THE NORWEGIAN ENVIRONMENT AGENCY

Bio-Based and Biodegradable Plastics

An Assessment of the Value Chain for Bio-Based and Biodegradable Plastics in Norway

eunomia

mepex

Project report

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Executive Summary:

This report aims to give a description of the value chain for bio-based and biodegradable plastics on a global and national scale.

Common bio-based and biodegradable materials based on their feedstock and traits:

- *Biobased and biodegradable*: PLA, PHAs, starch blends incl. Mater-Bi, bio-PBS(A)
- *Fossil-based and biodegradable*: PBAT, PBS(A), PCL, PVA
- *Bio-based and non-biodegradable*: bio-PET, bio-PE, PEF, bio-PP, bio-PAs, PTT

Raw materials come from forestry, agriculture, residues, bio-waste and other sources. Important bio-based feedstocks and the material types that can be produced using these feedstocks:

- *Sugarcane*: PLA, PHAs, bio-PBS(A), bio-PET, bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Sugarbeet*: PLA, PHAs, bio-PBS(A), bio-PET, bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Corn*: PLA, PHAs, starch blends, bio-PBS(A), bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Potato*: PLA, PHAs, starch blends, bio-PBS(A), bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Wheat*: PLA, PHAsstarch blends, bio-PBS(A), bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Castor seed oil*: bio-PAs
- *Biomass*: PBAT, PBS

0.016 % of the global agricultural areas is used to grow bio-based and biodegradable plastic feedstocks.

Most bio-based/biodegradable plastics are produced in Asia, South America, India, America and Brazil. There are 10-15 major companies that produce bio-based and biodegradable plastics. Some major market leaders and the production location of their material:

- *NatureWorks*: PLA (USA)
- *Novamont*: starch blends (Italy)
- *Indorama*: bio-PET
- *Braskem*: bio-PE (Brazil)
- *Avantium/BASF*: PEF (Belgium/Germany)
- *DuPont*: PTT (Switzerland)
- *BASF*: PBAT (Germany)

The total production capacity of bio-based and biodegradable plastics globally in 2017 was 2.05 million tons. Production amounts of the most common bio-based and biodegradable plastic materials in 2017:

- *PLA*: 211 000 tons
- *Starch blends*: 385 000 tons
- *Bio-PBS*: 100 000 tons
- *PBAT*: 103 000 tons
- *Bio-PE*: 199 000 tons
- *Bio-PET*: 539 000 tons
- *Bio-PA*: 244 000 tons

It is estimated that bio-based and biodegradable plastics constitute **8850 tons**, or roughly **3 %** of the total consumption of plastics in Norway. It is estimated that **60 %** of this material is used for plastic packaging where most of the material is found in food waste bags and PET bottles.

Bio-based plastics can be categorised as drop-in plastics (have the ability to be exchanged directly with their fossil counter-part) or novel plastics (have a chemical structure like no other). In Europe there are no agreed standards for the minimum amount of bio-based content for a product or material to be called a bio-based plastic.

Certain bio-based materials like bio-PE and bio-PP are fully recyclable. Newer bio-based plastics, such as PLA, cannot be recycled together with conventional plastics.

The term biodegradable has little or no meaning without a clear specification of the exact environmental conditions that this process is expected to occur in. The most recognised standard for the biodegradability of plastic packaging products in Europe is EN 13432, which covers their degradability in industrial treatment plants, both industrial composting and anaerobic digestion (biogas plants). The test conditions used for certification are not comparable to real life conditions in most Norwegian plants.

There are limited downstream systems in place for material recovery of biodegradable plastic products in Norway today. Such products are in most cases sent to incineration with energy recovery.

Several challenges related to biodegradable plastic products in the Norwegian waste handling system are identified:

- The mixing of biodegradable plastics with recyclable plastics contaminates the recyclate and reduces the quality. Studies indicate levels of 2-10 % could be problematic.
- Although some products are certified as compostable according to EN 13432, there are only 3 composting plants in Norway, out of a total of ca. 15-20 plants that receive food waste, that will accept such products. Although certified as composable, it is not guaranteed that they will degrade in Norwegian composting and biogas plants as the treatment period does not match the criteria of the test method.
- Residues of plastics in the digestate (output from biogas plants) and compost can cause mechanical trouble to the equipment used in agriculture after spreading the digestate on fields.
- A pre-treatment process is in place in all Norwegian biogas and composting plants that receive food waste from households to remove contaminations before the food waste enters the plants. This pre-treatment process will remove plastic objects regardless of what material they are made of whether biodegradable or compostable, or made from fossil resources.

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Contents

ABBREVIATIONS

PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PHBV	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)
PHV	Polyhydroxyvalerate
PHH	Polyhydroxyhexanoate
PBS	Polybutylene Succinate
PBSA	Polybutylene Succinate Adipate
Bio-PBS	Bio-based Polybutylene Succinate
Bio-PBSA	Bio-based Polybutylene Succinate Adipate
PET	Polyethylene Terephthalate
Bio-PET	Bio-based Polyethylene Terephthalate
PE	Polyethylene
Bio-PE	Bio-based Polyethylene
PEF	Polyethylenefuranoate
PP	Polypropylene
Bio-PP	Bio-based polypropylene
PA	Polyamides
Bio-PA	Bio-based Polyamides
PTT	Polytrimethylene terephthalate
PCL	Polycaprolactone
PVA	Polyvinyl Alcohol
MEG	Monoethylene Glycol
PTA	Purified Terephthalic Acid
LA (D-LA and (L-LA)	Lactic Acid
1,4-BDO	1,4-Butanediol
2,5-FDCA	2,5-Furan dicarboxylic acid
FDME	Furan dicarboxylic methyl ester
PLA	Polylactic acid

1 Summary

1.1 Definitions

The term bioplastics is often used to cover bio-based and biodegradable plastics. However, this term is confusing as it covers a range of different types of material, even fossil-based material, and should therefore be avoided. Bio-based and biodegradable plastics can be split into three main groups;

- biodegradable bio-based: PLA, PHAs, starch blends, bio-PBS(A)
- biodegradable fossil-based: PBAT, PBS(A), PCL, PVA
- non-biodegradable bio-based: bio-PET, bio-PE, PEF, bio-PP, bio-PAs, PTT

'Old economy' bioplastics are well established and produced in large amounts. 'New economy' bioplastics have been developed in the past 30 years and only hold 12 % of the total bio-based and/or biodegradable market share globally. This report focuses on the new economy plastics, as it is a growth market with the most potential in any transition away from fossil-based industries. 'Old economy' bioplastics are excluded from the scope of this report.

Oxo-degradable plastics claim to be biodegradable, or just degradable, but the reality of such assertions is questionable. As the current evidence suggests that these materials do not fully biodegrade in a reasonable timeframe, they are not included in the scope of this report.

1.1.1 Bio-based Plastics

Bio-based plastics can be further categorised as drop-in or novel plastics. 'Drop-in' bio-based plastics are so called because of their ability to be exchanged directly with their fossil-based counterpart. On the other hand, there are completely novel bio-based plastics with a chemical structure like no other, for example PLA and PEF.

1.1.2 Biodegradable Plastics

Some biodegradable plastics may biodegrade very quickly in one environment but not in others. It is therefore very important to define timeframe and environment when talking about biodegradation. The term 'biodegradable' has little or no meaning without a clear specification of the exact environmental conditions that this process is expected to occur in. The term compostable plastic refers to a material that can biodegrade in an industrial composting facility but not necessarily in a home composting environment, in the ocean or in any other natural environments.

1.2 Standards and Certifications

1.2.1 Standards for Bio-based Content

In Europe there are no agreed standards for the minimum amount of bio-based content for a product or material to be called a bio-based plastic. However, there are independent certifications that allow manufacturers to indicate the content using a labelling scheme.

1.2.2 Standards for Biodegradability

It is more difficult to set standards and certifications for biodegradable plastics as the requirement is not around the specification of the material, but how it performs in many varied environments. The rate of decomposition is affected by the presence of bacteria, fungi and oxygen, hence why a 'biodegradable' material may decompose in industrial composting, but not (or at a considerably slower rate) on land or in the marine environment.

Industrial composting and anaerobic degradation are the only environments that have been subject to international standards for biodegradation, in the form of the European Standard EN 13432 for plastic packaging and EN 14995 for other plastic items. This is primarily because a test can be developed that simulates *some* industrial composting and AD facilities. However, there is scepticism towards these standards and the methods used to determine the requirements as some have argued that it is not possible to recreate these environments. Industrial composting and AD processes vary from place to place.

The EN 13432 composting standard requires disintegration and biodegradability. The six months biodegradation requirement is far longer than the actual processing time in an industrial composting plant, with a plant's active phase normally lasting 3-6 weeks and post-composting stabilization lasting 2-3 months.

The anaerobic biodegradation test in EN 13432 requires only 50% degradation after two months as anaerobic fermentation, but the assumption is that this will be followed by aerobic composting, during which biodegradation can further continue.

Further difficulty arises in more uncontrolled, open environments. The marine environment is actually a whole host of environments with varying temperatures and organic life. To categorically state that a particular plastic will biodegrade in all these environments is, perhaps, an impossible task.

1.3 Key Materials

Raw materials come from forestry, agriculture, residues, bio-waste and other sources. Raw materials come from forestry, agriculture, residues, bio-waste and other sources. This includes timber, cassava, plant oils, fructose, maize, sugar cane/beet, corn, potato, wheat and algae.

Important bio-based feedstocks and the material types that can be produced using these feedstocks:

- *Sugarcane*: PLA, PHAs, bio-PBS(A), bio-PET, bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Sugarbeet*: PLA, PHAs, bio-PBS(A), bio-PET, bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Corn*: PLA, PHAs, starch blends, bio-PBS(A), bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Potato*: PLA, PHAs, starch blends, bio-PBS(A), bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Wheat*: PLA, PHAsstarch blends, bio-PBS(A), bio-PE, PEF, bio-PP, bio-PAs, PTT
- *Castor seed oil*: bio-PAs
- *Biomass*: PBAT, PBS

0.016 % of the global agricultural areas is used to grow bio-based and biodegradable plastic feedstocks.

1.4 Global Markets

The primary processing of raw materials is predominantly by 10-15 key industry players. In an everchanging market these producers, their production locations and their capacity are changing rapidly. Exact production data and demand for bio-based and biodegradable plastics is very hard to come by. Production capacity data is more readily available. Although it is unlikely that production capacity is reached, it gives a good indication of the potential market and the areas in which materials are produced.

Most bio-based/biodegradable plastics are produced in Asia, however there is also production in South America, India, America and Brazil. The global market for bio-based raw materials is rather unstable as there has been a mass industry restructure in recent years. Some major market leaders and the production location of their material:

- *NatureWorks*: PLA (USA)
- *Novamont*: starch blends (Italy)
- *Indorama*: bio-PET
- *Braskem*: bio-PE (Brazil)
- *Avantium/BASF*: PEF (Belgium/Germany)
- *DuPont*: PTT (Switzerland)
- *BASF*: PBAT (Germany)

Total production capacity is estimated to be 2.05 million tonnes for the year 2017. The reported global production capacity of conventional plastics is 335 million tonnes (2016), making the bio-based/biodegradable market share only 0,6%. Production amounts of the most common bio-based and biodegradable plastic materials in 2017:

- *PLA*: 211 000 tons
- *Starch blends*: 385 000 tons
- *Bio-PBS*: 100 000 tons
- *PBAT*: 103 000 tons
- *Bio-PE*: 199 000 tons
- *Bio-PET*: 539 000 tons
- *Bio-PA*: 244 000 tons

Bio-based and biodegradable products can be used for a wide range of applications, including plastic packaging (the most common application), consumer goods, building and construction, textiles, electronics, automotive and transport, and agriculture and horticulture. In the global market of bio-based and biodegradable plastics, 58 % of the material is used in plastic packaging.

1.5 The Norwegian Market

The latest credible figure showed that in 2016 the amount of plastic waste in Norway was ca. 300 000 tons, where 60 % of that was plastic packaging. It is unknown how much production of bio-based and biodegradable products takes place in Norway, though it is likely that this share is quite small. The production of materials and products often take place abroad due to high operating costs in Norway.

Part of this report project included mapping the use of bio-based and biodegradable material on the Norwegian market today. This has been a challenging task. Based on information gathered, assessments and the estimated market shares in Europe, bio-based and biodegradable plastics constitute roughly **3 %** of the total consumption of plastics in Norway. It is estimated that roughly **60 %** of the material is used for plastic packaging where most of the material is found in food waste bags and PET bottles. There is no official reporting, statistics or data on the use of bio-based or biodegradable plastics in Norway today. As result of this, there is a lot of uncertainty tied to this estimate and it should be viewed with caution.

According to producers and suppliers of bio-based and biodegradable plastics, consumer demand has led to an increase in these materials in 2018 in Norway. However, the development in Norway is uncertain. Many producers are choosing to use more recycled material in their products over material from bio-based sources.

1.6 Waste Management Systems

1.6.1 Bio-based and Biodegradable Plastics in Plastics Recycling Streams

Certain bio-based materials can produce common fossil plastic types like PE, PP and PET, which are fully recyclable. These drop-in bio-based plastics are easier to process in existing manufacturing and recycling systems as they are identical to their fossil-based counterparts. Newer bio-based plastics, such as PLA, cannot be recycled together with conventional plastics as existing sorting plants are set to accept fossil-based plastics and do not have separate streams for the newer bio-based plastics. PLA will therefore go to incineration with energy recovery.

The interference of biodegradable plastics amongst fossil-based plastics gives a contamination that reduces the quality of the recyclate. It is possible that the NIR sorting technology in the sorting plants can be programmed to sort out biodegradable plastics to avoid contamination of the other fractions. The effects of small quantities of biodegradable plastics in the recycled material is uncertain. Studies indicate levels of 2-10 % could be problematic.

1.6.2 Bio-based and Biodegradable Plastics in Biogas and Composting Plants

There is a range of problems tied to the use of biodegradable and compostable items in the waste management systems in Norway. Most food waste (60 %) is sent to treatment plants for biogas production while the remaining food waste is sent to industrial composting. As contamination levels are so high, due to incorrect sorting and the use of bags to collect food waste, a pre-treatment process is in place to remove all contaminations before the food waste enters both biogas plants and industrial composting plants. Regardless of what material the bag is made of, or whether a product is biodegradable or compostable, or made from fossil resources, the objects will be removed in the pre-treatment process.

In this pre-treatment process the bags are ripped open and shredded and the removal of the entire bag, and other contaminations, is challenging. Some particles will follow the process and mix in with the final product (digestate or compost). Leftover plastics that are not removed can cause mechanical trouble to the equipment used in the plant, but also to the equipment used in agriculture when using the digestate or compost. Microplastics have become a severe challenge and there is a high risk that food waste bags and contaminations will give rise to microplastics in the digestate. Some plastics are biodegradable, and these will degrade over time.

1.6.3 Industrial Composting Versus Biogas Production

There are clear environmental advantages to biogas production compared to industrial composting, so many Norwegian municipalities deliver collected food waste to biogas plants. Biogas plants have the overall best utilization of food waste, henceforth the compostable quality given to certain biodegradable products has little purpose in Norway.

The recognised standard for the biodegradability of packaging products, EN 13432, covers their degradability in industrial treatment plants, both industrial composting and biogas plants. Although some products are certified as *compostable* as per EN 13432, it is not guaranteed that they will degrade in Norwegian composting and biogas plants as the treatment period does not match the criteria of the test method. The test conditions used for certification of biodegradability of packaging products are not comparable to real life conditions in most Norwegian plants. The pre-treatment process in place at these industrial plants will also remove waste bags and other contaminations to the food waste, including biodegradable and compostable products.

There are only 3 composting plants in Norway that will accept certified, compostable products (out of 15-20 composting plants that accept food waste), but only if they are source-separated so their input to the plant can be controlled. The environmental benefits of composting compostable plastics are low, and it is uncertain if the end products will give a positive attribution to the compost. Compostable and biodegradable packaging products sold in Norway will in most cases be sent to incineration with energy recovery.

2 Introduction

Plastics provide a valuable means to perform a vast range of functions; often providing a lightweight solution that is hard to match using other materials. Recent studies, along with the BBC's Blue Planet II and the 'plastic whale' that was found in Sotra, have raised awareness and highlighted the problems of plastic litter and micro-plastics in the marine environment. The use of fossil resources and climate change has also gained lots of media attention recently, with consumers and producers alike having to find more sustainable alternatives to fossil resources.

Bio-based and biodegradable plastics have been proposed as alternatives to conventional plastic material as a way of reducing reliance on fossil fuel feedstocks and as a solution to plastic littering/waste respectively. Bio-based and biodegradable plastics are a small share of the total amount of plastics put on the market today; however, if this share were to grow, it is necessary to understand what consequences this will have.

2.1 Project Description

Before one can understand the consequences that bio-based and biodegradable plastics can have in Norway, it is necessary to understand the market for these materials. This report will provide knowledge of the value chain for these materials in Norway, and worldwide. Information will be provided within 4 main areas:

1. **Raw material**
2. **Production rates**
3. **Usage areas**
4. **Waste**

Bio-based and biodegradable plastic material must adhere to standards and regulations. This will be assessed when relevant in relation to each focal point.

2.2 Aims and Objectives

The Norwegian Environment Agency (NEA) wishes to build up knowledge of bio-based and biodegradable plastics. To this end, this report will review the value chain for plastic based on biological material and biodegradable plastics.

Specific questions to be answered are:

- What raw materials are used today, including estimates of quantities?
- Which types of bio-based and biodegradable plastics are produced, including estimates of amounts?
- Where is production located?
- What are the applications of bio-based and biodegradable plastics today?
- Are the products suitable for recycling, composting or other biological treatment (based on Norwegian conditions)?

The geographical scope will be twofold; within Norway and on a global basis, and the report will look at both the production and demand within these two geographies.

3 Methodology

This report has been produced based on as much up-to-date information and knowledge as possible. To understand the market and obtain data from the most reliable sources, creating a dialogue with experts within the plastics industry was a central part of the project.

3.1 Literature Review

The project relied on identifying and collating available information whilst establishing contacts in representative organisations worldwide to build up a picture of what information was available. Eunomia and Mepex made use of:

- Commercially available data-sets;
- Publicly available data online;
- Available reports and documentation from organisations, conferences, and other meetings; and
- Newsletters and journals.

Commercially available information is limited and, in some cases, data would vary between sources. Bio-based and biodegradable plastics are a hot topic in the media and there is often no screening process of the information that is shared; anyone can publish information with no standard way of identifying credible sources. The literature review process was used to critically review all available information. It was found that locating useful, reliable, balanced information was challenging. There has been limited research on determining volumes of bio-based and biodegradable plastics on the market and available statistics are often based on estimations. In addition, there are many ways of reporting volumes and statistics in each country, and published data would include little information on what these data sets included and how they were acquired.

