative is shown. This is connected to if there is a developed or underdeveloped waste management system and if the individual polybags is used for e-commerce or to retailers/distribution centers.

The logistics and supply-chain within the retail-industry for transporting products all over the world are diverse, but sometimes also similar. Therefore there may be solutions that are applicable for some companies, but difficult to apply for other companies. This can be a reason for that the companies have slightly different strategies in chapter 5.1. The globalization of companies is a matter to take in consideration; a smaller local company with shorter transportations can possibly apply other solutions than a global company with transportations in many different countries and environments.

At least one of the companies within the retail-industry is looking into using a tissue-bag for the application of the individual polybag, which is tissue-paper but with “stronger” properties. As this material is not fully transparent, the question arises of the requirement of transparency for the application of the individual polybag. Is this really a requirement in the supply chain and for logistics within the retail-industry? As mentioned in chapter 4.1.3, a company has utilized folding and tying techniques which has reduced their polybag usage up to 74%, which raises the question of the required protective properties for the transportation of products. As there was no personal contact with this company and therefore no specific questions could be asked directly to the company of how this solution works in more detail, as well as no further information could be found, there is an uncertainty of exactly how this solution is utilized. But, according to Sarah (2017), the products that arrived when ordering online was folded and tied with raffia as the previously mentioned solution. “What are the minimum protective requirements to transport the products safely and deliver them unharmed?” and “Is the individual polybag as it is used today really necessary for a safe transportation of the products?" are important questions that requires further evaluation for the companies within the retail-industry. A re-evaluation of the material requirements for the individual polybag is in place. To evaluate this a thorough analyzation is required of the supply-chain and logistics when transporting products both to retailers and for e-commerce.

Material alternatives, recycling and solutions that could reduce the material used or reduce the use of the entire package has been discussed, but what should be prioritized? With a circular economy in mind, the following hierarchy should be followed for conventional individual polybags and all the proposed materials (Odegard, Nusselder, Roos Lindgren, Bergsma. & de Graaff. 2017):

1. Reduce – Less material and products will reduce the size of the economy, i.e. the amount of materials in system.
2. Re-use – Decrease the dependence on new materials and products.
3. Recycle – Reduces need for virgin feedstock for new products and therefore contributes to a lower emission of greenhouse gases.

7. Conclusions

To conclude how to reach sustainable individual polybags several aspects has to be taken into consideration. The chosen material should be applicable in a circular economy, therefore it should be recyclable, decoupled from fossil-resources by using feedstock from renewable resources or recycled content, and also fulfill the protective properties required for transporting the products unharmed. From the findings of this study, bio-LDPE and recycled LDPE are two materials that fulfill these requirements and therefore these are proposed as sustainable material alternatives for individual polybags. In the area of bioplastics, caution should be taken due to possible misconceptions that can lead to negative impacts on the environment. More research is required regarding biodegradable plastics to be utilized in a sustainable way for the application of individual polybags. This regarding to the aspects of the biodegradability in nature's many different environments, the waste management, and proper labelling that communicates to the consumers of how to handle the waste.

There are possibilities to reduce the amount of used material as well as almost the entire use of the individual polybag, and this should be evaluated in first hand and prioritized before a material substitution. Using thinner polybags, master polybags, smaller size polybags, folding and tying the garment with raffia, and polybands are examples of this. This may not be possible to implement in all companies in the industry, but some companies have utilized some of these solutions and therefore the possibility should be evaluated.

Closed loop recycling is a strategy to work towards for the individual polybags, and to do this it will require efficient re-take and collection systems. The individual polybags used for e-commerce can be re-taken to the retailers by communicating to and creating more incentives for the customer to return it. This can be done by giving bonus-points or vouchers for a certain amount of individual polybags returned to the retailers. This waste stream of individual polybags together with the pre-customer polybags that reaches the retailers directly can be collected and bailed. These can be sent for mechanical recycling and converted into new individual polybags in a closed loop recycling.

China has an underdeveloped waste management system and is a large contributor to plastic leakage into the environment. Therefore would a material that biodegrades in nature which has the required protective properties be preferable for the application of individual polybags used for e-commerce in China, where there is a lack of control for the companies. With that said, littering should never be promoted and a biodegradable plastic that biodegrades in a reasonable time in all natural environments do not exist on the market today. Therefore should a paper-based alternative with required protective properties be looked into as a material alternative for the conventional individual polybags used in e-commerce. By doing so it is of importance to discuss trade-offs of the environmental impact. As there is full control by the companies for the individual polybags that reaches the retailers and distribution centers, recycled plastic content and bio-LDPE should be a material alternative for these individual polybags in China as well. Utilization of efficient re-take and collection systems for the presently and future used individual polybags in China is essential. This concerning all the materials used by the retail-industry, e.g. LDPE and starch-based biodegradable plastic. It is especially important considering the aspect that the likelihood of a less environmentally friendly end-of-life option as well as leakage into nature is greater in China than in a country with a developed waste management system such as Sweden.

8. Further Studies

This thesis has provided an understanding and overview of the opportunities and challenges to enable a sustainable use of individual polybags. But, there are several areas that can be investigated in more detail and are proposed as further studies below:

- A detailed analysis of the logistics and supply chain for specific companies in the retail-industry should be conducted. This to acquire the knowledge of what the minimum protective requirement a packaging solution needs for the garments and products to be transported safely and unharmed. This concerning both e-commerce and transportation to retailers. Which mechanical and physical properties do the material require? Is the conventional individual polybag really necessary?

- Biodegradable plastics are not a solution to plastic littering today, but can give an additional waste stream that could be treated via the organic recycling. More research should be done of how the waste management infrastructure for biodegradable plastics is developed for the future with aspect of the increasing market of biodegradable plastics.

- When choosing a specific material the costs are a factor that will be a trade-off for the companies, and therefore a closer analysis of the costs for utilizing different materials should be done.

- Large e-commerce companies in China as Alibaba and JD.com has utilized drones as an innovative transportation method (Xinhua 2017). This could enable other possibilities in case of packaging materials as well as transportation and should be investigated further.

- An analysis between other countries with diversifying waste management and recycling system can be done regarding different approaches towards sustainable individual polybags or other packaging solutions.

- A back-casting of the strategies towards sustainable individual polybags would be of interest to identify which steps that are necessary to take to reach the goal.

9. References

Accinelli, C., Saccà, M., Mencarelli, M. & Vicari, A. (2012). Deterioration of bioplastic carrier bags in the environment and assessment of a new recycling alternative. *Chemosphere*,, 89(2), p. 136-143. doi:10.1016/j.chemosphere.2012.05.028

Alvehus, J. (2013). *Skriva uppsats med kvalitativ metod: En handbook*. Stockholm: Liber.

Avfall Sverige. (2017). *Svenska Avfallshantering "2017.* https://www.avfallsverige.se/fileadmin/user_upload/Publikationer/svensk_avfallshantering_2017.pdf

Balke, V. (2018). *How China's ban of plastic waste imports can help us beat pollution.* https://www.unenvironment.org/news-and-stories/story/how-chinas-ban-plastic-waste-imports-can-help-us-beat-pollution [2018-06-10]

Braskem. (n.d.). *I'M Green™ Polyethylene.* http://www.braskem.com/site.aspx/Im-greenTM-Polyethylene [2018-02-15]

Business Sweden. (2017). *Circular Economy in China – Opportunities For Companies.* https://www.business-sweden.se/contentassets/c5d6f8e5acc041aca5f7187920559930/circular-economy-in-china.-report-v.1.0_final.pdf

Caputo, L. (2016). PRANA BECOMES A POLYBAG HERO. *Outdoor Industry Association*, November 4. https://outdoorindustry.org/article/prana-becomes-a-polybag-hero/

CE Delft. (2017). *Biobased Plastics in a Circular Economy – Policy suggestions for biobased and biobased biodegradable plastics.* https://www.cedelft.eu/en/publications/2022/biobased-plastics-in-a-circular-economy

Cefur. (2016). *Guide för bioplaster: från tillverkning till återvinning.* https://www.ronneby.se/download/18.2375207615dac0245ae3fc9c/1502367767253/Guide%20f%C3%B6r%20Bioplaster%20(3%20MB).pdf

Chen, G. & Jiang, X. (2017). Engineering bacteria for enhanced polyhydroxyalkanoates (PHA) biosynthesis. *Synthetic and Systems Biotechnology*, 2(3), p. 192-197. doi:10.1016/j.synbio.2017.09.001

Cohen, N. (2014). *Patagonia's Plastic Packaging – A study on the challenges of garment delivery.* https://www.patagonia.com/blog/2014/07/patagonias-plastic-packaging-a-study-on-the-challenges-of-garment-delivery/

Cronin, P., Ryan, F. & Coughlan, M. (2008). Undertaking a literature review: a step-by-step approach. *British Journal of Nursing*, 17(1), p. 38-43. doi:10.12968/bjon.2008.17.1.28059

Dahlgren, L. & Stripple, H. (2016). *A comparative LCA study of various concepts for shopping bags and cement sacks.* Stockholm: IVL Swedish Environmental Research Institute 2016. https://www.billerudkorsnas.com/globalassets/billerudkorsnas/sustainability/lca-and-epd/lca-for-packaging-concepts--billerudkorsnas-report-u5732-ivl-2016.pdf

DIN CERTCO. (n.d.). *Biobased products.* http://www.dincertco.de/en/dincertco/produkte_leistungen/zertifizierung_produkte/umwelt_1/biobasierte_produkte/biobasierte_produkte_mehr_nachhaltigkeit.html [2018-06-11]

E4tech, LCAworks, Macedo, I., Seabra, J. (2013). *Environmental assessment Braskem's biobased PE resin – Summary of the life cycle assessment, land-use change and water footprint reports.* http://www.braskem.com.br/Portal/Principal/Arquivos/ModuloHTML/Documentos/1204/20131206-enviro-assessment-summary-report-final.pdf

EcoEnclose. (n.d.) *The Truth About Paper vs Plast (and Bio-plastic).* http://www.ecoenclose.com/paper-vs-plastic-vs-bioplastic-s/26031.htm [2018-03-06]

European Bioplastics e.V. (2015). *Home composting of compostable bioplastics*. http://www.plastics.org.nz/images/documents/PDFs/EUBP_pp_home_composting.pdf

European Bioplastics e.V. (2016a). *Position of European Bioplastics – Marine Litter*. http://docs.european-bioplastics.org/2016/publications/pp/EUBP_pp_marine_litter.pdf