3.2 Interviews

Gaps identified in the literature review were filled as much as possible through interviews with relevant players in the industry. Gathering concrete data on the production volume of bio-based and biodegradable material on the Norwegian market was challenging as suppliers of these materials often had little interest in sharing this information.

3.3 Analysis

The information gathered from the literature review and from interviews was collated and is described in the following chapters.

The volume of bio-based and biodegradable plastics within each market segment is an assembly of data shared with us from producers and suppliers, but also includes estimations of the volume of different product groups. As stated, gathering enough information for different products to assemble data on volumes was challenging. Import statistics from SSB (Statistics Norway) were of little help as products cannot be separated by their detailed material types; making it impossible to separate, for example, carrier bags made from bio-based material, biodegradable material, recycled fossil plastics, or virgin fossil plastic.

4 Definitions

The term 'bioplastic' is often used to cover bio-based and biodegradable plastics. However, this term is confusing as it covers a range of different types of material, even fossil-based material, and is misleading to the consumer therefore its use should be avoided. The term can be split into the following three groups of plastic:

- biodegradable bio-based;
- biodegradable fossil-based; and
- non-biodegradable bio-based.

Figure 1 shows an overview of these three groups including examples, coloured green, orange and turquoise respectively. Also shown are examples of feedstocks for each of the plastics. The bio-based plastics are often made from corn, sugarcane or similar, whereas the fossil-based plastics are made from petrochemicals such as crude oil. It is debatable whether biodegradable fossil-based plastics should be described alongside the other two categories, however, they often are. For example, The European Bioplastics Association produces annual reports that include all three material types—their members include manufacturers in the bio-based and petrochemical industry that would otherwise be competing industries. This is perhaps not an issue whilst the market for bio-based plastics is relatively small but may change as the market grows and the association is required to balance the needs of two competing feedstocks.

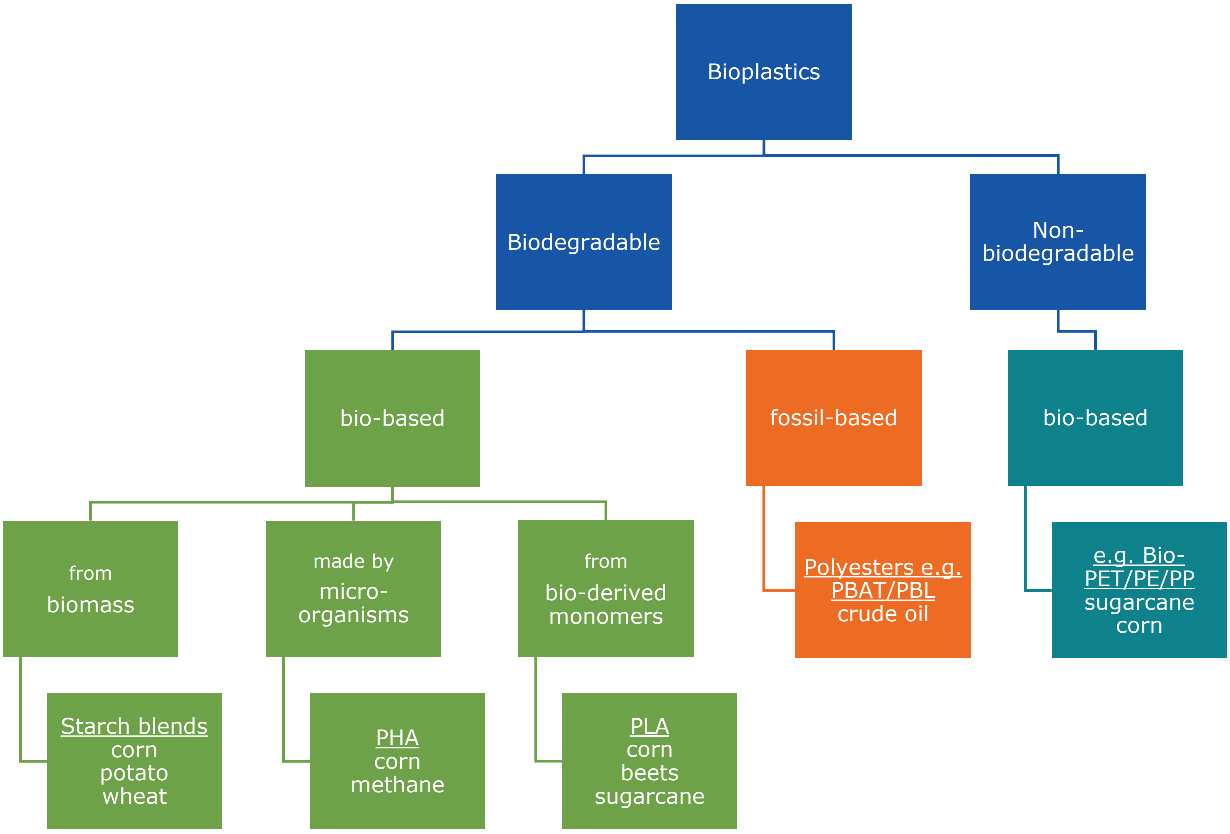

Figure 1: Overview of Types of Material and their Feedstocks

4.1 Bio-based Plastics

There are several definitions for the term 'bio-based plastic' although most are similar to the one used by the International Union of Pure and Applied Chemistry[1]:

"a polymer composed or derived in whole or in part of biological products issued from biomass (including plant, animal, and marine or forestry materials)."

It should be noted that, while fossil fuels had their origins in animal life and biomass, hydrocarbon fossil fuels are not considered bio-based. Importantly, however, under most definitions a product can be referred to as bio-based even if it has mostly fossil-based content, thus it is important to look at 'bio-based content'. The bio-based content is the amount of biomass used by percentage of weight to create the final product; for example, in bio-PET 32% of the final product is made of a completely bio-derived monomer whereas the other monomer is fossil-based, giving the product a 32% bio-based content. It is measured either through the material's bio-based carbon content or the mass of bio-derived substances within the material. Some certifications require a minimum bio-based content under one or either of these tests. Test and certification methods for this are further described in Section 5.1.

For the purposes of this report there is no lower limit of bio-based content specified, but all materials discussed fall under the above definition.

4.1.1 'Drop-in' and Novel Bio-based Plastics

Bio-based plastics can be further categorised as drop-in or novel plastics. 'Drop-in' bio-based plastics are so called because of their ability to be exchanged directly with their fossil-based counterpart. Many of these have been available for a long time and are identical in chemical structure but using a biomass feedstock. For example, bio-PET (as used in CocaCola's PlantBottle™) is simply PET made partially from biomass. There are similar bio-based alternatives to PE and PP.

On the other hand, there are completely novel bio-based plastics with a chemical structure like no other, for example PLA (the most common biodegradable bio-based material) and PEF (a newer non-biodegradable bio-based PET replacement). These novel materials are used because of their specific performance capabilities or properties e.g. PEF has better barrier properties than PET.

Compared to novel bio-based plastics, drop-in bio-based plastics are easier to process in existing manufacturing and recycling systems as they are identical to their fossil-based counterparts. Existing sorting plants for plastic products are set to accept fossil-based plastics and do not have separate streams for the newer bio-based plastics. Further discussion on the issues around waste management of these different products can be found in chapter 11.

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[1] Vert, M., Doi, Y., Hellwich, K.-H., et al. (2012) Terminology for biorelated polymers and applications (IUPAC Recommendations 2012), *Pure and Applied Chemistry*, Vol.84, No.2, pp.377–410

4.2 Biodegradable Plastics

It is important to note that almost all materials may ultimately biodegrade, even in the open environment, though some plastic items are predicted to take many hundreds of years[2]. Conventional plastics are hydrocarbon fossil-based and do not biodegrade in any reasonable timeframe in human terms (i.e. hundreds of years). Also, some biodegradable plastics may biodegrade very quickly in one environment but degrade over hundreds of years in a different environment. Therefore, it is very important to define timeframe and environment when talking about biodegradation.

Biodegradation is more difficult to define and there are many definitions from national and international organisations which vary significantly but generally do not specify a particular environment or timeframe. Two definitions from CEN[3] are shown below:

Biodegradation

"A degradation caused by biological activity, especially by enzymatic action, leading to a significant change in the chemical structure of a material."

Biodegradable Plastic

"A degradable material in which the degradation results from the action of microorganisms and ultimately the material is converted to water, carbon dioxide and/or methane and a new cell biomass."

Some definitions (notably from ISO) only refer to a chemical change in the material by microorganisms, however, the CEN (and German DIN) standards refer to the conversion of material into microbial metabolic products i.e. they can be consumed by microbes.

These definitions are further qualified with corresponding test methods, standards and certifications for specific environments, such as industrial composting. It should be emphasised that the term biodegradable has little or no meaning without a clear specification of the exact environmental conditions that this process is expected to occur in. The term compostable plastic refers to a material that can biodegrade in an industrial composting facility but not necessarily in a home composting environment (which would be termed 'home compostable').

Biodegradation can occur in an aerobic (with oxygen) or anaerobic (without oxygen) environment. 'Composting' is defined by the European Commission[4] as enhanced biodegradation under managed conditions, predominantly characterised by forced aeration and natural heat production resulting from the biological activity taking place inside the material.

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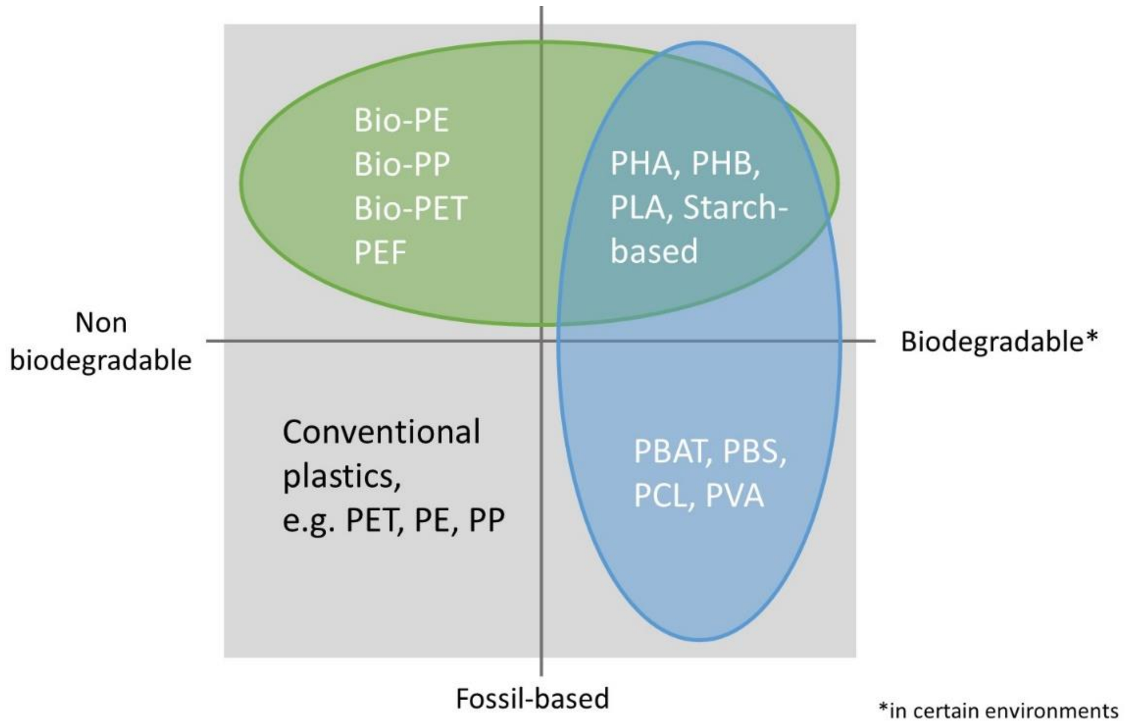
[2] The Ocean Conservancy (2003) *Pocket Guide to Marine Debris*, 2003
[3] European Committee for Standardization *EN 13193:2000 Packaging. Packaging and the environment. Terminology*
[4] *Report from the commission to the European Parliament and the Council on the impact of the use of oxo-degradable plastic, including oxo-degradable plastic carrier bags, on the environment,* accessed 8 November 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516986702401&uri=CELEX:52018DC0035

The resulting output material, compost, can contain valuable nutrients and may sometimes act as a soil improver. Anaerobic digestion (AD) is the process in which microorganisms are used to break down biodegradable material in the absence of oxygen.[5]

4.3 The Links Between Bio-based and Biodegradable Plastics

There is often confusion around the nature of bio-based plastics in comparison to biodegradable plastics. Consumers may—quite understandably—believe that bio-based plastics will biodegrade. Whilst this may be true of some, it is not true of all, as the plant-based feedstock can also be used to make conventional (non-degradable) plastic. **Figure 2** shows some of the common types of plastic and whether their feedstock is fossil or bio-based.

Only a few are both derived from natural materials and known to biodegrade under certain conditions. Equally, there are also bio-based versions of conventional plastics which are chemical and functionally identical but are synthesized from organic rather than a fossil-based feedstock. There are also plastic materials that are made from fossil-based material but are known to biodegrade. A common example of this is polyvinyl alcohol (PVA) which is water soluble and is often used as the wrapper for dishwasher tablets of washing detergent pouches. This category does not include a group known as oxo-(bio)degradable plastics which is discussed in the following section.



[5] (2018) *Anaerobic digestion*, accessed 8 November 2018, https://ec.europa.eu/knowledge4policy/bioeconomy/glossary/anaerobic-digestion_en

Figure 2: Examples of bio-based and biodegradable plastics[6]

4.4 Blends

It should be noted that the market includes products that are blends of different types of material, for example ecovio®, which is a blend of PBAT (a fossil-based biodegradable material) and PLA (a 100% bio-based biodegradable material). This reduces clarity around the communication and marketing of these materials and makes waste management an even more challenging task.

4.5 Oxo-degradable Plastics

There are also other kinds of material which claim to be biodegradable or just degradable, but the reality of such assertions is questionable. They are known as 'oxo-degradable', 'oxy-degradable' or 'oxo-biodegradable' plastics and should not be confused with the biodegradable plastics already discussed. These are conventional plastics such as polyethylene (PE) which include an additive that is designed to help them break down and fragment (often this additive is a type of metal salt).

The manufacturers often claim that, once in the environment, plastic containing their additive will degrade in the presence of oxygen (oxidation) which can be accelerated by light, heat and physical stresses. This can lead to fragmentation and make the plastic bioavailable to micro-organisms—this is reached much more rapidly than would be the case for conventional plastics. However, there is little evidence for full biodegradation in practice in any meaningful timeframe especially in the marine environment[7]. The European Commission announced in January that "a process to restrict the use of oxo-plastics in the EU will be started", with the European Parliament passing the revised Packaging and Packaging Waste Directive in April stating "oxo-biodegradable plastic packaging shall not be considered as biodegradable" [8]. The manufacturers themselves note that their products will not biodegrade quickly enough in composting environments to meet EN13432[9]. As the current evidence suggests that these materials do not fully biodegrade in a reasonable timeframe, they are not included in the scope of this report.

4.6 Old and New Economy

Plastics can be further categorised as new and old economy. 'Old economy' bio-based plastics can be even older than the fossil-based plastics that are ubiquitous today, and they make up the majority of the bio-based plastic market. Examples of these include cellophane, cellulose

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[6] Based on the figure shown at: https://www.european-bioplastics.org/bioplastics/materials/

[7] *The Impact of the use of "oxo-degradable" plastic on the environment,* accessed 9 November 2018, https://publications.europa.eu/en/publication-detail/-/publication/bb3ec82e-9a9f-11e6-9bca-01aa75ed71a1

[8] *Report from the commission to the European Parliament and the Council on the impact of the use of oxo-degradable plastic, including oxo-degradable plastic carrier bags, on the environment,* accessed 8 November 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516986702401&uri=CELEX:52018DC0035

[9] *Oxo-biodegradable plastic FAQs*, accessed 9 November 2018, https://www.symphonyenvironmental.com/frequently-asked-questions/

acetate in cigarette filters and linoleum in floor coverings. Natural rubber is also a form of bio-polymer although with very different properties. These old economy bio-based plastics are well established and production capacity is stable, with approximately 17 million tonnes produced annually.[10]

'New economy' plastics have been developed in the past 30 years and are largely bio-based plastics that are alternatives to fossil-based plastics, although some have their own unique properties that lend them to specific applications. Currently, new economy plastics hold roughly 12% of the total bio-based and/or biodegradable market share globally.[11] This report focuses on the new economy plastics, as it is a growth market with the most potential in any transition away from fossil-based industries.

[10] Institute for Bioplastics and Biocomposites *Biopolymers facts and statistics 2017*, https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren/Biopolymers-Facts-Statistics_2017.pdf
[11] ibid

5 Standards and Certifications

For this section of the report the focus is on how the definitions in the previous section are tested and certified in practice and the issues around doing this.

Test Methods – These are often standardised and detail the conditions the material should be tested under to obtain specific and repeatable results.

Standards – These are national or international standards that provide specific thresholds to achieve under related test methods. Meeting the standard is often considered a requirement for certifications.

Certifications – Distinct from standards in that certifications can be provided by an organisation (public or private) and therefore do not necessarily provide legitimacy unless they refer to established and accepted test methods and standards. Often these incorporate a labelling scheme.

5.1 Bio-based Plastics

In Europe there are no agreed standards for the minimum amount of bio-based content for a product or material to be called a bio-based plastic. However, there are independent certifications that allow manufacturers to indicate the content using a labelling scheme. The two test methods most often used to test the level of bio-based materials are European Standard CEN 16137 and American Standard Test Method (ASTM) D6866 which are comparable in their methods and measure the bio-based carbon content.[12]

These are both used in two European certification and labelling schemes—TUV Austria's OK bio-based and DIN Certco's DIN Geprüft— to determine the bio-based content with the appropriate label awarded as a result (See **Figure 3** and **Figure 4**). Both certifications do not certify any materials or products under 20% bio-based carbon content and do show the level of bio-based content in the labelling scheme.

OK biobased TÜV AUSTRIA ★	OK biobased TÜV AUSTRIA ★★	OK biobased TÜV AUSTRIA ★★★	OK biobased TÜV AUSTRIA ★★★★
20-40% bio-based	40-60% bio-based	60-80% bio-based	More than 80% bio-based

Figure 3: TUV Austria OK bio-based Labelling[13]

[12] Results based on CEN 16137 reports percentage of biomass-derived carbon relative to total organic carbon.
[13] *TUV Austria website homepage,* accessed 9 November 2018, http://www.tuv-at.be

Figure 4: DIN Certco DIN Geprüft Labelling[14]

5.2 Biodegradable Plastics

Biodegradable plastics are more difficult to set standards and certifications for as the requirement is not around the specification of the material, but how it performs in many varied environments. There is a general hierarchy of 'aggressiveness' for environments, with industrial composting being the most aggressive and the oceans being one of the least aggressive—see **Figure 5**. The rate of decomposition is affected by the presence of bacteria, fungi and oxygen, hence why a 'biodegradable' material may decompose in industrial composting, but not (or at a considerably slower rate) on land or in the marine environment.