European Bioplastics e.V. (2016b). *Bioplastics – furthering efficient waste management*. http://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_end-of-life.pdf

European Bioplastics e.V. (2017a). *Bioplastics market data 2017*. http://docs.european-bioplastics.org/publications/market_data/2017/Report_Bioplastics_Market_Data_2017.pdf

European Bioplastics e.V. (2017b). *Accountability Is Key – Environmental Communication Guide for Bioplastics*. http://docs.european-bioplastics.org/publications/EUBP_Environmental_communications_guide.pdf

European Bioplastics e.V. (2018). *Bioplastics facts and figures.* http://docs.european-bioplastics.org/publications/EUBP_Facts_and_figures.pdf

European Commission. (2018a). *A European Strategy for Plastic in a Circular Economy.* http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN

European Commission. (2018b). *The impact of the use of oxo-degradable plastic, including oxo-degradable plastic cariier bags, on the environment*. http://ec.europa.eu/environment/circular-economy/pdf/oxo-plastics.pdf

Farah, S., Anderson, D. & Langer, R. (2016). Physical and mechanical properties of PLA, and their function in widespread applications – A comprehensive review. *Advanced Drug Delivery Reviews*, 107, p. 367-392. doi:10.1016/j.addr.2016.06.012

Gill, P., Stewart, K., Treasure, E. & Chadwick, B. (2008). Methods of data collection in qualitative research: interviews and focus groups. *British Dental Journal*, vol. 204(6), p. 291-295. doi:10.1038/bdj.2008.192

G-STAR RAW. (n.d.). *Sustainable Operations.* https://www.g-star.com/en_gb/archive/about-us/responsibility/sustainable-operations [2018-03-18]

Gu, H. & Patton, D. (2017). *With plastic bags and plates, China tries to cure its corn hangover.* https://www.reuters.com/article/us-china-corn-stockpile/with-plastic-bags-and-plates-china-tries-to-cure-its-corn-hangover-idUSKBN15A36I [2018-04-19]

Hedin, A. (2011). *En liten lathund om kvalitativ metod med tonvikt på intervju.* https://studentportalen.uu.se/portal/portal/uusp/student/filearea?uusp.portalpage=true&entityId=88018&toolAttachmentId=108197&toolMode=studentUse&mode=filearea108197 [2018-06-10]

Hemköp. (n.d.). *Hemköps pantbara plastpåsar*. https://www.hemkop.se/artikel/pantpasen [2018-05-10]

Material Economics. (2018). *Ett värdebeständigt svenskt materialsystem.* http://materialeconomics.com/reports/las-mer

McDowall, W., Geng, Y., Huang, B., Bartekoá, E., Bleischwitz, R., Türkeli, S., Kemp, R. & Doménech, T. (2017) Circular Economy Policies in China and Europe. *Journal of Industrial Ecology,* 21(3), p. 651-661. doi:10.1111/jiec.12597

McKinsey & Company and Ocean Conservancy. (2015). *Stemming the Tide: Land-based strategies for a plastic-free ocean.* https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability%20and%20resource%20productivity/our%20insights/saving%20the%20ocean%20from%20plastic%20waste/stemming%20the%20tide%20full%20report.ashx

Nesic, A. & Seslija, S. (2017). The influence of nanofillers on physical-chemical properties of polysaccharide-based film intended for food packaging. *Food Packaging*, 7, p. 637-697. doi:10.1016/B978-0-12-804302-8.00019-4

Netto. (n.d.). *PLASTIK HØRER IKKE TILL I NATUREN*. https://netto.dk/ansvar/plastik/ [2018-05-10]

Niaounakis, M. (2015). *Biopolymers: Applications and Trends.* Oxford: Elsevier Inc.

Odegard, I., Nusselder, S., Roos Lindgren, E., Bergsma, G. & de Graaff., L. (2017). Biobased Plastics in a Circular Economy – Policy suggestions for biobased and biobased biodegradable plastics. CE Delft: Delft. https://www.ce.nl/publicaties/2021/biobased-plastics-in-a-circular-economy

Ong, S., Chee, J. & Sudesh, K. (2017). Degradation of Polyhydroxyalkanoate (PHA): a Review. *Journal of Siberien Federal University. Biology 2017*, 10(2), p. 211-225. doi:10.17516/1997-1389-0024

Overcash, M. (2007). *Life cycle assessment for three types of grocery bags – recyclable plastic; compostable, biodegradable plastic; and recycled, recyclable paper.* https://plastics.americanchemistry.com/Life-Cycle-Assessment-for-Three-Types-of-Grocery-Bags.pdf

PackWebasia. (2014). *Regulations for the bioplastics industry in China.* http://www.packwebasia.com/index.php/sustainable-packaging/environmental-legislation/3338-regulations-for-the-bioplastics-industry-in-china [2018-02-22]

Palm, E. & Svensson Myrin, E. (2018). *Mapping the plastics system and its sustainability challenges. Lund University. Department of Environmental and Energy Systems Studies.* http://lup.lub.lu.se/search/ws/files/40307312/Mappning_the_plastics_system_and_its_sustainability_challenges.pdf

PantaPåsen. (n.d.). *Panta din förpackning.* http://www.pantapasen.se/ [2018-05-10]

Paptic Ltd. (2018). *Environmental Assessment of PAPTIC Material*. www.paptic.com

PlasticsEurope – Association of Plastics Manufacturers. (2017). *Plastics – the Facts 2017.* https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

Plastics Magazine. (2012). *Lots More Choices in PHA Bioploymers, 28th December.* https://www.ptonline.com/articles/lots-more-choices-in-pha-biopolymers [2018-02-15]

PrAna. (n.d.). *Polybag Reduction – THINKING OUTSIDE THE BAG*. https://global.prana.com/about-us/sustainability/polybag-reduction.html [2018-02-20]

Ragaert, K., Delva, L. & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste Management*, 69, p. 24-58. doi:10.1016/j.wasman.2017.07.0444

Sarah. (2017). Sustainable clothing for conscious consumers with prAna (+ coupon for you!), *Vegan Chickpea*, [blogg]. https://veganchickpea.com/sustainable-clothing-conscious-consumers-prana/ [2018-05-30]

Sashiwa, H., Fukuda, R., Sato, S. & Nakayama, A. (2018). Microbial Degradation Behavior in Seawater of Polyester Blends Containing Poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBHHx). *Marine drugs*, 16(1). doi:10.3390/md16010034

SEKAB. (n.d.). *Närodlad Plast – är det möjligt?* [2018-05-15]

Sen, K.S., Raut, S. (2015). Microbial degradation of low density polyethylene (LDPE): A review. *Journal of Environmental Chemical Engineering*, 3(1), p. 462-473. doi:10.1016/j.jece.2015.01.003

Shahlari, M.& Lee, S. (2012). Mechanical and Morphological Properties of Poly(butylene adipate-co-terephtalate) and Poly(lactic acid) Blende With Organically Modified Silicate Layers. *Polymer Engineering & Science*, vol. 52.

Singh, J. & Cooper, T. (2017). Towards a sustainable business model for plastic shopping bag management in Sweden. *The 24th CIRP Conference on Life Cycle Engineering*, 61, p. 679-684. doi:10.1016/j.procir.2016.11.268

Song, J.H., Murphy, R.J., Narayan, R. & Davies, G.B.H. (2009). Biodegradable and compostable alternatives to conventional plastics. *Philos Trans R Soc Lond B Biol Sci.*, 364(1526), p. 2127-2139. doi:10.1098/rstb.2008.0289

Statens Offentliga Utredningar - Rundabordssamtal med Vetenskapliga Rådet för Hållbar Utveckling. (2017). *Plast – en drivkraft i den cirkulära ekonomin*. http://www.sou.gov.se/wp-content/uploads/2016/02/Plast-rapport-fr%C3%A5n-rundabordssamtal-15dec17.pdf

Su, B., Heshmati, A., Geng, Y. & Yu, X. (2013). A review of the circular economy in China: moving from rhetoric to implementation. *Journal of Cleaner Production*. 42, p. 215-227. doi:10.1016/j.jclepro.2012.11.020

Sustainable Packaging Coalition. (2011). *Definition of Sustainable Packaging*. https://sustainablepackaging.org/wp-content/uploads/2017/09/Definition-of-Sustainable-Packaging.pdf

Szaky, T. (2014). Finding recycling solutions for commercial packaging waste. *Packaging Digest*, May 28. http://www.packagingdigest.com/sustainable-packaging/finding-recycling-solutions-commercial-packaging-waste140528

TerraCycle. (n.d.). *Recycling in partnership with The North Face*. https://www.terracycle.com/en-US/brigades/tnf#how-it-works [2018-03-07]

The Danish Environmental Protection Agency. (2018). *Life Cycle Assessment of grocery carrier bags*. https://www2.mst.dk/Udgiv/publications/2018/02/978-87-93614-73-4.pdf

The North Face. (n.d.). *Sustainability – Waste - Packaging* https://thenorthface.com.au/innovation/sustainability/sustainability-waste [2018-05-09]

TIPA. (2017). *Portfolio*. https://tipa-corp.com/wp-content/uploads/TIPA-A5-catalog-05-2017-screen.pdf [2018-02-27]

Tokiwa, Y., Calabia, B., Uqwu, C. & Aiba, S. (2009). Biodegradability of Plastics. *Int. J. Mol. Sci.*, 10(9), p. 3722-3742. doi:10.3390/ijms10093722

TÜV AUSTRIA Group. (n.d.). *OK BIOBASED and USING LOGOS – Frequently Asked Questions*. http://www.okcompost.be/data/pdf-document/Doc%2031e-a%20-%20Using%20Logos%20OK%20biobased%20(Recovered)%20tuv.pdf

UN Environment. (2017). *UN declares war on ocean plastic*. https://www.unenvironment.org/news-and-stories/press-release/un-declares-war-ocean-plastic [2018-02-23]

UNEP. (2015). *Biodegradable Plastics and Marine Litter. Misconceptions, concerns and impacts on marine environments. United Nations Environment Programme (UNEP), Nairobi.* http://hdl.handle.net/20.500.11822/7468

Van der Oever, M., Molenveld, K., Van der Zee, M & Bos, H. (2017). *Bio-based and biodegradable plastics – Facts and Figures*. doi:10.18174/408350

Velis, C.A. (2014). *Global recycling markets – plastic waste: A story for one player – China*. ISWA Globalisation and Waste Management Task Force. doi: 10.13140/RG.2.1.4018.4802

Vlugter, J. (2017). *Scaling Recycled Plastics Across Industries*. M.Sc Candidate, Strategic Product Design. Delft: Delft University of Technology. https://www.ellenMacArthurfoundation.org/assets/downloads/ce100/Scaling-Recycled-Plastics-across-Industries.pdf

World Commission on Environment and Development. (1987). *Our Common Future.* Oxford; New York: Oxford University Press.