[14] *Din Certco website homepage*, accessed 9 November 2018, http://www.dincertco.de/

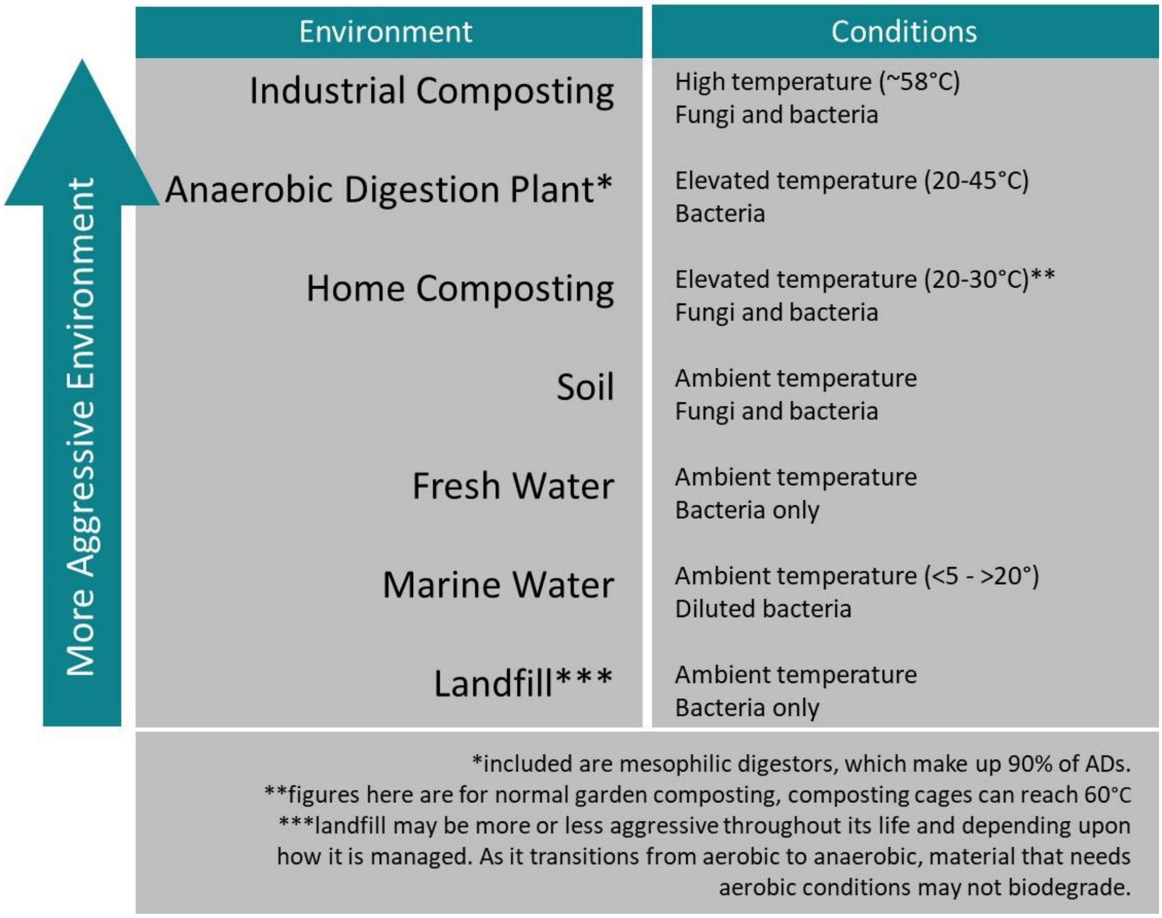

Figure 5: Ranking of the Aggressiveness of Biodegradation Environments

5.2.1 Standards

Until recently, the only environments that were subject to current international standards for biodegradation were industrial composting and AD, in the form of the European Standard EN 13432[15] for plastic packaging and EN 14995 for other plastic items (the test criteria are identical between the two standards with only the scope differing). This is primarily because a test can be developed that simulates *some* industrial composting and AD facilities. However, there is scepticism towards these standards and the methods used to determine the requirements in these standards. Some have argued that it is not possible to recreate these environments, as the industrial composting and AD processes themselves are not standardised and vary from place to place. As a particular test method does not account for the wide variety of conditions that actual exist in real life composters or ADs, they can not necessarily be relied on.

[15] European Committee for Standardization (2000) *EN 13432 - Packaging - Requirements for Packaging Recoverable Through Composting and Biodegradation - Test Scheme and Evaluation Criteria for the Final Acceptance of Packaging*, 2000

5.2.1.1 Industrial Composting

The EN 13432 composting standard essentially requires:

- Disintegration – the sample is mixed with organic waste and maintained under test scale composting conditions for 12 weeks after which time no more than 10% of material fragments are allowed to be larger than 2 mm.

- Biodegradability – a measure of the actual metabolic, microbial conversion, under composting conditions, of the sample into the water, carbon dioxide and new cell biomass. Within a maximum of 6 months, biodegradation of the test sample must generate an amount of carbon dioxide that is at least 90% as much as the carbon dioxide given off from a control/reference material—usually cellulose.

- The absence of any negative effect on the composting process.

It is important to emphasise that the six months biodegradation requirement is far longer than the actual processing time in an industrial composting plant, with a plant's active phase normally lasting 3-6 weeks and post-composting stabilization lasting 2-3 months. A similar standard for the US exists in the form of ASTM D6400, but the limits are even less strict with a 60% degradation over 1 year.[16]

5.2.1.2 Anaerobic Biodegradation

The anaerobic biodegradation test in EN 13432 (for simulation of AD) requires only 50% degradation after two months as anaerobic fermentation, but the assumption is that this will be followed by aerobic composting, during which biodegradation can further continue. With regard to disintegration, the standard requires that after five weeks of combined anaerobic and aerobic treatment less than 10% of the original sample remains after sieving over a 2 mm mesh. Second-stage composting is not always undertaken and AD plants will in any case aim to screen out the majority of polymers (of all kinds) as they cause problems in the processing equipment. This is elaborated on in further detail in chapter 11.3.

5.2.1.3 Other Environments

Further difficulty arises in more uncontrolled, open environments. No current international standard exists for biodegradation in the marine environment. The American ASTM standard specification for biodegradable plastic in the marine environment — ASTM D7081[17] — was withdrawn in 2014 and has yet to be replaced. Although work has been ongoing for a number of years to develop a new standard, there are significant challenges in doing so. For example, the marine environment is actually a whole host of environments with varying temperatures and organic life. To categorically state that a particular plastic will biodegrade in all these environments is, perhaps, an impossible task. The certification 'OK Marine' (described in Chapter 5.2.2) wholly relies on this withdrawn standard and is still widely used by

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[16] ASTM International (2018). *Standard Specification for Labeling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities*. Accessed 23.22.18. https://www.astm.org/Standards/D6400.htm

[17] *ASTM D7081-05: Standard Specification for Non-Floating Biodegradable Plastics in the Marine Environment,* accessed 9 November 2018, https://www.astm.org/DATABASE.CART/WITHDRAWN/D7081.htm

organisations to certify and promote their products as marine biodegradable, despite the issues described.

The challenge of deciding what is an acceptable period of time for a plastic to reside in the ocean has yet to be overcome. Most of this research is focused on the time to biodegrade in different marine environments, but much less is known about whether the risk posed to wildlife from entanglement or ingestion is directly linked to this timescale i.e. does the risk reduce as biodegradation time reduces? This is unlikely to be resolved soon.

5.2.1.4 Mulch Film Standard

In mid-2018 a new standard for biodegradable mulch films for use in agriculture and horticulture has been introduced— EN 17033.[18] This standard aligns with the TUV Austria and DIN Certco certifications on soil biodegradation (see Table 1) with a minimum specification of 90% biodegradation required within two years, as well as various eco-toxicity tests and restrictions on the use of hazardous substances. The standard is product and application specific, therefore claims of adherence to the standard for anything other than mulch films would be incorrect. As this standard is so new, the impact of its adoption and acceptance has yet to be realised.

This is expected to override all existing country level standards in the EU and may be the catalyst for an increase in the use of biodegradable mulch films in Europe. This also comes at a time when the standard for recoverable mulch films— EN 13655—was updated to include a minimum material thickness of 25μm to help prevent the material breaking up as it is removed from the field. Conventional mulch films can be as low as 5 - 10μm, so assuming that the majority of conventional mulch films will be compliant with EN 13655, the increased lower limit may result in an increase in thickness and subsequently the average cost. Consequently, thinner biodegradable alternatives may become more competitive.

There are also potential increases in costs on the horizon if proposals in the EU Plastics Strategy[19] for mandatory extended producer responsibility schemes (EPR) are taken forward. This may also drive the market towards thicker films (and may even require compliance with EN 13655) to reduce recovery costs. The true cost of mulch film waste management is often disguised, but this may no longer be the case. These changes may drive the biodegradable mulch film market in Europe, but this is too early to determine at this time.

5.2.2 Certifications

Despite the lack of agreed standards, there are third-party certifications for many environments. Table 1 shows the certifications available from TUV Austria[20]. Only the OK Compost Industrial is based entirely on a recognised standard. The other certifications use standardised test methods or other related standards, but the test threshold has been

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[18] *BS EN 17033:2018 – Plastics. Biodegradable mulch films for use in agriculture and horticulture. Requirements and test methods.*
[19] *A European Strategy for Plastics in a Circular Economy*, accessed 9 November 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN
[20] *TUV Austria webpage: OK compost certification,* http://www.tuv-at.be/certifications/ok-compost-industrial-ok-compost-home/

independently set by this organisation. For example, the home composting certification uses EN 13432, but specifies a lower temperature and a longer test period. It is these test thresholds that are potentially contentious, as they allow materials to be certified as biodegradable in these environments without a rigorous scientific basis— as previously discussed, the marine certification is particularly complicated in this regard. The soil certifications broadly align with the new EN 17033 standard but were developed before this standard was introduced. Din Certco[21] also provide a certification using the same criteria for soil and industrial composting.

Table 1: European Certifications for Biodegradable Plastics

Labels	Reference Standard	Test Conditions (if different from reference standard)	Test Threshold
	EN 13432		90% in 6 months[3]
	EN 13432	Ambient temperature (20°C – 30°C)	90% in 12 months
	ISO 17556[1]		90% in 2 years[4]
	ASTM D7081 (withdrawn)		90% in 6 months
	EN 14987[2]	20°C and 25°C	90% in 56 days

Notes:

1. *This is the test method for aerobic biodegradability of plastics in soil.*
2. *This is the test method for biodegradability of plastics in waste water treatment plants—used as a proxy for fresh water environments.*
3. *Test threshold the same as EN 13432*
4. *Test threshold the same as EN 17033*

[21] *Din Certco webpage: Biodegradability in Soil,* http://www.dincertco.de/en/dincertco/produkte_leistungen/zertifizierung_produkte/umwelt_1/biodegradable_in_soil/biodegradable_in_soil.html

6 Key Materials

An overview of the main types of bio-based and biodegradable plastics on the market at the time of writing is shown in Table 2—these materials are the ones identified with the largest market share (more detail on markets in chapter 9). Some of the key materials are outlined in more detail below where more specific information was available. There are also a large number of other products under proprietary brand names and formulas that are sold in much smaller quantities; little information is available on these and often these are short-lived as it is difficult to get a foothold in this market.

6.1 Bio-based and Biodegradable

6.1.1 Polylactic Acid (PLA)

PLA is a 100% bio-based and biodegradable plastic that can biodegrade in industrial composting plants. It is relatively low cost compared to many other bio-based and biodegradable plastics, and is widely used as an alternative to conventional fossil-based plastics, particularly PET but other polymers too. PLA is approved for food contact applications, making it suitable for many different types of packaging. It is also transparent, making it particularly desirable for packaging which requires the consumer to be able to view the product. The material is breathable, thus an ideal packaging for food products that require oxygen, for example salad leaves. PLA is regularly combined with paper to produce compostable paper cups and plates. [22] Heat-stable PLA is also available, meaning that compostable coffee cups can be produced.[23] It has also been used as a replacement for expanded polystyrene foam packaging.[24] In 2015 the PLA market size for packaging was over $200 million; it is expected that this will grow to $800 million by 2024. [25]

Other markets include textiles and consumer goods. The PLA market from textiles, including dyeing and breathable material, will also continue to grow rapidly. In 2015, the total PLA market in Europe was above $400 million, and it is expected that this will exceed $1,600 million by 2024.[26] One example of PLA use in consumer goods is the Sony Walkman; in 2002 Sony became the first company to use PLA for a whole product casing.[27] Additives were included to improve the durability of the plastic and put off biodegradation during the product's lifetime. Despite isolated examples such as this, there has not been a significant penetration of PLA into the consumer goods market.

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[22] Jamshidian, M. et al (2010) Poly-Lactic Acid: Production, Applications, Nanocomposites, and Release Studies, *Comprehensive Reviews in Food Science and Food Safety*, Vol.9, No.5, pp.552–571.
[23] *Heat resistant PLA for coffee cups*, https://www.plastics.gl/packaging/hot-stuff/
[24] *BioFoam*, https://www.synbratechnology.com/biofoam/
[25] *Lactic Acid & Polylactic Acid (PLA) Market Size, Price Trends 2024*, https://www.gminsights.com/industry-analysis/lactic-acid-and-polylactic-acid-market
[26] *Lactic Acid & Polylactic Acid (PLA) Market Size, Price Trends 2024*, accessed 15 October 2018, https://www.gminsights.com/industry-analysis/lactic-acid-and-polylactic-acid-market
[27] Mori, H., et al, (2005) Sony's Activity for Vegetable-based Plastic, paper given at 4th International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Japan, December 2005

NatureWorks are currently the biggest PLA manufacturer, currently producing approximately 200,000 tonnes. Total Corbion are setting up a 75,000 tonne production plant in Thailand and it is expected that in future they will become the market leader. [28]

6.1.2 Starch blends

Following bio-PET (see below), starch blends are the most widely produced bio-based plastic globally. They make up a large number of different plastics, thus have a wide variety of bio-based carbon contents and biodegradability grades. Starch blends are extremely versatile as they can be blended with many different materials to get the required characteristics. They made up almost half of all flexible packaging and hold a large percentage of the bio-based and/or biodegradable market share in agriculture.[29]

Perhaps the most common starch blend is Mater-Bi, a biodegradable plastic produced by the Italian company Novamont. It is available in four different biodegradability grades (in terms of TUV certifications), including a soil biodegradable and industrially and home compostable plastic.[30] These are most widely used as the liner for household food waste bins. In agriculture it is also used as a mulch film.

The data for starch blends shows that it is growing at an unsteady rate with a slight decrease in 2017, however literature states that growth is slow and steady.

6.1.3 Polybutylene Succinate (Adipate) (PBS(A))

PBS and PBSA are biodegradable plastics that can be made from 100% fossil-based or 100% bio-based materials. PBS(A) can be used in an enormous variety of applications. It is currently used most in films, single use bags or food and cosmetics packaging. It has similar properties to PP and thus can be used for the same applications (see section 6.2.4).

Bio-PBS reached the market in 2016 and is currently only being produced by Mitsubishi Chemicals. Their production capacity is currently 100,000 tonnes. Bio-PBS was slower to reach commercialisation than expected due to the low supply of bio succinic acid and bio-BDO.

In September 2018 Mitsubishi Chemicals and PTT Global Chemical joined forces to create a plastic blend from PBS and PLA. This has novel properties and is stronger than other plastics but still biodegradable. It is expected that this will increase demand for PBS.[31]

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[28] Barrett, A. (2018) *The NatureWorks Saga*, accessed 11 October 2018, https://bioplasticsnews.com/2018/06/05/natureworks-saga-thai-fiasco/

[29] Rosenheim, H., De, I., and Hyvedemm, S. *Bioplastics market data 2017*, Report for European Bioplastics, https://docs.european-bioplastics.org/publications/market_data/2017/Report_Bioplastics_Market_Data_2017.pdf

[30] *MATER-BI Certifications*, accessed 15 October 2018, https://novamont.it/eng/mater-bi-certifications

[31] Barrett, A. (2018) *Mitsubishi Chemical and PTT Create a New Bioplastic for Straws*, accessed 18 October 2018, https://bioplasticsnews.com/2018/09/05/mitsubishi-chemical-and-ptt-create-a-new-bioplastic-for-straws/

Table 2: Types of Bio-based and/or Biodegradble Plastics and Key Information

Plastic type	Typical bio-based carbon content	Claimed biodegradability in typical applications	Bio-based feedstock (if any)	Market leader	Typical uses
Bio-based and biodegradable					
PLA	100%	OK compost	Sugarcane, sugarbeet, corn, potato, wheat	NatureWorks	Food service ware, bottles, bags, cups, tubs, cartons, coffee cups.
PHAs (incl. PHB, PHV, PHH)	100%	OK compost industrial & home, OK biodegradable soil, water & marine	Sugarcane, sugarbeet, corn, potato, wheat	Danimer Scientific (formerly Meredian Holdings Group)	Food service ware, bottles, bags, packaging, medical.
Starch Blends (incl. Mater-Bi)	25 – 100%	Vary dependent on brand Mater-Bi: OK biodegradable soil, OK compost home & industrial	Varies dependent on brand e.g. corn, potatoes, wheat	Novamont	Primarily compostable bin liners under Biobags brand
Bio-PBS(A)	20 - 100%	OK compost home & industrial	Sugarcane, sugarbeet, corn, potato, wheat	Mitsubishi Chemicals	Films, bags, food and cosmetics packaging
Bio-based and non-biodegradable					
Bio-PET	20 - 30%	N/A	Most often sugarcane but possible with sugarbeet or starch	Indorama	Bottles, films, food packaging

Bio-PE	100%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	Braskem	Packaging, film, single use bags
PEF	100%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	Avantium/BASF	bottles, textiles, food packaging, carpets, electronic materials and automotive applications
Bio-PP	30%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	FKuR	Packaging, textiles, bottles, banknotes
Bio-PAs (Nylons)	30 - 100%	N/A	Sugarcane, sugarbeet, corn, potato, wheat, or castor seed oil	Rennovia	Fibres, films, engineering
PTT	37%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	DuPont	Fibres e.g. textiles and carpets, food packaging, engineering.
Fossil-based and biodegradable					
PBAT	0 – 50%	OK compost industrial	Biomass	BASF	Film, clingwrap, single use bags, mulch films
PBS(A)	0 – 20%	OK compost home & industrial	Biomass	Mitsubishi Chemicals	Films, bags, food and cosmetics packaging
PCL	0%	Some comply with EN13432 e.g. Capa 6500	None	N/A	Medical, artists putty
PVA	0%	N/A	None	N/A	Soluble containers, e.g. washing tablet, paper adhesive, thickener

6.1.4 Polyhydroxyalkanoates (PHAs)

PHAs are a family of extremely diverse plastics, including PHB, PHBV, PHV and PHH. They are all 100% bio-based and are often claimed to be biodegradable in a range of different environments, including industrial composters, home composters, soil, fresh water and sea water. In the 1990s it was expected that PHA would quickly become a market leader, however due to the low prices of oil and the high processing price of PHA, they didn't break into the market as previously predicted.

PHAs are extremely versatile materials as their properties can be fully controlled during production, thus they are suitable for a wide range of applications. They generally have good barrier properties, similar to that of conventional packaging materials such as PET and PP. Their main drawback is they are generally quite brittle compared to other plastics, however this can be monitored and controlled during production to optimize the product.[32]

They were first used as packaging materials, such as shampoo bottles for Wella AG and have also been used by several other companies including Procter & Gamble.[33]

Despite their high suitability for a number of products, as PHA prices are extremely high they are perhaps more suitable for thin materials such as films and coatings.[34] PHBV, in particular, has been approved for food contact applications, thus is sometimes used as a thin film on paper for single use cups, plates or food trays. PHA also has the advantage that it can be printed on or dyed easily, however, due to the high price of PHAs, they are often used as a printed coating on another biodegradable material.

PHAs are also non-toxic to humans and completely biocompatible, giving them many applications in medicine, such as implants that do not later need to be removed.[35]

PHA growth has been stunted in the past two years, however it is expected to grow steadily in coming years. Danimer Scientific are due to open a commercial production facility in Kentucky in 2019. The production capacity of this facility has not yet been published, however it is known that Danimer received large tax incentives from Kentucky of over $1.5 million.[36]

Mango materials are also working to commercialize the production of PHA and are researching producing it from methane in low gravity environments. They are currently receiving funding

[32] Samyn, P. (2018) Abstract for the 1st PHA platform World Congress, September 2018, https://www.bioplasticsmagazine.com/en/events/1PHAworldcongress/abstracts.php?viewmode=blank
[33] Guo-Qiang Chen (2009) A Microbial Polyhydroxyalkanoates (PHA) Based Bio- and Materials Industry, *Chemical Society Reviews*, Vol.38, No.8, pp.2432–2446
[34] Philip, S., Keshavarz, T., and Roy, I. (2007) Polyhydroxyalkanoates: biodegradable polymers with a range of applications, *Journal of Chemical Technology & Biotechnology*, Vol.82, No.3, pp.233–247
[35] Valappil, S.P., Misra, S.K., Boccaccini, A.R., and Roy, I. (2006) Biomedical applications of polyhydroxyalkanoates, an overview of animal testing and in vivo responses, *Expert Review of Medical Devices*, Vol.3, No.6, pp.853–868
[36] Staff, P. (2018) *Danimer Scientific to open world's first PHA commercial production plant*, accessed 18 October 2018, https://www.plasticstoday.com/packaging/danimer-scientific-open-worlds-first-pha-commercial-production-plant/98060730659534

from NASA and it is not clear of a project timescale, however if they succeed this could mean enormous growth for the PHA industry due to the availability of methane.[37]

6.2 Bio-based and Non-biodegradable

6.2.1 Bio-polyethylene Terephthalate (bio-PET)

Bio-PET is the most common bio-based plastic, with production figures peaking at over 900,000 tonnes in 2016. It is a drop-in bio-based, non-biodegradable option for traditional PET. It is currently made of up to 32% biomass, although there have been efforts to move to a 100% bio-based PET.

Coca Cola, Procter & Gamble, Nike, Heinz and Ford Motors have formed a strategic partnership called the Plant PET Tech Collaborative, in order to accelerate the development of 100% bio-PET, and it is believed that these large investors are the reason that Bio-PET is currently the most well-established bio-based plastic. The collaboration created a prototype of a 100% bio-based PET bottle in 2015[38], however this version has yet to be produced on a commercial scale.

PET is made up of 32% monoethylene glycol (MEG) and 68% purified terephthalic acid (PTA); it is the MEG that is derived from biomass in the currently commercially available bio-PET. To produce a bio-PET made entirely of biomass, one would require bio-PTA, which isn't currently commercially available, however Coca-Cola expect this to reach the market by 2020.[39]

In 2016, approximately 70% of rigid bio-based and/or biodegradable packaging was bio-PET.[40] Similarly, to fossil-based PET, the majority is used for bottles, including for soft drinks, alcoholic beverages, detergents, oils and cosmetics however it can also be used as a film in food packaging. One key example is Coca Cola's product PlantBottle™[41] which contains up to 32% bio-based material.

It was previously expected that bio-PET would continue to be a market leader. In 2013 it was predicted that bio-PET production capacity would be at 5 million tonnes by 2018, [42] an enormous difference to the current value of little over 0.5 million tonnes. It was expected that

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[37] *Mango Materials selected for Phase II STTR NASA award*, accessed 18 October 2018, https://www.bioplasticsmagazine.com/en/news/meldungen/20170810-Mango-Materials-wins-NASA-award.php
[38] Guzman, D. de (2015) *Coca-Cola produces 100% bio-based PET bottle*, accessed 11 October 2018, https://greenchemicalsblog.com/2015/06/09/coca-cola-produces-100-bio-based-pet-bottle/
[39] *Coca-Cola's 100% Plant-Based Bottle*, accessed 11 October 2018, https://www.packaging-gateway.com/projects/coca-cola-plant-based-bottle/
[40] Rosenheim, H., De, I., and Hyvedemm, S. *Bioplastics market data 2017*, Report for European Bioplastics, https://docs.european-bioplastics.org/publications/market_data/2017/Report_Bioplastics_Market_Data_2017.pdf
[41] *Innovative packaging: An introduction to PlantBottle™*, accessed 11 October 2018, https://www.coca-cola.co.uk/stories/inovative-packaging-an-introduction-to-pantbottle
[42] Aeschelmann, F., and Carus, M. (2015) Bio-based Building Blocks and Polymers in the World: Capacities, Production, and Applications–Status Quo and Trends Towards 2020, *Industrial Biotechnology*, Vol.11, No.3, pp.154–159

the market would increase dramatically due to investments by Coca Cola, however there have been difficulties arising, primarily due to variation in the bio-MEG supply.

6.2.2 Bio-polyethylene (bio-PE)

Bio-PE is also a very popular 'drop-in' bio-based plastic; however, unlike bio-PET, it is 100% bio-based. It is used for a wide variety of applications, including single use bags, cosmetics, soap and food packaging, as well as packaging films. It is mainly produced by Braskem and sold under the trademark 'I'm green'.[43]

Bio-PE is identical in structure to traditional PE; thus, it can be used in the same way. It is extremely versatile however is most often used in bottles, food packaging and carrier bags.

Bio-PE is not showing much market growth compared to other plastics, largely due to its high price compared to fossil-based PE. Growth in future years is unexpected as the market turns towards novel plastics rather than drop-in.

6.2.3 Polyethylenefuranoate (PEF)

PEF is a very new bio-based plastic to enter the market and another alternative to bio-PET, as it is a 100% bio-based non-biodegradable plastic. It is not yet commercially produced, however Avantium and BASF have collaborated to make it commercially available and are currently in the process of starting up a plant with a production capacity of 50,000 tonnes. It is expected that this will be operational by 2024[44], however it has also been reported that Avantium and BASF are in dispute about this date.[45]

The process to produce PEF feedstocks is reportedly much cheaper than the proposed process for creating 100% bio-PET, meaning that this is potentially a low-cost alternative.[46] PEF also has slightly different properties due to its novel chemical structure. It is reported to have better CO_2, water and oxygen barrier properties than PET, meaning that it is better suited to some packaging applications. PEF also has better mechanical properties than PET, meaning that PEF packaging could result in light weighting by up to 60%.[47]

It is not clear how much of the market for PET that PEF will take, but at full capacity the Avantium factory will only account for 2% of the overall PET market in Europe. This amount is thought to be acceptably incorporated as contamination into existing and well-established PET recycling, however this should be treated with caution and is not a permanent solution.[48] If the market grows beyond 2%, there will likely be the need for separate recycling streams. As PET bottle recycling is the cleanest and most effective post-consumer recycling stream at present it is unclear how this issue will be navigated; this comes as there is increased focus on

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[43] *Braskem*, accessed 11 October 2018, http://hollandbioplastics.nl/over-ons/partners/braskem/
[44] (2018) *PEF pilot phase set to be extended*, accessed 11 October 2018, https://www.avantium.com/press-releases/pef-pilot-phase-set-extended/
[45] Guzman, D. de (2018) *BASF, Avantium in Synvina dispute*
[46] Barrett, A. (2013) *Bottles from Furfural*, accessed 11 October 2018, https://bioplasticsnews.com/2013/12/17/bottles-from-furfural/
[47] *Polyethylene Furanoate (PEF) - The Rising Star Amongst Today's Bioplastics*, accessed 11 October 2018, https://omnexus.specialchem.com/selection-guide/polyethylene-furanoate-pef-bioplastic
[48] Guzman, D. de (2017) *PEF to be integrated in European PET recycling*, accessed 25 October 2018, https://greenchemicalsblog.com/2017/05/24/pef-to-be-integrated-in-european-pet-recycling/

simplifying recycling streams (especially for consumers) to increase recycling yields as part of new EU targets on plastics recycling.

6.2.4 Bio-Polypropylene (PP)

Both fossil and bio-based PP are suitable for a wide variety of applications, most notably in plastic hinges, due to its resistance to fatigue. Despite this, it is also a fairly rigid plastic and therefore ideal for many packaging applications. It is also used to make buckets and car battery casings, where mouldings can be produced in high volume, at relatively low cost and with a lower grade finish.

Use of Bio-PP is expected to be led by the automotive industry and IKEA. IKEA has recently announced that they will be using bio-PP in all its plastic products, starting with a 20% renewable content, and are working with Neste to make 100% bio-PP commercially available with the intention of moving to 100% bio-PP by 2030.[49] This is expected to boost the bio-PP market massively.

Bio-PP is also expected to see growth in the automotive industry[50], due to the recent EU carbon dioxide limits[51], putting pressure of vehicle manufacturers to reduce vehicle weight.

6.2.5 Bio-polyamides (Nylons/bio-PA)

PAs, or nylons as they are more widely known, are used mostly in textiles and engineering. Engineering includes the automotive industry, machinery, electronics, consumer goods, films and coatings. Currently, the automotive industry holds the largest market share of bio-PA, which can be used to decrease vehicle weight—combined with glass fiber it is a very strong material. The European Union carbon dioxide limits[52] are putting pressure on vehicle manufacturers to reduce weight, which is driving the PA market in this area.

6.2.6 Polytrimethylene terephthalate (PTT)

PTT is a type of polyester used solely in carpet fibers. It is favoured as it is more durable and resilient than traditional polyester and feels much softer. It is hydrophobic, therefore naturally very stain resistant. PTT is also cheaper than Nylon, giving it an economic advantage.[53] As with other bio-based polymers, the introduction of these into recycling streams (e.g. for carpet PP) can cause contamination issues for the recyclers.

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[49] Barrett, A. (2018) *Ikea and Neste Go Bioplastics*, accessed 15 October 2018, https://bioplasticsnews.com/2018/06/08/ikea-and-neste-go-bioplastics/

[50] *Bio Polypropylene (PP) Market Size, Growth Trends Report 2022*, accessed 18 October 2018, https://www.gminsights.com/industry-analysis/bio-based-polypropylene-pp-market-size

[51] *Regulation (EC) No 333/2014 of the European Parliament and the Council: amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars*, accessed 17 October 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009R0443-20140408

[52] *Regulation (EC) No 333/2014 of the European Parliament and the Council: amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce CO2 emissions from new passenger cars*, accessed 17 October 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02009R0443-20140408

[53] *What You Didn't Know About Triexta, the New Carpet Fiber*, accessed 15 October 2018, https://www.thespruce.com/triexta-ptt-carpet-fiber-2908799

6.3 Fossil-based and Biodegradable

6.3.1 Polybutylene adipate terephthalate (PBAT)

While there are many fossil-based and biodegradable materials, PBAT is the market leader. This is a biodegradable fossil-based plastic, with BASF producing it under the brand name ecoflex®. It holds OK Compost industrial certification and therefore meets EN 13432.[54] It also produces a variation called ecovio® which has a PBAT base blended with bio-based PLA. Both materials are used for products such as mulch films and carrier bags.

PBAT has a random structure resulting in high flexibility and toughness. It has many similar properties to LDPE with the extra functionality of biodegradability, therefore it is often used for single use carrier bags and cling wraps. It is also not soluble to water, meaning it is a good coating to waterproof paper cups.

Due to its flexibility, PBAT is often combined with more rigid plastics for uses such as water bottles.

6.3.2 PBS(A)

As outlined above, PBS(A) can be 100% bio-based or 100% fossil-based. When 100% fossil-based, the properties and uses are the same as outlined in section 6.1.3.

At present, it is unknown how much of the market is bio-based compared to fossil-based PBS(A).

6.3.3 Polycaprolactone (PCL)

PCL is a fossil-based biodegradable polyester. It is often marketed to be added to other biodegradable plastics to increase durability. There is little mention of it in literature and it is not used in any common biodegradable plastic brands, and thus it is assumed that it hasn't broken into the market.

6.3.4 Polyvinyl Alcohol (PVA)

PVA is another fossil-based biodegradable polymer. It is water soluble and is therefore often used for dissolvable items such as dishwasher tablet casing and bait casing in fishing. It is also breathable, so often used as a backing sheet in feminine hygiene products and nappies.

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[54] BASF *Certified - the compostability of ecoflex®*, accessed 16 October 2018, https://www.plasticsportal.net/wa/plasticsEU~en_GB/portal/show/content/products/biodegradable_plastics/ecoflex_compostability

7 The Value Chain

The value chain for bio-based and biodegradable plastics starts with the production of raw materials which are later converted and used to produce various bio-based and/or biodegradable plastic products. Table 3 illustrates a simplified value chain for bio-based and biodegradable plastics.

The key materials have already been addressed in the previous chapter, however their production and process routes will be investigated in more detail in subchapter 7.1. The waste management options for these is discussed in chapter 11.

Table 3 - Description of the value chain for bio-based and biodegradable plastics with information on products and a short description of each step.

Stage	Feedstock/Products	Description
Raw materials (biomass)	Waste streams Multiple organic waste By-products and by-streams Forestry side-streams Dedicated agricultural crops and residues Aquatic biomass Food processing residues Process and waste water	Raw materials from forestry, agriculture, residues, bio-waste and other sources. This includes timber, cassava, plant oils, maize, sugar cane/beet, and algae.
Primary processors (including biomass refineries and converters)	(Pre-)treatment Transformation - Biochemical - Thermochemical - Biotechnological - Physical/Mechanical	Depending on the biomass material and the end product, this step can be divided into multiple stages. The biomass refineries convert the raw material to produce fuel, power, heat and chemicals. Primary processors produce for instance bio-based plastic granules while the converters convert these to different products.
Industrial applications	Bio-based plastics Biopolymers Surfactants Active ingredients Biomaterials Biolubricants	Biomass can be used in a wide range of applications across society. Technical, economic and political developments in this industry play a role in the demand of biomass as a resource for these applications.

Consumer goods	Biofuels Textiles and clothing Packaging Furniture Cosmetics Construction elements Pharmaceuticals Car components	The extent of consumer goods that are produced are dependent on demand from consumers of these products. This will also be dependent on the price and which regulations and standards that are put forward.
Waste management and recyclers	Material recycling In-vessel composting Anaerobic digestion with biogas Incineration with energy recovery	There are several possible downstream routes that bio-based and biodegradable products can take once they are disposed of, each with different conditions, requirements and outcomes.

7.1 Process Routes

To understand trends in the production of bio-based and/or biodegradable plastics, it is first necessary to look at how these plastics are produced. Already outlined in Table 2 are the feedstocks for key plastics. These feedstocks are processed several times to obtain raw material building blocks that can then be turned into bio-based or biodegradable products. Details of some key building blocks are outlined in the Appendix (chapter 12).

It should also be noted that waste from the food industry can be used to replace many of these feedstocks, such as the husks from cocoa beans or waste from wheat crops. Waste products from the production of sugar cane, timber and logs can be used to produce ethanol. Ethanol can produce ethylene, a plastic material, through a dehydration process (see section 7.1.5).

In terms of land use, data from the European Bioplastics Association shows that 0.016 % of the global agricultural area is used to grow bioplastic feedstocks.[55] Replacing 50 % of the global consumption of plastics with plastics from renewable resources, i.e. over 150 million tons of plastic, would result in 1.24 % of global agriculture area taken up for this practice.[56]

'Feedstock efficiency' is a term often used to mean the ratio of feedstock weight to final plastic weight. In less efficient process routes some valuable material is lost. Shown in Table 4 are some feedstock efficiencies. It can be seen that the 100% bio-based alternatives often have less efficient process routes than their partly fossil-based counterparts.

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[55] European Bioplastics (2017). *Bioplastics market Data 2017*. https://docs.european-bioplastics.org/publications/market_data/2017/Report_Bioplastics_Market_Data_2017.pdf
[56] Klimastiftelsen (2018). *Plast og Klima – To Sider av Samme Sak.* Last accessed 29.11.2018. https://klimastiftelsen.no/wp-content/uploads/2018/09/NK4_2018_Plast-og-klima_rev1.pdf

Table 4 - Feedstock efficiencies[57]

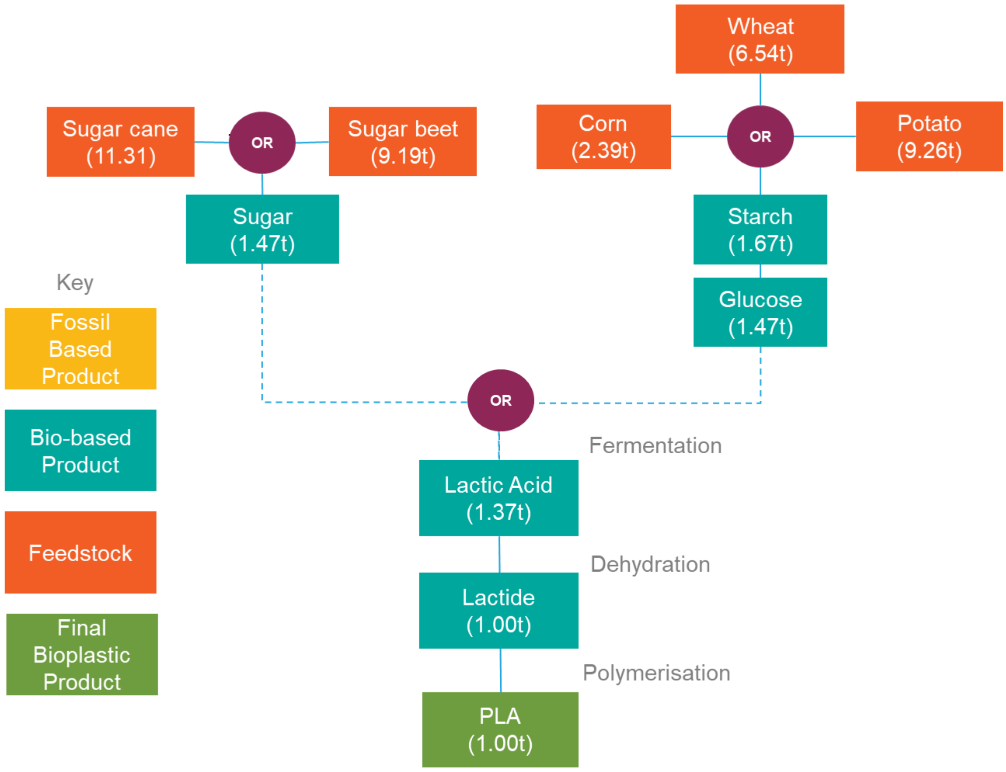
Plastic	Feedstock efficiency (final/sugar weight)%
PBS (with bio-succinic acid and fossil-based 1,4-BDO)	72%
PLA	68%
Bio-PET (32% bio-MEG)	62%
PBS (100% bio-based)	58%
PHB	35%
Bio-PET (100% bio-based)	35%
Bio-PE	23%

Data on feedstock ratios and process diagrams from the Institute for Bioplastics and Biocomposites[58] have been adapted and are shown in the following sections. It should be noted that the use of a different feedstock will alter the first stage, however, after this the processes are essentially the same.