World Economic Forum, Ellen MacArthur Foundation and Mckinsey & Company. (2016). *The New Plastics Economy – Rethinking the future of plastics*. http://www.ellenMacArthurfoundation.org/publications

Xinhua. (2017). *Economic Watch: Cracking China's e-commerce packaging puzzle*. http://www.xinhuanet.com/english/2017-11/10/c_136743347.htm [2018-05-22]

Companies and consultants/scientists:

Company 1 – A global company in the retail-industry (confidential) (communication by phone, February 15, 14.30-15.00)

Company 2 - A global company in the retail-industry (confidential) (communication by physical meeting, Mars 21, 9.30-10.30 and e-mail correspondence)

Company 3 - A global company in the retail-industry (confidential) (communication by secondary source and collected by e-mail correspondence)

Company 4 - A global company in the retail-industry (confidential) (communication by e-mail correspondence)

Company 5 - A global company in the retail-industry (confidential) (communication by e-mail correspondence)

Company 6 – G-Star Raw, a Dutch clothing company (public information)

Company 7 – The North Face, an American outdoor product company (public information)

Company 8 – Patagonia, Inc., an American outdoor clothing company (public information)

Company 9 – prAna, an American lifestyle clothing company (public information)

Company 10 – A Swedish recycling company with global business (confidential) (communication by phone, Mars 27, 9.00-10.00)

Company 11 – A Swedish waste management and recycling company (confidential) (communication by phone, February 28, 10.30-11.30)

Company 12 – A Swedish waste management and recycling company (confidential) (communication by physical meeting, February 15, 9.00-10.00)

Consultant/scientist 1 – Consultant within plastics, recycling and sustainability (confidential) (communication by phone February 20, 9.00-10.00)

Consultant/scientist 2 – Scientist within polymers and biopolymers (confidential) (communication by physical meeting, Mars 26, 10.00-11.00)

Consultant/scientist 3– Consultant and scientist within packaging, polymers and biopolymers (confidential) (communication by physical meeting, Mars 21, 13.00-14.00)

10. Appendix

In 10.1-10.3 below, information from the respective companies and consultants/scientists is provided. This data is collected by semi-structured interviews, e-mail correspondence and public information.

10.1 Companies within the retail-industry

Company 1 (interview) – Using LDPE as material for polybags. This global retail-company is about to develop a sustainable packaging strategy and the individual polybag is a great part of this strategy. They have recently started to use individual polybags that are thinner than before, which means less material is used for every polybag. The thinner polybags have fulfilled the protective requirements needed for the application. Another possibility, but is not utilized, to use less material is to educate the warehouse workers to fold the garments more efficiently that will result in smaller individual polybags and less plastic material. They are also looking to find solutions to use less amounts of individual polybags and looking into where they really are necessary in the supply chain. They are focusing on sourcing recycled plastic content for their individual polybags, and are still looking into suppliers that can provide high quality recycled plastics with enough volumes to meet their demand. The suppliers that they talked to initially say that they have the enough volumes of recycled plastics to cover the demand. The second option of material that they are looking into for individual polybags is bio-based LDPE, which is regarded as a "drop-in" bioplastic. Biodegradable plastics is not an option due to its uncertainty of biodegradation in natural environments. Paper is neither an option due to that it does not fulfill the protective properties that are needed for the application, as for example lack of resistance against water vapor which can damage the products during transportation. The individual polybag would also need to be transparent due to scanning logistics throughout the supply chain and transportation.

Company 2 (interview and e-mail correspondence) – Using LDPE as material for polybags. This global retail-company are mainly looking into avoiding the usage of the polybag wherever possible in the supply chain, both the master polybag and the individual polybag. They are using recycled content in the master polybags and this recycled plastic is from pre-consumer plastic waste. They want to utilize recycled plastic content in master- and individual polybags made from both pre- and post-consumer plastic waste. They are negative to using biodegradable plastics because it can be difficult to know how to handle it in a sustainable way. Bio-based "drop-in" plastic could maybe be used, but it still contributes to non-degradable plastic waste in the same way as conventional plastic which makes it uncertain. A material alternative that possibly could replace the individual polybag is paper envelopes or tissue paper-bags (the same requirement of transparency as the conventional individual polybag may not be needed). The tissue-bag is about to be tested for e-commerce instead of the conventional individual polybag, this mainly due to reduce the plastic waste but also to gain the biodegradable property. A LCA study has not been done regarding this possible transition. A way of reducing the amount of plastic used when transporting to retailers is by using a polyband, see figure 16, for assortments instead of individual polybags and also by using master polybags. The thickness of the polybag is determined concerning what the garments and products demand. They use durable and re-usable containers, see figure 17, for transportation from distribution centers to retailers, but the polybands and polybags are not removed until they reach the retailers. They provided the information concerning that large e-commerce companies in China are using a biodegradable plastic as material alternative for individual polybags, often a starch-based biodegradable plastic.