7.1.1 PLA

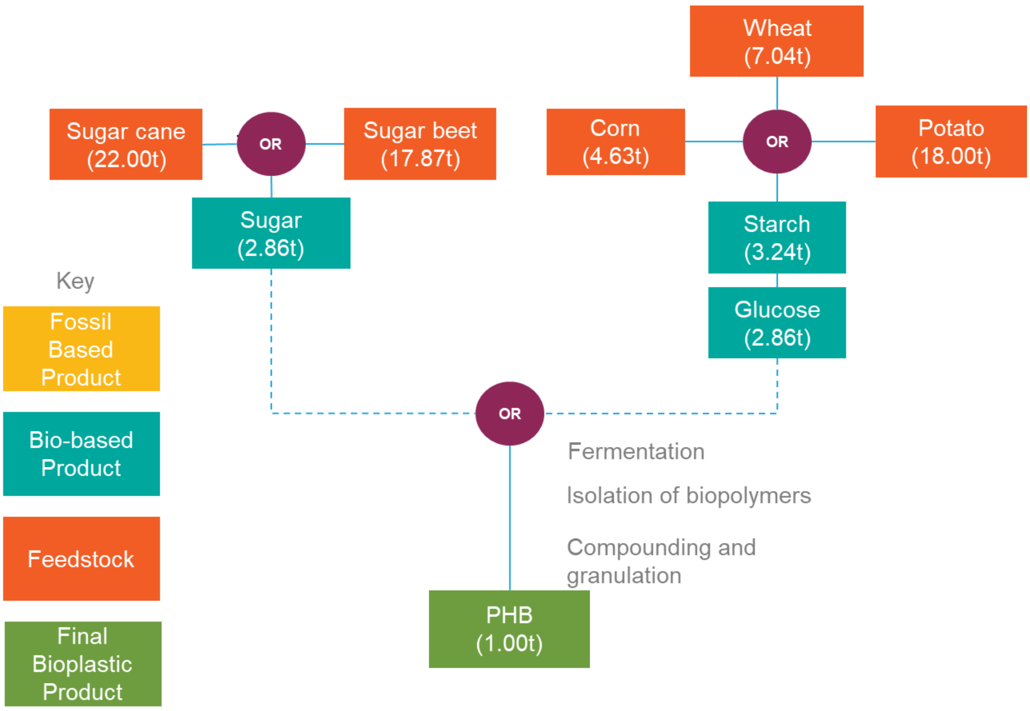
The feedstock for PLA is a renewable, carbohydrate rich product such as sugar cane, sugar beet, corn, wheat or potato. To produce 1 tonne of PLA these feedstocks are each turned to 1.47 tonnes of sugar, and then fermented to produce lactic acid (1.37 tonnes). This lactic acid is dehydrated to lactide (1 tonne), before undergoing polymerisation to get PLA. PLA is therefore relatively high-yield, turning 1.47 tonnes of sugar to 1 tonne of plastic.

[57] Institute for Bioplastics and Biocomposites *Biopolymers facts and statistics 2017*, https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren/Biopolymers-Facts-Statistics_2017.pdf
[58] Institute for Bioplastics and Biocomposites *Biopolymers facts and statistics 2017*, https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren/Biopolymers-Facts-Statistics_2017.pdf

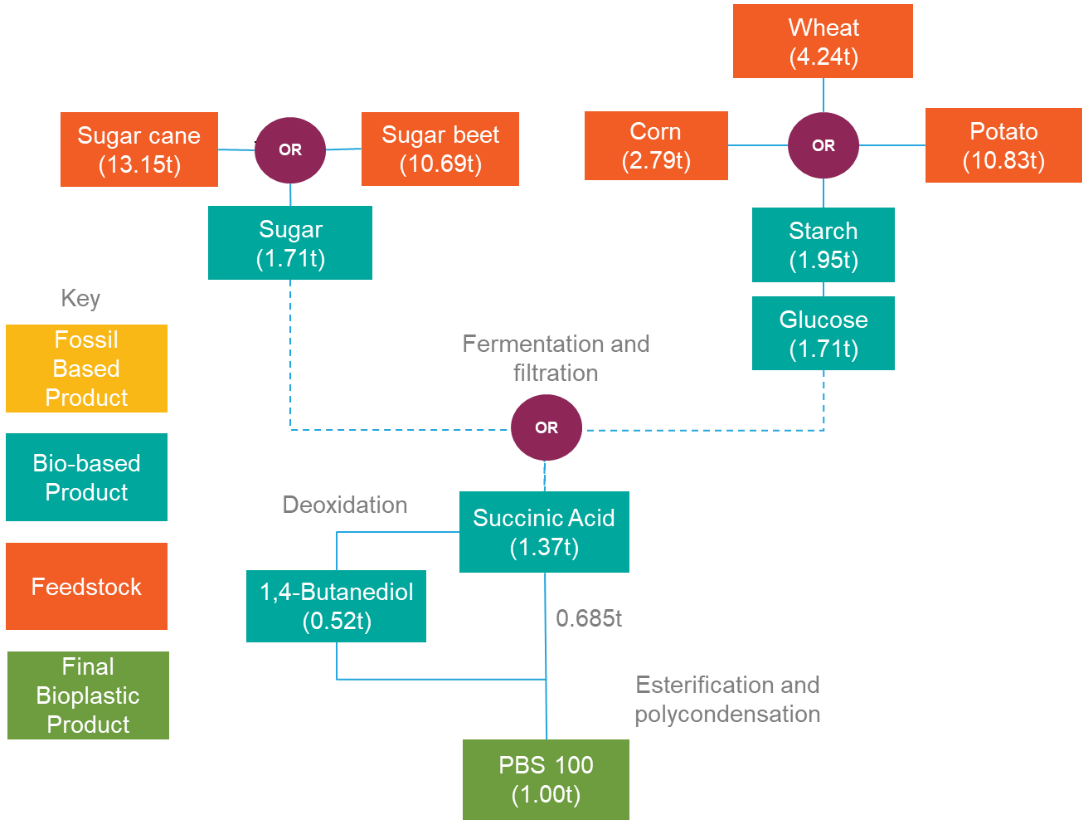


7.1.2 PHA

The process diagram for PHB, an example in the family of PHAs, is shown below. PHB is produced directly from the fermentation of carbohydrates and the isolation of these polymers with no intermediate products. Although the process route is short, the feedstock efficiency isn't as good as PLA, with 2.86 tonnes of sugar being turned to 1 tonne of PHB.

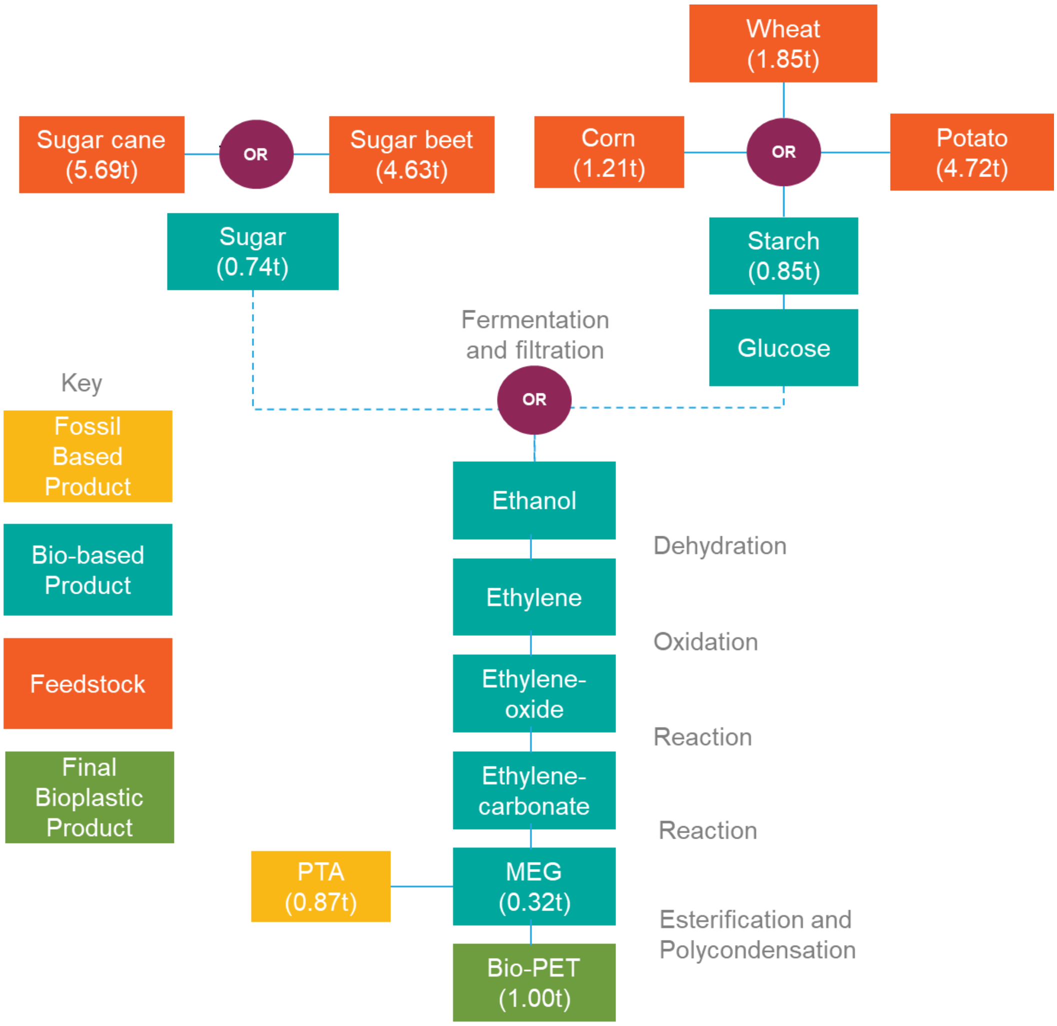


7.1.3 Bio-PBS



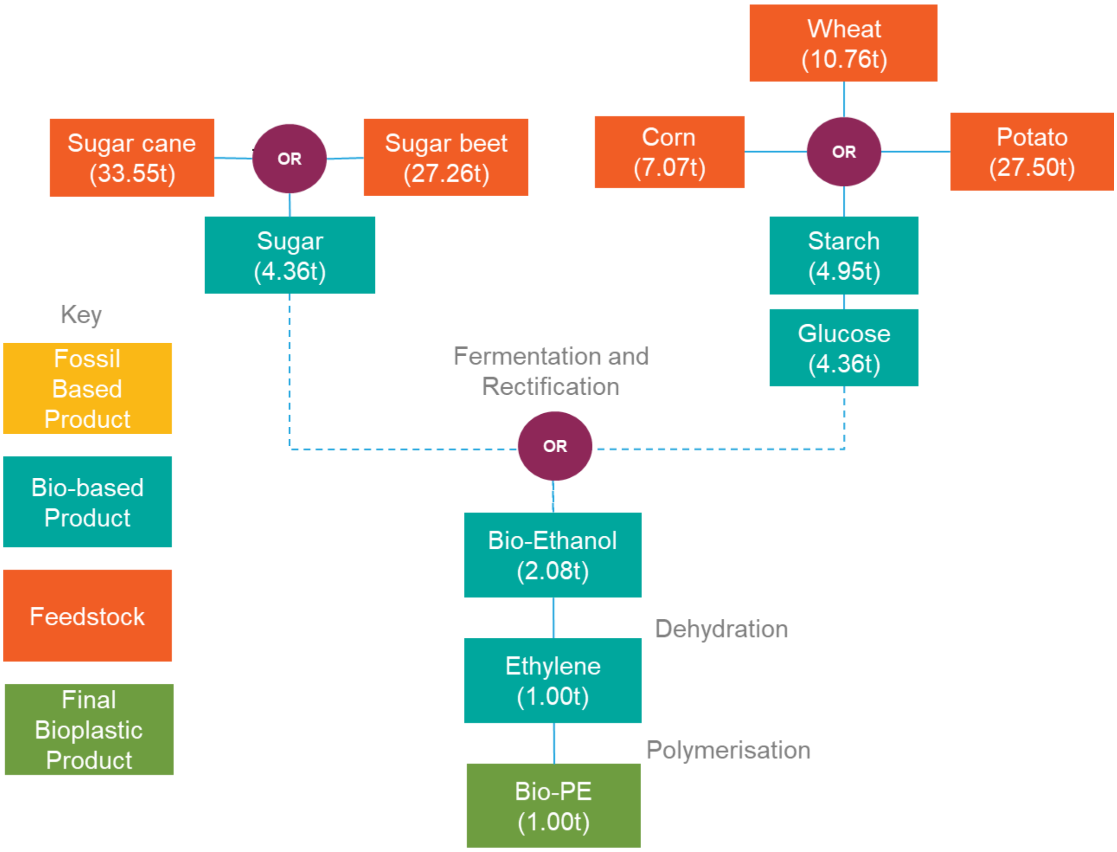
1 tonne of bio-PBS can be produced from 1.71 tonnes of sugar if succinic acid is used to make 1,4-BDO. This is the most efficient way to produce bio-1,4-BDO, however it should be noted that there are no production facilities at present which are producing 1,4-BDO commercially from succinic acid (see section 9.1.1.5). For partly bio-based or fossil-based PBS the 1,4-BDO and/or Succinic Acid are simply replaced with their fossil-based counterparts.

7.1.4 Bio-PET



To produce 1 tonne of bio-PET 0.32 tonnes of bio-MEG is required. This can be produced using 0.74 tonnes of sugar, by fermenting to produce ethanol and subsequently treating to obtain MEG. 0.87 tonnes of conventional PTA is then added to the bio-MEG to produce the final product. To obtain 100% bio-PET the PTA would need to be replaced with bio-PTA.

7.1.5 Bio-PE



1 tonne of bio-PE is produced using 4.36 tonnes of sugar, thus this process route has a very low yield. The sugar is fermented and rectified to produce bio-ethanol, and then dehydrated to produce ethylene before being polymerised to produce bio-PE.

7.2 Primary processors and converters

The primary processing of raw materials is predominantly by 10-15 major companies. One-third of these are originally petrochemical companies which have expanded their production to include bio-based sources.

Biomass refineries are facilities that integrate biomass conversion processes. The International Energy Agency has defined biorefining as the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat).[59] The processes that take place in biorefineries are very similar to those in today's petroleum refinery. It is possible to replace the production of petrochemicals with materials from biomass in the same facility.The production of raw materials in Norway is limited, however there is one major biorefinery, Borregaard, that produces bioethanol, vanillin, cellulose and lignin. Borregaard produces a range of products and raw materials from renewable sources for the chemicals industry.

[59] https://www.iea-bioenergy.task42-biorefineries.com/upload_mm/6/1/6/3dc6bf0d-9871-4841-be91-5d79e7fc3e5f_Leaflet%20IEA%20LR%20100309.pdf

Converters of bio-based plastics will convert the materials into new products that can be sold to brand owners. The presence of converters in Norway is higher, however the majority of the bio-based and biodegradable plastics in Norway are imported, in large as the finished product.

It is unknown how much production takes place in Norway, though it is likely that this share is quite small. The production of materials and products often take place abroad due to high operating costs in Norway. Some companies that used to produce bio-based and biodegradable products in Norway have in later years moved their production abroad.

8 Market Segments

Albeit the small market share of bio-based and biodegradable plastics, they can be found in many market segments, including packaging, textiles, automotive, consumer goods, agriculture, construction and electronics. **Figure 6** shows the global market of these materials by product group in 2017. It shows that packaging accounts for the majority of the bio-based and/or biodegradable packaging market. Packaging is also the dominant sector in the conventional plastics market in Europe, with buildings and construction the second most—this sector is much less well developed in the bio-based/biodegradable market.

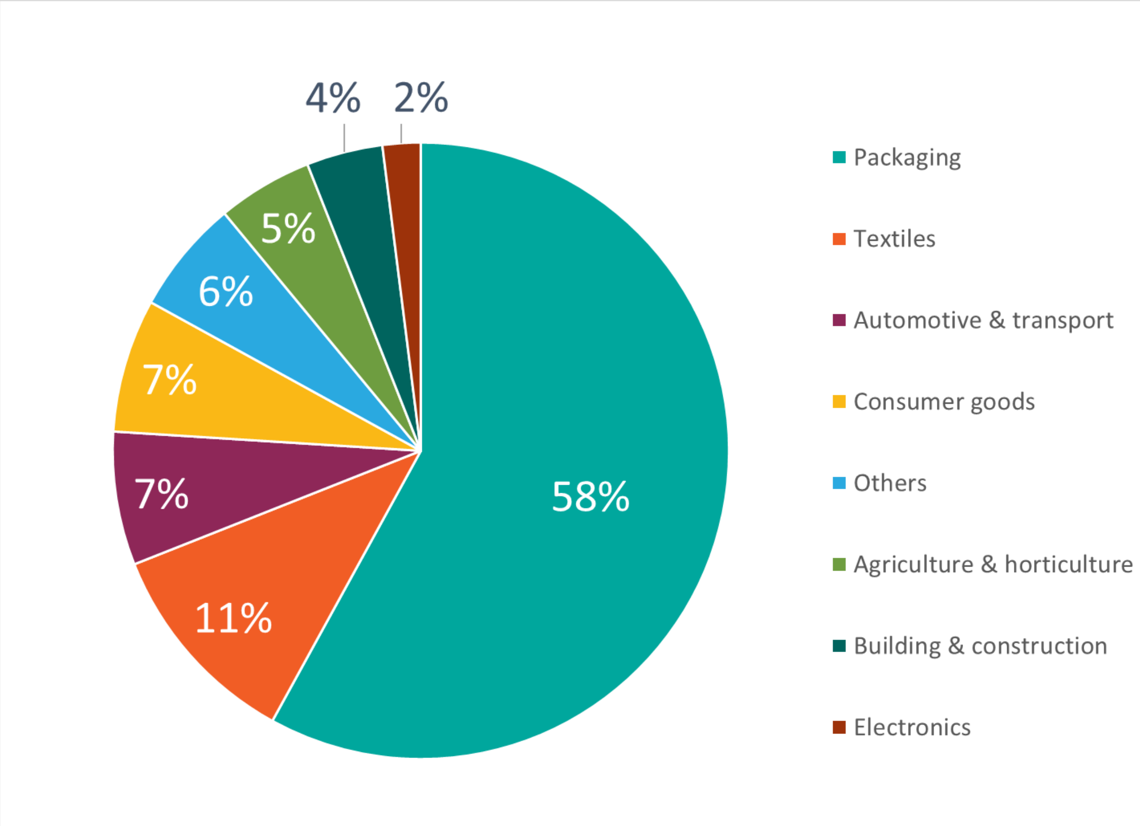


Figure 6: Global production capacity of bio-based and biodegradable plastics, by product group (2017)[60]

8.1 Packaging

Packaging is the main use, as shown in **Figure 6**, taking 58% of the market share. Packaging includes both rigid and flexible plastics. The highest share is flexible packaging which has over half of this market segment. Biodegradable plastics are predominantly used in packaging as the products can often have a short functional life and are used in food contact applications and so can become contaminated which makes recycling challenging.