Company 3 (interview by secondary source) – This global retail-company is looking into reducing the thickness of the polybags as well as reducing the utilization of them. They use recycled plastic for their master polybags and are looking into how to create a closed loop of these. For the individual polybags that reaches the customer by e-commerce, recycled content is problematic due to that the plastic often smells. This results in that they cannot use recycled plastic for packaging that reaches the customers directly, but they are working towards implementing recycled plastic content for their packaging solutions. They have not taken any decisions about using paper instead of plastic, because they are not certain of if it would be better from an environmental perspective as well as concerned about the deforestation. They are not using any bioplastics and are not focusing on doing so right now, the focus is on recycled plastic content.

Company 4 (e-mail correspondence) – They use LDPE as material for polybags. They use polybags for all of their garments, but use a master polybag for retail assortments (same sizes, collections etc.) and individual polybags for e-commerce. They have not utilized polybags with recycled content or looked into utilizing other materials than LDPE, but as mentioned, they have reduced their amount of polybags by packing assortments in master polybags. They collect the polybags at the retailers, which are taken care of by the municipal waste management and are destined for mechanical recycling. Their biggest concern from an environmental perspective of using conventional individual polybags is the amount of plastic waste that it generates and that it is made from virgin fossil resources.

Company 5 (e-mail correspondence) – They use LDPE as material for polybags. Size sets of garments are transported together in a master polybag to retailers, but for e-commerce they are individually packed in individual polybags. The polybags that are discarded at distribution centers and retailers is mechanically recycled, but for e-commerce they have no control and customer will have the responsibility of discarding the individual polybag for recycling. Not using recycled plastic content for their polybags, but for their shopping bags they use a mix of recycled and bio-based LDPE. In general they are looking for bio-based and/or recycled materials that are recyclable. They are constantly looking into sustainable solutions for packaging and minimizing the amount that is used and a long term goal is to have recycling systems for all their main waste streams, which includes plastic packaging. Their biggest environmental concern of using conventional individual polybags is the resources used when producing them, as water, energy and chemicals, but also the lack of control of recycling when reaching customers by e-commerce.

Company 6 (collected from public information) – The Dutch clothing company G-Star Raw is testing compostable and biodegradable polybags since 2015, and if this is successful they will identify how they could replace all the conventional polybags. Their aim is to contribute to the reduction of plastic pollution and want to ban single-use and non-durable plastics that are unnecessary plastics in all their operations (G-STAR RAW n.d.).

Company 7 (collected from public information) – The outdoor clothing and equipment supplier The North Face has a polybag recycling program in collaboration with the recycling company TerraCycle. This to ensure that the polybags are recycled and not be destined for landfills. The North Face collects the used polybags at retailers when unpacking the products and sends them for recycling to TerraCycle (Szaky 2014; TerraCycle n.d.). They evaluated alternatives to the conventional polybags in 2008, by looking into bags made from renewable materials, eliminating the bags and substituting reusable bags. These alternatives did not fulfill the strict quality control and protection requirements (The North Face n.d.)

Company 8 (collected from public information) - Patagonia encourages customers to mail the polybags back to their service center or drop them off at their retail stores. They have done a study, mainly regarding polybags, to evaluate how they can reduce the plastic use in their supply chain. This was spurred to be done by disappointments expressed by customers due to the large amounts of plastic waste that was generated. The study concluded amongst others that paper mailers cannot be used, a reduction of size of the polybags should be done and sourcing of recycled polybags should be done. They are looking into of implementing several alternatives of reducing the plastic waste within their system in the future (Cohen 2014).

Company 9 (collected from public information) – PrAna is an outdoor apparel company that has reduced their polybag usage by 74 percent by 2016 and from 2011 to 2016 has eliminated up to 10.6 million+ polybags from the negative end-of-life option, landfills. This was done by utilizing a folding technique and tying it with raffia ribbon which resulted in that the products was unharmed and in great shape during the transportations. They have a polybag reduction initiative and want to inspire as well as push the industry towards environmental-friendly business models (Caputo 2016; prAna n.d.).

10.2 Companies within the waste management and recycling sector

Company 10 – Biodegradable plastics are not positive in the current industry from a recycling point of view. Talking for the whole sector, they are harmful for the mechanical recycling streams. For certain specified applications, as for example one-time use cutlery it could maybe be a good solution, but even in this case the question remains, will it be fully biodegradable in all different environments? Negative to utilize biodegradable plastics in common plastic products, such as shopping bags etc. More positive to bio-based drop-ins, but important to communicate that it will have the exact same properties as conventional plastics. Skeptical to if it really is more environmentally friendly with bio-based drop-ins compared to the conventional alternative, is all aspects taken in consideration in a LCA study? Does it compete with the food-industry and are the plantations managed in a sustainable way? The main barrier for the utilization of drop-ins are the additional price-level.

The price-level for virgin fossil-based plastics is low, which is a barrier for utilization of recycled plastics. The costs are high for waste management and recycling companies to collect, sort, shred, wash etc., and this makes it difficult to reduce the price for recycled plastics further. There need to be incentives and demands on the producers to use recycled plastic in their products, which will result in a greater utilization. In turn, this will increase the volumes of collected and recycled plastics and likely result in a decreased price for recycled plastics. The design of plastic packaging is essential to increase the recycling possibility and this has to start from the producers. Plastic packaging with for example several plastic layers, strong colors or additives will most likely not be able to be mechanically recycled and therefore they will end up for incineration.