Recent changes to the EU Packaging and Packaging Waste Directive (PPWD) and Waste Framework Directive (in regard to minimum standards for Extended Producer Responsibility)

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[60] European Bioplastics, Nova-Institute (2017)

will place greater focus on more sustainable packaging and biodegradability/compostability is likely to have a role to play in certain circumstances.

The EU Single Use Plastics (SUP) Directive will also have a large impact on plastic packaging in the EU as some products such as bottles and takeaway cups and boxes have been singled out for specific measures to help reduce their use. It is not clear what place biodegradable plastics will have in this as yet, but they are increasingly being offered as a solution to the problem of single use plastic products. However, the uncertainty around whether claims of biodegradability in the marine environment are credible means that the SUP Directive does not exempt them at this time.[61] [62]

Rigid bio-based and/or biodegradable plastics are also used widely in cosmetics packaging, for example lipstick cases or shampoo bottles. Flexible packaging, on the other hand, is most often used in films and trays for fresh produce to improve shelf life. Plastic food packaging has to follow strict regulations in the EU with specific safety requirements for materials in contact with food.

The most prominent biodegradable packaging product that has been on the Norwegian market for many years is the biodegradable bags used to collect food waste in Norwegian households. Household food waste is separated in each household and collected and sent to composting or biogas plants. Biodegradable bags gained a large footing in Norway as consumers disliked putting organic waste in plastic bags.

In recent years, consumers have discovered challenges with these biodegradable bags; they start degrading after a few days and need to be frequently replaced. There has therefore been a move to PE-bags in many municipalities (both fossil-PE and bio-PE) and the need for biodegradable waste bags has decreased. This has resulted in a saturated market in terms of suppliers of biodegradable waste bags. It has been difficult for new suppliers to gain access to this saturated market and existing suppliers have had little growth.

8.2 Textiles

Nearly 70 % of all textiles that are produced globally are made from synthetic materials made from oil and are plastics.[63] Polyester is the most common synthetic material. Other common synthetic materials are polyamide (nylon), acrylic, elastane, modacrylic, polyurethane and polyethylene. Other synthetic textiles or trademarks are spandex, lycra, goretex, windstopper, aquaguard and thinsulate amongst others.

There are also textiles that are made from plants that have undergone a process that alters their properties. Regenerated cellulose fibres are made of cellulose, primarily derived from

[61] Draft EU legislative resolution on the proposal for a directive of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment, http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+REPORT+A8-2018-0317+0+DOC+XML+V0//EN&language=en
[62] Packaging Europe, *European Parliament approves ban on single-use plastics,* https://packagingeurope.com/european-parliament-approves-wide-ranging-ban-single-use-plastics/
[63] Aas, K. (2018). *Plast Overalt.* Accessed: 15.11.2018. https://naturvernforbundet.no/naturogmiljo/plast-overalt-article37987-1024.html

wood pulp, but modified to encompass the many properties of plastic fibres. Known textiles made from reactive cellulose fibres are viscose, modal, and rayon amongst others.

It is well known that the washing of synthetic materials can lead to microplastic pollution in the marine environment.[64] International reports point to synthetic textile fibres generated from washing of clothing as being one of the largest contributors to plastic pollution of the oceans.[65] This microplastic, as with other microplastics from other sources, is often mistaken for food by marine life and can be ingested causing harm to the animal. How viscose fibres behave in nature is unclear, however there is reason to believe that they may be more easily degradable than conventional plastic material. As already identified in chapter 5.2.1 there is no internationally recognised way of varying this for the marine environment currently, therefore the use of these fibres in products such as wet wipes—specifically designed to be flushed down a toilet—is still questionable at this stage.

Bio-based and biodegradable materials (e.g. bio-polyesters and PLA) are available, but again, even where compostable are unlikely to be marine biodegradable—or at least troublesome to categorically prove as such.

The textile industry is notorious for producing large volumes of waste[66]. It is therefore important that producers are moving towards more sustainable solutions. Changing Markets has recently identified that the production of Viscose results in highly polluted water discharges and that many of the large manufacturers based in the far-east are ignoring calls to introduce best practice in the form of closed-loop chemical systems. The situation is reportedly improving as the two largest manufacturers have made commitments to investing in cleaner technologies.[67]

8.3 Agriculture and Horticulture

Flexible plastics are mainly found in two areas of the industry – as bale wrap and mulch film. Bio-based and biodegradable options are available and, in some cases, biodegradability can potentially offer significant advantages over other conventional plastics.

Bio-based bale wrap is a solution that is available on the market and can give a significant reduction in greenhouse gas emissions from agriculture. The renewable bale wrap is chemically similar to bale wrap made out of fossil-based material. This solution is only used in small scale today due to the higher price of renewable plastic.

Mulch film is used in vegetable and strawberry cultivation and is laid for one season before it is removed. Biodegradable plastics are used in mulching films as they can simply be ploughed into the soil after use and do not have to be separated from organic matter; a task that is both laborious and costly.

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[64] De Falco, F., Gullo, M.P., Gentile, G., et al. (2017) Evaluation of microplastic release caused by textile washing processes of synthetic fabrics, *Environmental Pollution*
[65] https://naturvernforbundet.no/naturogmiljo/plast-overalt-article37987-1024.html
[66] Claudio, L. (2007) Waste Couture: Environmental Impact of the Clothing Industry, *Environmental Health Perspectives*, Vol.115, No.9, pp.A449–A454
[67] Changing Markets (2018) *Dirty Fashion: on track for transformation*, July 2018

Biodegradable mulch film is becoming competitive. There is a lot that indicates that the market for biodegradable mulch film is developing without any external influence because of the savings farmers can make by ploughing it into the soil instead of removing it. It is estimated that 75-80 % of the mulch film is biodegradable and the use is increasing.[68] The biodegradable mulch film sold in Norway today contains renewable material, but it also has fossil content. Film with a higher share of renewable raw material is under continuous development.

Requirements for biodegradation are regulated in accordance with the standard NS-EN 17033 (*Plastics – biologically degradable mulch films for use in agriculture and horticulture – Requirements and test methods*). A central requirement is 90 % degradation after 2 years at room temperature (about 25 °C), i.e. warmer than Norwegian conditions. As the Norwegian environment is colder and harsher, the consequences are not clear. Films will likely degrade differently in the fields depending on the time of year and the environment in the field and could produce microplastics that can be detrimental to microorganisms in the soil. Further research is needed in this area to evaluate whether biodegradable mulch films fully degrade and do not pose a threat to the quality or biodiversity of the soil.

The use of single use biodegradable films could also be considered a waste of resources, particularly as there are well functioning take back and re-use schemes in Norway which would be threatened by these products.

Similarly, biodegradable plastics are used in horticulture, for example as plant pots for herbs. Once the herbs have been harvested, the whole of the remaining plant including the pot could be composted, although potential negative consequences of this are not clear.

8.4 Consumer Goods

Bio-based materials could, in theory, replace a wide range of consumer goods originally made using fossil resources. Items such as glasses, cameras, umbrellas, toys, water bottles, computers, recycling bins, paint, transportation, and cosmetics could all have fossil elements replaced with material from a bio-based resource. They can be made breathable but still waterproof, a function that is particularly important in personal hygiene products such as female sanitary products, nappies and disposable gloves.

This is already happening in many parts of the global society, and it is visible in Norway as well. The largest biorefinery in Norway, Borregaard, produces bio-based material for paint, cosmetics, car batteries, and glasses amongst others.

8.5 Others (incl. catering and medical)

There are also many other diverse applications where conventional plastics are being replaced with bio-based or biodegradable plastic alternatives as companies want to increase their sustainability credentials.

Catering products include disposable packaging as well as disposable non-packaging items. The definition of packaging might differ, and these products are just partly included in packaging

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[68] Gjerset et al. (2018). *ZERO-notat – Fornybar Landbruksplast.* ZERO. Accessed: 15.11.2018 https://zero.no/wp-content/uploads/2018/08/ZERO-notat-fornybar-landbruksplast.pdf

EPR schemes. Catering products have a short functional life, with cups, plates and cutlery often being used once and then disposed of whilst still dirty with food remnants. This provides a huge market for biodegradable products, as these could be disposed of together with the food waste in some countries. However, this could cause contamination in traditional recycling streams (further discussed in chapter 11.2 and 11.3).

Biodegradable plastics are useful in medical applications. One example is starch blends used as a gelatine replacement for medicine capsules. Non-toxic biodegradable plastics are also extremely useful for surgical implants, such as pins, plates or threads to aid broken joint recovery, as traditional methods require a second surgery to remove these objects once the process is complete, however biodegradable plastics will simply degrade themselves, thus avoiding this additional surgery. Poly(glycolide), PGA, for example, is used in medicine as sutures, which lose about 50% of their strength after two weeks, 100% after four weeks and are completely absorbed in 4 - 6 months.

Roughly 10 % of the plastics produced globally are used in the automotive industry. Many of the products used here can be replaced with bio-based alternatives. Composite is a material used to make lighter, safer and more fuel-efficient vehicles.[69] It is both used in engine parts, and in the interior of the car. Biocomposite is a replacement for the fossil-based composite and can replace composite in many car parts, causing fewer greenhouse gas emissions.

Even the market for children’s toys is changing. Danish toy manufacturers are moving to bio-based sources over fossil-based.[70] LEGO has committed to using more sustainable materials in their core products and packaging by 2030.[71]

[69] University of Utah College of Engineering (2011). *Composites in Cars: Making Vehicles Lighter, Safer and More Fuel-Efficient.* Research Report. Accessed 15.11.2018. https://mech.utah.edu/composites_cars/
[70] Plastindustrien (2018). *Hvad kan Bioplast Bruges til?*. Accessed: 15.11.2018 https://plast.dk/hvad-kan-bioplast-bruges-til/
[71] LEGO (2018). *First sustainable lego bricks will be launched in 2018*, accessed 9 November 2018, https://www.lego.com/sv-se/aboutus/news-room/2018/march/pfp

9 Global Markets

9.1 Global Production Capacity

Production is dominated by several key industry players, most notably Total Corbion, Avantium, BASF, Braskem, DuPont and Novamont. In an everchanging market these producers, their production locations and their capacity are changing rapidly. Several key players and their specifics can be found in Appendix 12.1.

Exact production data and demand for bio-based and biodegradable plastics is very hard to come by, however, production capacity data is more readily available. Although it is unlikely that production capacity is reached, this gives a good indication of the potential market and the areas in which materials are produced. The Institute for Bioplastics and Biocomposites (IfBB) estimates that old and new economy bio-based and/or biodegradable plastics have a combined share of about 6% of the global plastic market.[72]

The total global production capacity of biodegradable and bio-based plastics for similar years, but from differing sources is shown in **Figure 7**.

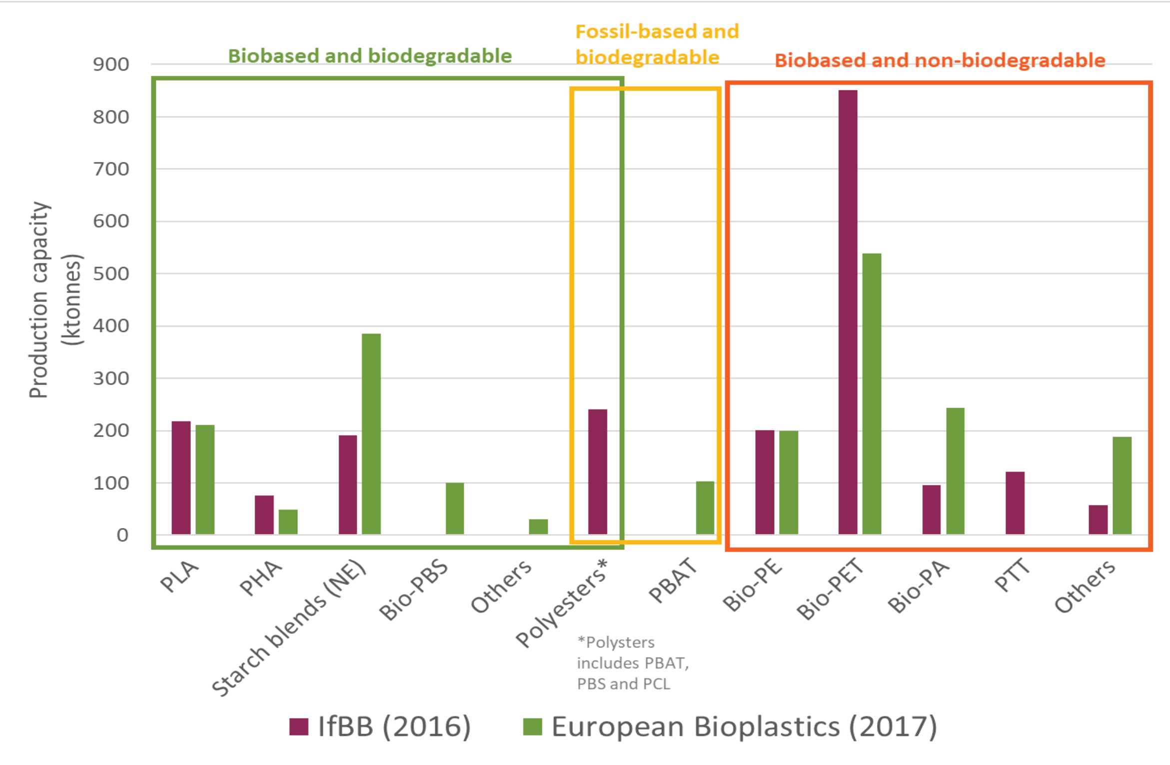

Figure 7: Global Production Capacity of Bio-based and biodegradable plastics in 2016 and 2017[73]

[72] Institute for Bioplastics and Biocomposites *Biopolymers facts and statistics 2017*, https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren/Biopolymers-Facts-Statistics_2017.pdf
[73] Nova-Institute and IfBB

Both the IfBB and European Bioplastics estimate the total production capacity to be 2.05 million tonnes for the year 2017. In comparison, Plastics Europe reported the global production capacity of conventional plastics to be 335 million tonnes in 2016, making the bio-based/biodegradable market share only 0,6% bioplastics.[74] This figure includes plastic materials (thermoplastics and polyurethanes) and other plastics (thermosets, adhesives, coatings and sealants). It does not include 'old economy' biobased plastics and other fibres (PET fibers, PA fibers, PP fibers and polyacryls-fibres), however there is likely to be an element of crossover. European Bioplastics estimate that the production capacity will grow consistently over the next five years (see **Figure 8**), with the largest growth in the biodegradable sector.

Although the market for bio-based and biodegradable materials is small on a global scale, it is nevertheless a billion-dollar market. Certain types of bio-based film, fibres, and single-use cutlery sold had an estimated value of 2.6 billion USD in 2015.[75]

It is predicted that in the near future we will see more growth for the plastics with a novel chemical structure in comparison to 'drop-ins', as they often have additional functionality, and due to current low petrochemical prices, a product being bio-based is simply not enough for it to break through in the market.

Figure 8 shows predictions for global production capacities up to 2022 that were developed in 2017. The total production capacity is divided into biodegradable and non-biodegradable plastics, where the amount of non-biodegradable (biobased) plastics accounts for over half the share.

Predictions are unreliable and will not describe how the future market will develop. Predictions made by European Bioplastics in 2012, when the market share was only 1.16 million tons, estimated the market share in 2016 to be 5.78 million tons.[76] The production capacity in 2017 was only 2.05 million tons, over 3.0 million tons less than predicted by European Bioplastics in 2012. There are many factors that will influence (and have influenced) the growth of these plastics.