Closed-loop systems is a good strategy, but the mindset from companies of wanting the exact same plastic that was used in their previous product is wrong. The important aspect should be that the plastic is properly recycled and the same or similar plastic product is delivered back made from high quality recycled plastic. As for transparent LDPE bags, it is difficult to contain the same transparency when gone through a recycling-cycle. But, should that really be necessary for the application of polybags? A new standard of this kind of packaging solution, in aspects of transparency should maybe be discussed.

Company 11 – From a mechanical recycling point of view, biodegradable plastics are not a good option. This is due to that there is an uncertainty of how long the plastic has been degraded, therefore it may not be able to be mechanically recyclable. Some biodegradable plastics is biodegradable in certain controlled environments, as industrial composting. The problem is that there are no such facilities (in Sweden) and no separate collection system for these. If they end up in the plastic packaging waste stream they are sorted away (in most cases) and then end up for incineration, which is not the most sustainable way. Some biodegradable plastics, the oxo-degradable, cannot be detected and sorted away in the mechanical recycling stream, and therefore they can contaminate the recycled plastic material and result in bad quality of the recycled plastic. The oxo-degradable plastics do not exist on the Swedish market, but other countries in Europe and the rest of the world suffers from this kind of plastic. The bio-based drop-in is more positive from a recycling point of view, and will increase the next few years. Bio-based drop-ins are good from an environmental point of view as well, but recycled conventional plastic is even better from an environmental point of view.

The demand for recycled plastic is far too low, and this results in a less collection and recycling of several plastic fractions that technically can be collected, sorted and mechanically recycled. Another barrier for a greater utilization of recycled plastics are that the price-level on virgin plastic material is low, therefore there is no economic incentive for the producers to use recycled plastic over virgin plastic. If the price on for example conventional PE is raised and then the demand for recycled plastics is raised, there would be incentives from the waste management companies to sort mixed plastic waste even more thoroughly and result in greater amounts of recycled plastics. This will in turn result in less plastics that end up for incineration. Plastic packaging can be mechanically recycled and be produced to a similar valuable product, i.e. no down-cycling. For transparent LDPE plastic packaging, there is a possibility to collect, recycle and produce new LDPE plastic bags. Transparent bags are also more economically valuable than colored. As the polymer chains gets shorter when gone through a recycling cycle, some virgin plastic can be required to be blended with the recycled plastic to reach the required properties. If print and symbols is used on the plastic, one should choose a water soluble alternative, this to enable an efficient washing. If a solvent based ink is used it will follow through the recycling process and color the plastic, which in turn will result in a less valuable plastic.

Company 12 – Bioplastics can affect the sector negatively over the next few years and is of big concern for many in the sector. Have never met a producer or designer of bioplastic packaging that have been interested to know about how it will be taken care of down the value chain, i.e. when the bioplastic package is discarded and left to be taken care of by the waste management companies. The percentage of bioplastics in the plastic waste have been fairly low and therefore not problematic. But with the increasing utilization of bioplastics it can become problematic for the recyclers, mainly the biodegradable plastics. This kind of bioplastic requires clear labels of how to discard it properly and probably a separate collection stream. The general public have problems separating the plastics that is on the market today, with even more plastics entering the market, it is a challenge. Biodegradable plastics is a material against the strategies towards a circular economy, they are used once and then meant to be discarded to be broken down, i.e. not re-using or recycling. But for specific applications it could be a good solution, an optimal plastic should be both biodegradable and mechanically recyclable.

Mixed conventional plastic waste is of low value and therefore incentives to collect, sort and recycle this is low. A large part of this plastic waste ends up for incineration, but it is important to find incentives to collect as much as possible for a future market for recycled plastics. This market is struggling to expand and this can be due to a situation called: catch 22. The recycling companies perception is that there is no demand on recycled plastics but the markets perception is that there are not enough volumes or high quality of recycled plastics. Another barrier is that the price-level of conventional virgin plastics are still low, and that it is difficult to reach the same quality for recycled plastics.

10.3 Independent consultants/scientists

Consultant/scientist 1 (Consultant within plastics, recycling and sustainability) – Positive with a transition to a greater utilization of bioplastics. But, with this said it is important to ensure that they can be recycled in a proper and sustainable way. The transition from conventional plastics to bioplastics will take time and this is often due to that companies, especially large companies, requires a lot of time to utilize changes in their supply chain, logistics etc. Another thing that is a barrier is the additional price-level of bioplastics, but at some point, bioplastics will have a lower price-level than petroleum-based plastics. In the meantime, the willingness for consumers to pay a premium price for bioplastics is not a certainty. The additional price of bioplastics is due to an expensive manufacturing process compared to the conventional plastic manufacturing process. The conventional plastic process has been fine-tuned for many years and it will take time for the bioplastic process to reach this fine-tuning as well. Incentives from governments will likely accelerate the transition to bioplastics, but also the use of recycled plastics. The recycling companies needs to sell the recycled plastics at a certain price-level to make their business economically feasible, and this makes it difficult for them to compete with virgin plastic material. The sorting and washing from post-consumer plastic waste are two areas that is an issue and also expensive. The pre-consumer plastic waste is homogenous and relatively clean, which will result in a better business due to less sorting and washing. Therefore it is important to create incentives for the waste management and recycling companies to collect, sort and clean the post-consumer plastic waste. As for recycling, the mechanical recycling stream should be the recycling stream to use, chemical recycling is a good option as a last resort for plastic waste, i.e. if it is to mixed or to dirty to sort and wash it. Biodegradable plastics can be good for uncontrollable plastic waste streams that ends up in nature, this is because it will eventually disappear and is good in the long run. But, in most cases it is better to use plastic that can be mechanically recycled. There are biodegradable plastics that can be mechanically recycled, but the sorting of these is an issue, the aim for the biodegradable plastics should be to collect it and recycle it. It is important to work on several objectives at the same time to make plastics and packaging more sustainable.

Consultant/scientist 2 (Scientist within polymers and biopolymers) – From a technical point of view, there are several challenges to a greater utilization of bioplastics. They need good properties, low environmental impact, low price and good availability. Blends of bioplastics and conventional plastics is being more utilized and the reason for this is that they fulfill the required properties and is sold to a fair price. Biodegradable plastics can be problematic, a technical problem is that it is not certain that a biodegradable plastic will degrade as it should in a reasonable time-frame in all kinds of environments. A certain biodegradable plastic would possibly biodegrade properly in a warm and humid environment, but can have a degradation rate of several hundreds of years in a cold environment. Another issue is that it is difficult for the general public to know how to discard a biodegradable plastic in a proper way, which can lead to an increase in littering. It is also difficult for companies and governments to change the habits of using conventional plastics as well as biodegradable plastics is a complex problem. Even though these issues exist today, biodegradable plastics is a good thing and an ultimate solution for all plastics. In short term, the focus should be on developing high quality plastics and bioplastics, that are durable, can be re-used and recycled. Bio-based non-biodegradable drop-ins is a step in the right direction and one reason for this is that the dependence on fossil-resources is lowered. The main issue regarding these plastics is if the feedstock competes with food. The main focus should be that food supply should be balanced throughout the world and also reducing the food waste in countries where there are too much food, and not focusing on the small amounts of feedstock that is used for bioplastics. But, in principal plastics should not compete with food.

High quality plastics with good thermal stability will result in that plastics can be recycled more times than they are able to be today. Plastics degrade to some extent in every cycle of mechanical recycling due to oxidation, side-reactions or breakage of polymer chains. This will degrade the quality of the plastic which then will be used for low-quality plastic products. If scientists can develop a technique that makes the plastic more thermal stable and result in less degradation it would be very good. Chemical recycling is an interesting area, but the costs of the process are still very high compared to mechanical recycling. It can be a good solution for plastics that cannot be mechanically recycled, but to utilize this recycling stream more, incentives from governments would most likely be required to make it economically viable to use. Bioplastics are a positive thing and in the right direction from an environmental point of view. But, right now we should increase the quality of plastics, improve recycling efficiency and create incentives for the public to recycle. As we never can completely prevent littering, a biodegradable plastic of high quality, mechanically recyclable, easy to produce and design will be needed in the future.

Consultant/scientist 3 (Consultant and scientist within packaging, polymers and biopolymers) – Bioplastics is a good strategy to move from usage of fossil fuels, but the most important sector to reduce the dependence of fossil fuels is the energy sector. The plastic sector is only a small percentage of the dependence on fossil fuels, but of course also important to some extent. It is difficult to produce a plastic today that is renewable, biodegradable, good and strong properties and with controlled biodegradability. Companies as Braskem which produces bio-PE is important for the industry and is working towards finding sustainable solutions. More development and utilization should be done on wood fibres as a renewable resource for plastics. When or if everyone wants bio-PE it would not be enough as the production and availability is today. A solution to move from the conventional polybags could be to use paper mailers, but even though they are biodegradable it is not certain that it is more environmental friendly or cheaper. It is important that the products which are transported are protected and the mechanical properties of the package are fulfilled. If the only goal is to reduce the amount of plastics in the ocean, all biodegradable alternatives are a better solution than conventional plastics. There are some issues regarding biodegradable plastics of how it will degrade in natural environments, they often require industrial composting with presence of oxygen. With no oxygen present, the potent greenhouse gas methane is produced which is not good for the environment.

A circular society is essential for the future. The population is growing rapidly and the resources are not enough to please everybody. Therefore the plastic recycling industry is important, and they have several challenges ahead. The pre-consumer plastic waste is no problem, the control is greater for this stream compared to the post-consumer plastic waste, e.g. knowledge of the quality, where it comes from and the risk of contamination. The big problem is the post-consumer plastic waste, this stream can be contaminated with for example metals or fats that can react with the polymer in different ways, which decreases its quality. If a company should implement recycled content in plastic products, a good strategy could be to use recycled plastic waste from the same supplier and area to minimize unknown contaminations. To recycle plastic bags that has been at customers to use again for production of new bags can be a good solution, but the uncertainty of contaminations is still present. Chemical recycling is positive for the plastic recycling business, especially for mixed plastics that cannot be mechanically recycled. For some plastics as PET it works fine, but for plastics as PE it would probably demand high amounts of energy to break down to its building blocks. There are developments within this area which can be interesting for the future.