Projections of production capacities are ever-changing due to the rapidly growing sector, and different projections published at the same time can even be contradictory. However, it should be noted that since 2017 most projections have been dramatically reviewed due to the unexpected halt in bio-PET growth, outlined in more detail below. Overall, the capacities of bio-based and biodegradable plastics are currently growing at roughly 2-3% per year, which is the same rate as conventional fossil-based plastics.[77]

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[74] Plastics Europe (2018) *Plastics - the Facts 2017: An analysis of European plastics production, demand and waste data*, 2018, https://www.plasticseurope.org/application/files/1715/2111/1527/Plastics_the_facts_2017_FINAL_for_website.pdf
[75] Packnews (2016). *Bioplast Omsatte for 2,6 Milliarder US Dollar I 2015.* Accessed: 15.11.2018 http://www.packnews.no/default.asp?id=10650&show=more
[76] European Bioplastics 2012; EC Communication "Innovating for Sustainable Growth: A Bioeconomy for Europe".
[77] Chinthapalli et al (2018) *Bio-based Building Blocks and Polymers - Global Capacities and Trends 2017-2022*, Report for Nova Institute, May 2018

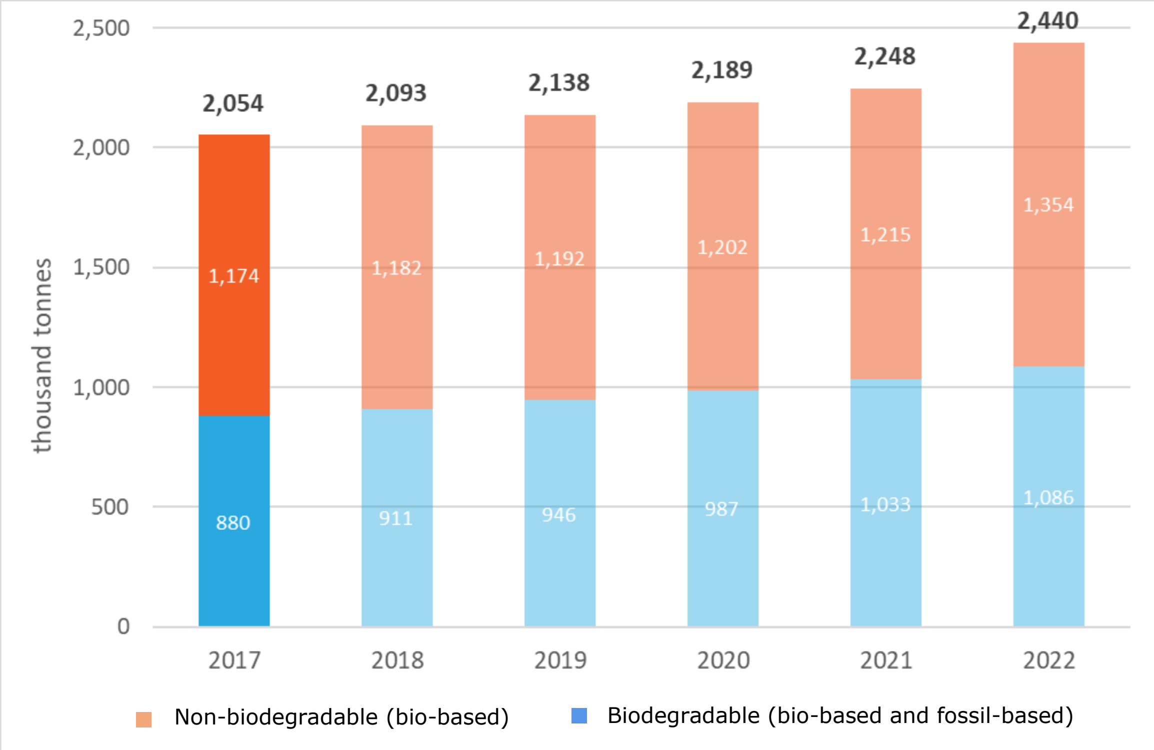

Figure 8: **Predicted Global Production Capacity of Non-biodegradable (Bio-based) and Biodegradable (both bio-based and fossil-based) Plastics**[78]

9.1.1 Production Rates of Raw Materials

The global market for bio-based raw materials is rather unstable as there has been a mass industry restructure in recent years. However, continued growth is still expected but from different products to previously predicted. Literature states that companies are moving away from high volume and moving towards more specialised high profit building blocks, due to the dropping petrochemical prices.[79] This indicates that in the coming years 'drop-in' material growth will slow, whilst novel building blocks will show better growth.

When looking at the production rates of raw materials it is hard to distinguish how many of these are for the bio-based/biodegradable plastics industry. One could look at, for example, data for how much lactic acid is produced globally. However, lactic acid is not only used for a raw material in polymer production, but in many other applications including food additives. Thus the quantitative data is hard to analyse.

It is likely that fossil-based material for biodegradable plastics markets are relatively stable and are not going to grow rapidly in the future.

[78] European Bioplastics (2017). *Bioplastics Market Data 2017*. Last accessed: 30.11.2018. https://docs.european-bioplastics.org/publications/market_data/2017/Report_Bioplastics_Market_Data_2017.pdf
[79] Iepitreb (2017) *Markets of bio-based building blocks by Philippa Davies*, accessed 15 October 2018, https://bioplasticsnews.com/2017/05/17/bio-based-building-blocks-philippa-davies/

Figure 9 shows a projection of the global production capacity of bio-based building blocks from 2011 to 2022. It shows steady growth for most building blocks, with particular growth in the 2,5-FDCA and 1,4-BDO markets from 2020 onwards. Succinic acid production is also shown to increase; however, this was published before the announcement that a key succinic acid producer was filing for bankruptcy (see Section 9.1.1.4). This illustrates well how small the amounts on the market are.

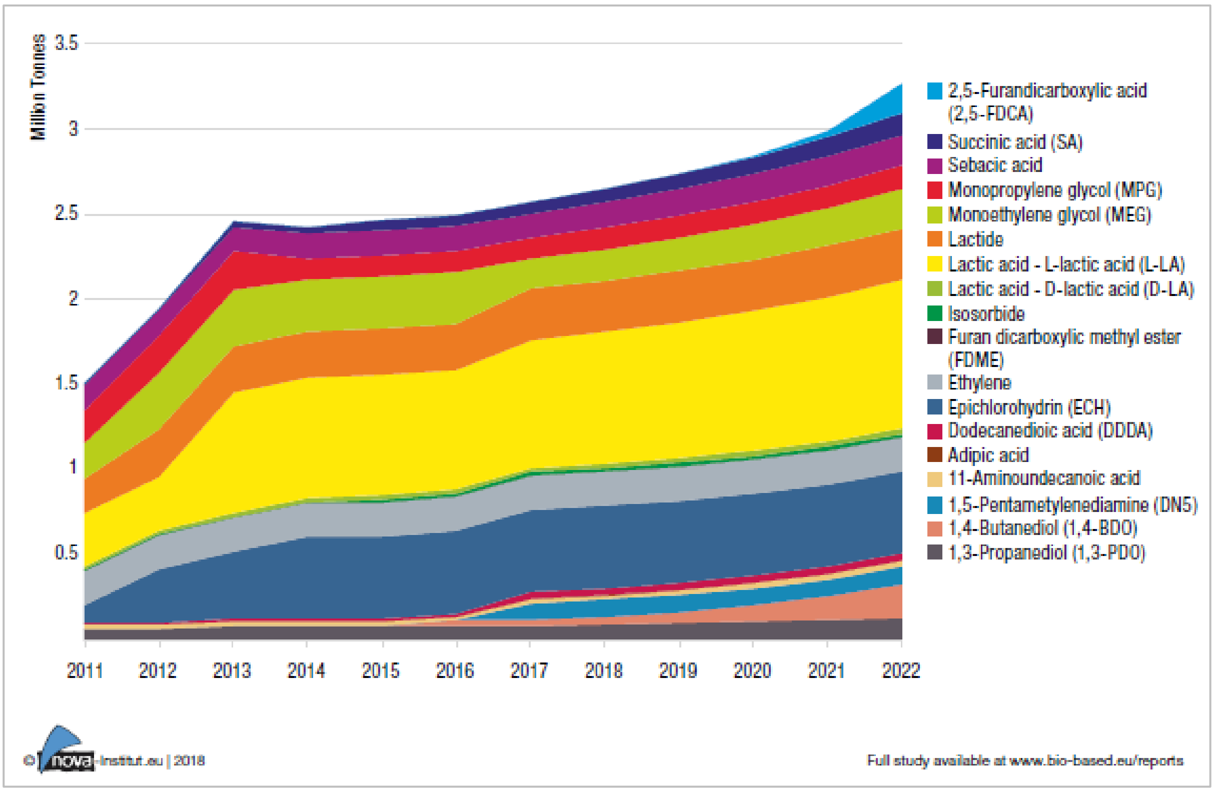

Figure 9: Bio-based Building Blocks Projection[80]

9.1.1.1 Monoethylene glycol (MEG)

MEG is one of PET's building blocks, making up 32% of the finished plastic. It is available in both fossil and bio-based form as a drop-in. Bio-MEG is solely produced in Asia and is most often made from sugarbeet, sugarcane, corn, potato or wheat. Both fossil and bio-based MEG can also be used for producing polyester fibres. As well as plastic production, fossil-based-MEG has applications in anti-freeze, and it is thought that ~50% is used for anti-freeze and 40% used for traditional PET production.[81] When looking at production rates for bio-MEG one can assume that it is used for biopolymer production only, with the majority being used for bio-PET and some being used for polyester fibre production.

[80] Nova-Institute (2018)
[81] Rebsdat, S., and Mayer, D. (2000) Ethylene Glycol, *Ullmann's Encyclopedia of Industrial Chemistry* (2000) American Cancer Society

In previous years the bio-PET industry has been growing rapidly to keep up with industry demand fuelled by Coca Cola's 'plant bottle'. Coca Cola's MEG producers are India Glycols who have a production capacity of 150,000 tonnes in India.[82] It was previously announced that Coca-Cola would partner with JBF Industries Ltd to build a bio-MEG facility in Brazil with a production capacity of 500,000 tonnes, however works never went ahead and this was not well publicised.[83] Other notable bio-MEG producers include Greencol Taiwan, with a production capacity of 100,000 tonnes/yr.

9.1.1.2 Lactic Acid (L-LA and D-LA)

Lactic acid (LA) is the building block of PLA and it comes in two forms: L-LA or D-LA. It is made using either sugarcane, sugarbeet, corn, potato or wheat

Lactic acid production is well established globally, as it has long been used for many other applications such as a preservative in the food industry or a mosquito attractant. It is expected that more than half of lactic acid produced globally is used by the food industry[84] with a market share of over $600 million[85], however data is not available on how much is used in PLA production.

In 2016 it was predicted that the lactic acid market shares would increase by 12% for biodegradable polymers and solvents; and 12.5% for personal and cosmetic applications.[86]

9.1.1.3 Ethylene

Ethylene (also referred to as ethene) is used to make PE and it is also an intermediary step in producing MEG. It can be produced using petrochemicals or by dehydrating bio-ethanol to produce bio-ethylene. It also has other less common uses, such as in anaesthetics, for fruit ripening and in chemical weapons. It is not possible to determine exactly how much ethylene is used for plastic production.

In recent years the price of fossil-based ethylene dropped massively due to the shale gas boom, resulting in bio-ethylene production being halted massively. Bio-ethylene is said to have 0.5% of the overall ethylene production capacity; a market that was valued at $160 billion in 2015 and is expected to reach $235 billion by 2024.[87] Due to the low price of fossil-based-ethylene, it is predicted that bio-ethylene will not increase dramatically in current years but

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[82] Guzman, D. de (2012) *Coca-Cola picks 2nd bio-EG supplier*, https://greenchemicalsblog.com/2012/10/01/coca-cola-picks-2nd-bio-eg-supplier/

[83] Tullo, A. (2014) *Coke Committed To PlantBottle Despite JBF's Bio-based Ethylene Glycol Cancellation*, http://cenblog.org/the-chemical-notebook/2014/04/coke-committed-to-plantbottle-despite-jbf-bio-based-ethylene-glycol-cancellation/

[84] Aeschelmann, F., and Carus, M. *Bio-based Building Blocks and Polymers in the World: Capacities, Production and Applications: Status Quo and Trends towards 2020*, Report for Nova Institute, http://www.bio-based.eu/market_study/media/files/15-05-13_Bio-based_Polymers_and_Building_Blocks_in_the_World-nova_Booklet.pdf

[85] *Lactic Acid & Polylactic Acid (PLA) Market Size, Price Trends 2024*, accessed 15 October 2018, https://www.gminsights.com/industry-analysis/lactic-acid-and-polylactic-acid-market

[86] *Lactic Acid & Polylactic Acid (PLA) Market Size, Price Trends 2024*, accessed 15 October 2018, https://www.gminsights.com/industry-analysis/lactic-acid-and-polylactic-acid-market

[87] *Bio-Based Ethylene Market Size – Industry Share Report, 2024*, accessed 15 October 2018, https://www.gminsights.com/industry-analysis/bio-based-ethylene-market

grow in line with its fossil-based counterpart. Most bio-ethylene is produced in Brazil from sugarcane, with lots also being produced in America and India.

9.1.1.4 Succinic Acid

Succinic acid is a building block used for many different plastics, including PUR and PBS, and it is available in both fossil and bio-based forms. As well as a plastic building block, succinic acid can be used in the food industry as a dietary supplement, flavouring agent or acidity regulator. It can also be used to produce 100% bio-based 1,4-Butanediol, another important plastic building block.Fossil-based succinic acid has long been disregarded for polymer production due to its high price, however bio-based succinic acid is reportedly cheaper than fossil-based so has enormous potential.[88] However, the market is relatively new for bio-based succinic acid.

At present, bio-succinic acid total global production capacity is 60,000 tonnes per year, however this capacity is never reached, and production stays low.[89] The future of the bio-succinic acid market is uncertain, particularly with BioAmber, the largest bio-succinic acid producer, filing for bankruptcy in May 2018.[90]

9.1.1.5 1,4-BDO

1,4-BDO is a very versatile plastic building block and can be either fossil-based or bio-based. Bio-based 1,4-BDO is very new to the commercial market. Novamont and BASF produce bio-based 1,4-BDO commercially and direct from biomass (not from succinic acid), in Italy and Asia respectively. Although it is known that 1,4-BDO can be made from succinic acid, no production plans have materialised, possibly due to low production rates of succinic acid.

9.1.1.6 2,5-FDCA

2,5-FDCA is similar to PTA, however it can be made from fructose, a 100% bio-based material. It can be combined with MEG to produce PEF. FDCA can also be used to synthesise succinic acid and FDME. FDME is an analogue of FDCA, however it is said to have a higher yield and take less energy to produce.

2,5-FDCA is a new building block entering the market and thus production capacities are currently low. The market leader is Origin with a production capacity of tens of thousands of tonnes, and DuPont have a small demo plant, which can produce up to 60 tonnes.[91] Avantium and BASF had announced that they would be collaborating to produce a FDCA production facility with a capacity of 50,000 tonnes, however it has been reported that there are disagreements between the companies and that plans are delayed.[92]

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[88] Jian Ping, T., Jamaliah, M., Harun, S., and Ta Yeong, W. (2017) Overview of the Potential of Bio-Succinic Acid Production from Oil Palm Fronds, *Journal of Physical Science*, Vol.28, pp.53–72
[89] Guzman, D. de (2018) Tecnon OrbiChem Update on Bio-Based Building Blocks, paper given at 11th International Conference on Bio-Based Materials, Germany, 14 May 2018, https://bioplasticsnews.com/2018/05/14/bio-based-building-blocks/
[90] Barrett, A. (2018) *BioAmber is Bankrupt*, accessed 18 October 2018, https://bioplasticsnews.com/2018/05/07/bioamber-is-bankrupt/
[91] OrbiChem, T. (2018) *Sleeping Giant, FDCA, Still Pretty Groggy*
[92] Guzman, D. de (2018) *BASF, Avantium in Synvina dispute*

9.1.2 Production Capacity of Plastics (by region)

Global production capacity of biobased/biodegradable plastics by region is as shown in **Figure 10**. Two data sources have been included to demonstrate the large differences in reported production capacity from two reputable sources and to highlight difficulties when comparing data. Data is not yet publicly available for the production capacity in 2018 by region, however a prediction has been included that was published in 2015 by the Nova Institute (the data analysts for European Bioplastics). Both of projected future estimates appear to be far higher than the recent estimates from European Bioplastics (2.2 million tonnes versus 6-9 million tonnes) which demonstrates the distinct lack of certainty around capacity especially in Asia, largely due to bio-PET not meeting previous expectations due to the lack of bio-MEG supply. European estimates remain most stable and this is largely due to the ease in which it is to track new plants coming on line within Europe compared with Asia.

This data shows that most bio-based/biodegradable plastics are produced in Asia and that production here is expected to continue to grow—although by how much is less certain. This is principally due to the large supply of feedstocks in these countries. Production in South America is expected to increase in coming years, primarily due to an increase in production of bio-PE in Brazil.

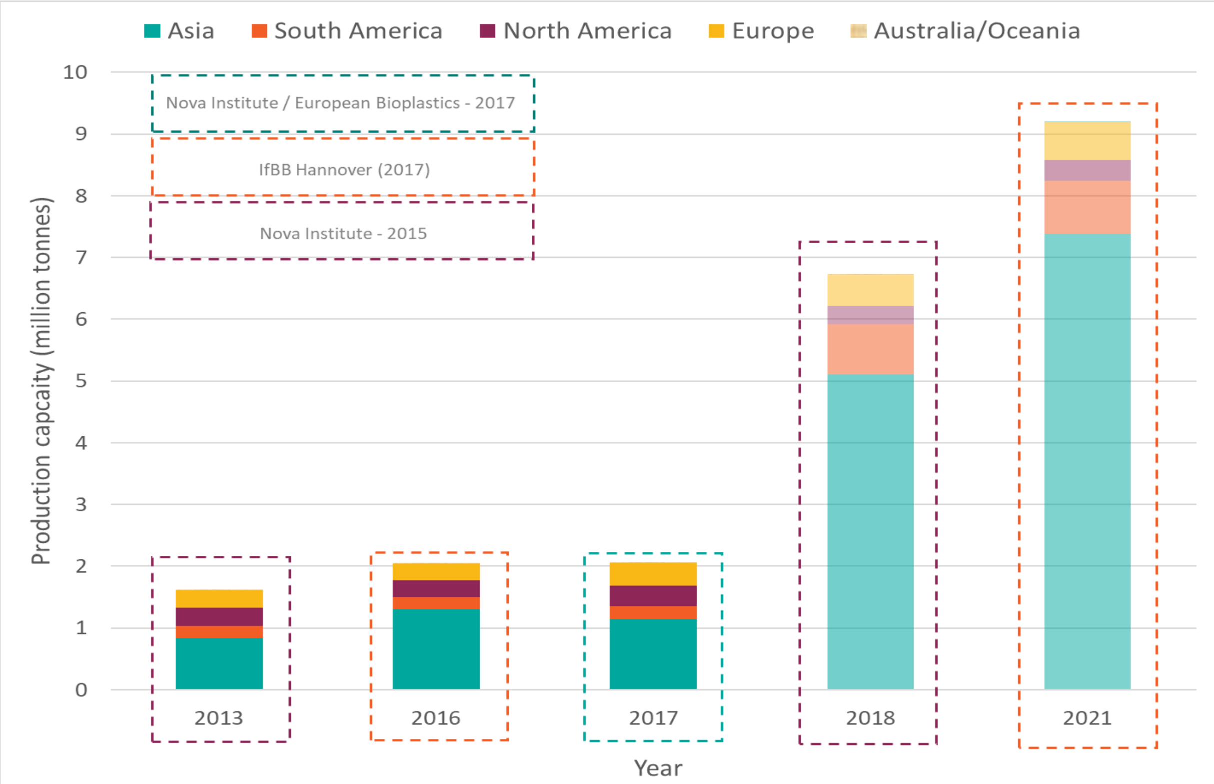

Figure 10: Global Production Capacity and Predictions of Bio-based and biodegradable plastics (by region)[93]

[93] *Nova-Institute (2013 and 2018), IfBB (2016 and 2021), European Bioplastics (2016)*

9.2 Supply and Demand

The market share of bio-based and biodegradable plastics is in large determined by supply and demand, but ultimately by price. There are many factors that influence the market prices of bio-based material. In general, bio-based and biodegradable plastics are more expensive than fossil-based plastics on weight basis.[94] There is no official information on the price of these products, however there are indications that the price of bio-based plastic is higher than for conventional fossil-based products. One buyer of PLA cups says the price for PLA is 30 % higher than for regular paper cups lined with a thin layer of plastic. Another source states that bio-PE costs 50 % more than fossil-PE.[95]

The final product price will vary based on the amount of bio-based material used. In many products the bio-based content is small, and the price difference will be minimal. Some products can be altered to use less plastic when the material is bio-based or biodegradable. As discussed previously, conventional mulch film now has to be thick to make to make it easier to remove form the soil, however as biodegradable film does not need to be removed, the film can be made thinner, reducing cost and easing biodegradation.

Research conducted and conversations with stakeholders informed that there have been many planned projects to include higher shares of bio-based material in various products. In many cases producers are still working on making their products biodegradable or bio-based. However, in the majority of cases the work on this has stopped due to increased prices or logistical difficulties. There are also technical challenges related to these new products. As the demand for these types of plastics increases, it is likely they will become more readily available to producers.

Producing renewable plastics requires a lot of energy and causes greenhouse gas emissions. Bio-based and biodegradable plastics have a lower carbon foot print than traditional, fossil plastic, in most products.[96] Recycled plastic used in new products has a lower carbon footprint than producing products from new materials, whether renewable or not.[97]

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[94] Wageningen UR (2017). *Bio-based and biodegradable plastics – Facts and Figures*, https://www.wur.nl/upload_mm/1/e/7/01452551-06c5-4dc3-b278-173da53356bb_170421%20Report%20Bio-based%20Plastic%20Facts.pdf

[95] J ortveit, A. (2018). *Fullt Mulig å Kutte Klimagassutslippene fra Plast*. Accessed: 15.11.2018. https://energiogklima.no/nyhet/fullt-mulig-a-kutte-klimagassutslippene-fra-plast/

[96] Friedsam, H. (2018). *Bioplast Utgjør under 1 Prosent av de Over 350 Millioner Tonn Plast som Produseres Hvert År*. TU. Accessed: 15.11.2018 https://www.tu.no/artikler/bioplast-utgjor-under-1-prosent-av-de-over-320-millioner-tonn-plast-som-produseres-hvert-ar/438505

[97] Jortveit, A. (2018). *Fullt Mulig å Kutte Klimagassutslippene fra Plast*. Accessed: 15.11.2018. https://energiogklima.no/nyhet/fullt-mulig-a-kutte-klimagassutslippene-fra-plast/

10 The Norwegian Market

In Europe, bio-based and biodegradable plastics are found in most groups of applications. Sometimes producers start testing the idea in cooperation with a converter, often producing a single part of a product from renewable material, e.g. the cap of a bottle. Many of these products and/or ideas will be transported to Norway. In this chapter, there is a focus on key applications illustrated with relevant examples.

The global production of plastics (2016) is ca. 335 million tonnes.[98] The bio-based/biodegradable plastic market constitutes only ~1 % of the total plastics market. Although it is easy to forget how small the market is due to increased hype in the media and marketing by brand owners.

There is limited data on the consumption of plastics in Norway. The latest credible figure showed that in 2016 the amount of plastic waste in Norway was 304 000 tons, where 60 % of that (185 000 tons) was plastic packaging.[99]

Figure 7 in Chapter 8 illustrates the global production capacities for each market segments and gives a good representation of where such materials are found in today's market. As it has not been possible to establish a detailed share of the market for bio-based and biodegradable plastics in Norway, the global distribution between market segments has been used as a guideline when calculating the market shares in Norway. I.e. on a global scale, bio-based and biodegradable plastics make up 4 % of the plastics used in building and construction. It was therefore estimated that bio-based and biodegradable plastics make up 4 % of the market for building and construction materials in Norway as well. This is highly uncertain as, all markets are different, and supply and demand will vary between countries.

An estimation of the market shares has been given in Table 5. The market shares listed are most likely the *maximum* estimation of bio-based/biodegradable plastics on the Norwegian market. It is important to highlight the uncertainty of the numbers presented here. They are based on estimates from numbers we have gained access to and are not based on actual market data.

[98] PlasticsTheFacts 2016, PlasticsEurope
[99] EPRO and PlasticsEurope, European Survey for 2016

Table 5 - Estimated share of bio-based and biodegradable plastics on the Norwegian market.

Market segment	Total amounts put on the market (tons)	Total amounts of bio-based/biodegradable plastics on the market (tons)	Share of total market segment
Packaging	185 000	5500	3.0 %
Textiles (all materials)	120 000	1000	0.8 %
Automotive and transport	Unknown	800	Unknown
Consumer goods	Unknown	800	Unknown
Agriculture and horticulture	13 000	100-150	0.8-1.2 %
Building and construction	Unknown	400	Unknown
Electric and electronics	Unknown	200	Unknown
Others	Unknown	Unknown	Unknown
Total	Ca. 300 000	8850	**Ca. 3 %**

The total market share is estimated at 2.9 %. The majority of bio-based and biodegradable plastics are found in food waste bags and PET bottles. There is no official reporting, statistics or data on the use of bio-based or biodegradable plastics in Norway today. All the data collected on this market has been through interviews with stakeholders and experts.[100] Due to time limits and market restrictions, we have not received access to the majority of the bio-based/biodegradable plastic market and have therefore had to result to estimates. There is a lot of uncertainty tied to each market share and each estimate should be viewed with caution. The distribution the plastics, as shown in **Figure 11**, has been the basis for calculating the market shares where there was not enough information.

These interviews have identified a lack of knowledge of these materials. Companies and organisations are aware of production in Norway, however the import of products or materials is more unfamiliar. Experts in this field have given up trying to quantify the amounts in Norway because of the lack of knowledge and willingness to share information. Experts have also voiced their opinion that there should be a system for reporting these figures to the government. This would allow for the generation of statistics that could show a decrease in greenhouse gas emissions, i.e. if a product has been replaced with a bio-based alternative.

[100] Gjerset et al. (2014). *Klimaløsning: Bioplast!*. ZERO. Accessed: 15.11.2018
https://zero.no/wp-content/uploads/2016/05/Bioplast-status-og-virkemiddelanalyse-ZERO-nett.pdf

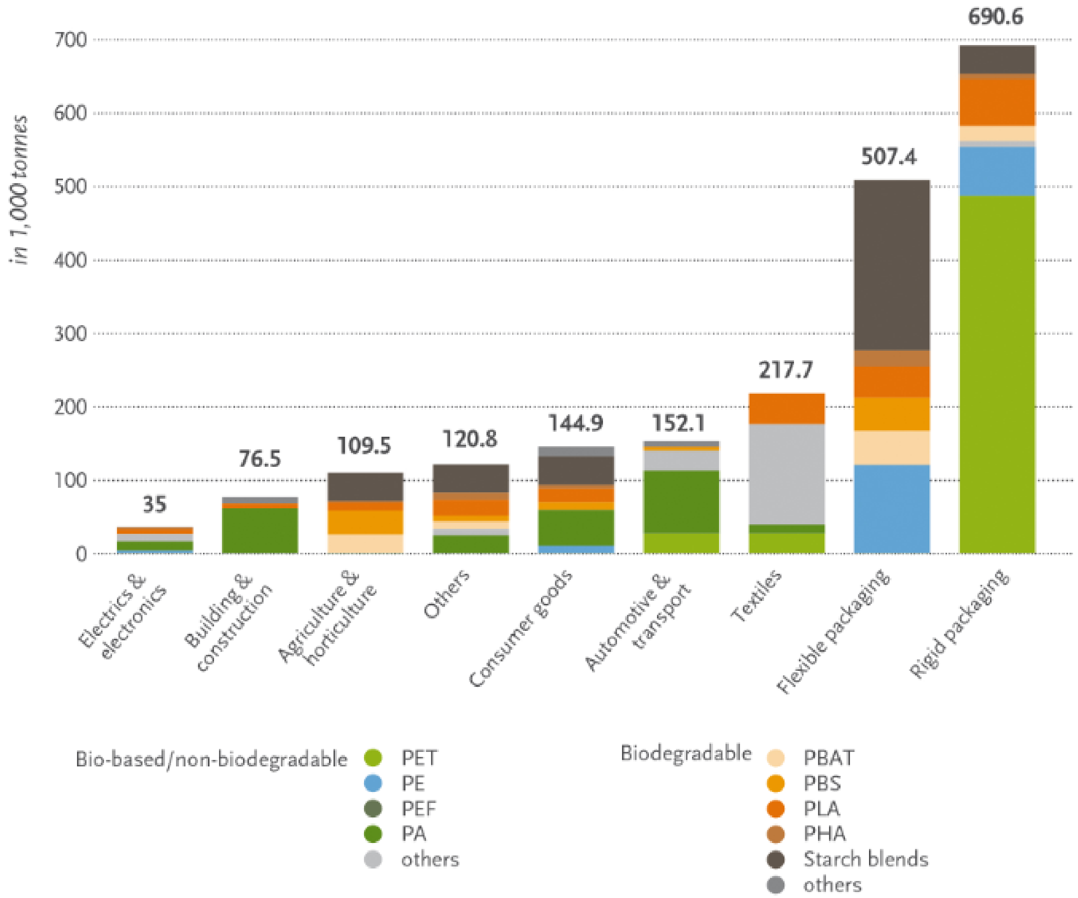

Figure 11: Global production capacities divided by market segments (2017).[101]

According to producers and suppliers of bio-based and biodegradable plastics, the demand for these materials has increased in 2018 in Norway. Through consumer demand, producers have had to increase their production and/or import of these products, especially when it comes to bio-based plastics.[102] Awareness of the enormous production of fossil plastic has reached many people and the media coverage has been high in large parts of the EU and in Norway. Research conducted one year from now will likely see a high increase in production levels from 2017 to 2018.[103]

On the other hand, our research has also indicated that the larger brand owners are getting more reluctant to the use of these materials. As mentioned earlier, CocaCola is decreasing the share of bio-based material in their PlantBottle™ and increasing the amount of recycled material instead. Research indicates that the greenhouse gas emissions from recycling fossil

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[101] European Bioplastics (2018). *Market Drivers and Development*. Accessed 15.11.2018 https://www.european-bioplastics.org/market/market-drivers/
[102] Friedsam, H. (2018). *Bioplast Utgjør under 1 Prosent av de Over 350 Millioner Tonn Plast som Produseres Hvert År*. TU. Accessed: 15.11.2018 https://www.tu.no/artikler/bioplast-utgjor-under-1-prosent-av-de-over-320-millioner-tonn-plast-som-produseres-hvert-ar/438505
[103] European Bioplastics

plastics are lower than the production of bio-based material.[104] It is possible that the increase expected in 2018 will not continue to 2019.

The following sub-chapters elaborate on some of the Norwegian bio-based and/or biodegradable plastic products. This is not an exhaustive list, but a selection of products we address in more detail.

10.1 Packaging

A large share of the bio-based material in Norway is found in CocaCola's PlantBottle™. CocaCola implemented this bottle on all their bottles sold in Norway starting in 2013 and they have been on the market since then. Information gained from conducting interviews during this research have indicated that the share of bio-based material in this bottle will decrease as the company prepares to increase the share of recycled PET to 50 % instead.[105] Recycled PET is cheaper, and the supply is more stable. This will assist in the creation of a closed loop system for PET, increasing the demand for recycled material.[106]

Elopak and Tetra Pak are producers of drink cartons and have replaced their fossil-based caps and plastic lining (PE) inside their drink cartons with bio-based material.[107][108] These companies supply most of the millions of drink cartons in Norway and their renewable cartons made with bio-based material will comprise a significant share of this material on Norway's market.

PLA is most commonly used in single use plastic glasses in Norway. These cups are common at festivals and areas where there is a requirement for many single-use plastic glasses. Nearly all breweries in Norway have PLA glasses. The market for PLA glasses has been well established for many years.

A large share of the biodegradable plastics in Norway are found in bin bags used to collect food waste. These bags are a blend with fossil-modified polyester and are certified for composting. However, as mentioned earlier, fewer and fewer municipalities have continued the use of these bags and instead gone over/back to fossil PE or in some cases bio-PE. In comparison to other Nordic countries, e.g. Sweden, there has been more interest in the use of recycled material in carrier bags and waste bags, over the use of paper bags or biodegradable bags. Recycled material is increasingly used with up to 50 % of most carrier bags containing recycled PE, and

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[104] European Bioplastics (2016). *Do Bioplastics have a Lower Carbon Footprint than Fossil Based Plastics?* Accessed: 15.11.2018
https://www.european-bioplastics.org/faq-items/do-bioplastic-have-a-lower-carbon-footprint-than-fossil-based-plastics-how-is-this-measured/
[105] CocaCola (2018). *How Much Recycled Material does Coca-Cola Europan Partners use in its Packaging?* Accessed: 15.11.2018
https://www.coca-cola.co.uk/faq/how-much-recycled-material-does-coca-cola-great-britain-use-in-its-packaging
[106] Sykes, T. (2018). Packaging Europe. *Insude Coca-Cola's Sustainability Strategy*. Accessed: 15.11.2018
https://packagingeurope.com/inside-coca-cola-sustainability-action-plan-europe/
[107] TetraPak (2018). *The Journey Towards Renewability*. Accessed: 15.11.2018
https://tetrapak.com/sustainability/cases-and-articles/tetra-rex-bio-based
[108] Packnews (2018). *Elopak Først med 1 Milliard 100 % Fornybare Kartonger*. Accessed 15.11.2018
http://www.packnews.no/default.asp?id=13607&show=more

this share is increasing. There are many companies claiming that the use of recycled material gives the best carbon footprint as it is the least energy-demanding process.[109]

For grocery wholesalers, there has been an increase in the use of recycled plastics in recent years, however there is increased interest in using bio-based or biodegradable material in food packaging.[110] Danone, a global food company, recently released its new Packaging Policy. This policy includes a commitment where all Danone packaging products will be 100 % recyclable, reusable or compostable by 2025. International suppliers to the Norwegian market could potentially supply Norway with products that are unsuited for Norwegian waste management systems (see chapter 11).

European data suggests that household cleaning products and cosmetics are also likely to contain bio-based materials, however there is no information on the volumes of these.

10.2 Agriculture and Horticulture

The volumes of renewable bale wrap sold on the market are still quite small, even though there has been an increase from previous years. Renewable bale wrap has been used for ca. 4000 bales in Norway (4-7 tons), whereas the total amount of bales per year is 4-5 million. The product is relatively unknown, which limits its dispersal. The main barrier to using this type of bale wrap is the price difference. Renewable bale wrap costs up to 20 % more than conventional bale wrap from fossil sources.[111]

The market for biodegradable mulch film is estimated at 100-150 tons in Norway today, however this varies from season to season. The price of this film is higher than conventional film, however this is saved as the film does not need to be removed, handled and disposed of as waste. The European market for this type of film is estimated at 80 000 tons per year, where 5 % of the total volume (4000 tons) is biodegradable.[112]

The amount of bio-based and biodegradable material in horticulture in Norway is unknown.

10.3 Consumer Goods

IKEA is one of the world’s largest furniture retailers and they have begun the process of phasing out fossil-based plastics in their products. Their aim is to design all IKEA-products using renewable or recycled material.[113]

Based on interviews with producers, single-use plastics such as cutlery, glasses, and plates are commonly made in bio-based or biodegradable alternatives due to the high presence of such articles found among urban pollution and marine litter. The market share is uncertain;

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[109] Supplier of carrier bags
[110] Jortveit, A. (2018). *Fullt Mulig å Kutte Klimagassutslippene fra Plast.* Accessed 15.11.2018. https://energiogklima.no/nyhet/fullt-mulig-a-kutte-klimagassutslippene-fra-plast/
[111] Belbo, T. (2018). *ZERO-notat: Fornybar Landbruksplast*. Accessed 15.11.2018 https://zero.no/wp-content/uploads/2018/08/ZERO-notat-fornybar-landbruksplast.pdf
[112] Ibid.
[113] IKEA (2017). *Bærekraftrapport 2017*. Accessed 15.11.2018 https://m2.ikea.com/no/no/people-and-planet/?_ga=2.11631028.1079599413.1540816943-83121820.1540816943

however, indications show that this is increasing and that 2018 numbers will be higher than they were in 2017.

10.4 Other

The fishing and aquaculture industry is an important industry in Norway and the third largest export industry.[114] Gear used in the fishing industry is often lost at sea and found washed up on beaches. Data from Keep Norway Beautiful have highlighted the vast amounts of marine litter that arise from the fishing and aquaculture industries.[115] Research has been conducted on developing fishing nets and crab pots made from bio-based and biodegradable material. This is still in the development phase but there could be a future market for this in Norway to decrease ghost fishing. Tests show that the quality is like nylon fishing nets, and it supposedly only takes a year for the biodegradable fishing net to degrade.[116][117]

Microplastic granules from artificial turf on football fields is a major source of microplastics to the environment in Norway. There is a research project underway with the aim of developing a biodegradable alternative made from tree fibres.[118]

Shotgun cartridges, a waste product from hunting activities, is a product often found washed up on beaches or littered in the environment. There have been developments in producing cartridge case parts made from renewable material. There are many technical requirements that are necessary for the materials used in cartridge cases. Work has been put into researching photodegradable and biodegradable options (PVA, PHA, EVA).[119] Studies show variations in the materials degradability in Norwegian nature, with conditions depending highly on humidity. There is also the issue of microplastics that could arise from the use of biodegradable material. Cartridge case parts based on corn starch are already available on the market. Several producers offer this product, however there is still a long way to go before all cartridge cases have parts made from biodegradable material.

The interest in biocomposites is growing in terms of industrial applications. The car industry is adopting the use of biocomposites, and Sweden has its own biocomposite factory.[120] According to VDI Nachrichten, biocomposites will soon be found in car doors and dashboards, reducing the carbon footprint by up to 30 %.[121] The largest single market of biocomposite today is in decking boards, where in China the volume is 16 million tons per year. It is unknown how

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[114] RSM (2018). *Fiskeri og Akvakultur*. Accessed 15.11.2018 https://www.rsm.global/norway/nb/bransjer/fiskeri-akvakultur

[115] https://holdnorgerent.no/2017/12/strandrydderapporten2017/

[116] NJFF (2016). *Tester nedbrytbare garn*. Accessed 15.11.2018 https://www.njff.no/nyheter/Sider/Nedbrytbare-garn-spokelsesfiske.aspx

[117] Backe, T. (2018). Fiskeri og Havbruk. *Forsker på Miljøvennlige Fiskegarn*. Accessed 15.11.2018 https://www.fiskerioghavbruk.no/forskning/forsker-pa-miljovennlige-fiskegarn/

[118] Forskningsrådet (2018). *Grønt Granulat for Kunstgressbaner*. Accessed 15.11.2018 https://www.forskningsradet.no/prosjektbanken/#/project/NFR/281914

[119] Farstad, E. (2018). NJFF: *Vil ha Slutt på Plastforurensning.* Accessed 15.11.2018 https://www.njff.no/nyheter/Sider/Plast-fra-haglpatroner.aspx

[120] Isaksen, A. (2018). Plastforum. *Biokompositter – er en fornybar erstatning for plast.* Accessed 15.11.2018. https://www.plastforum.no/article/view/603782/biokompositter_en_fornybar_erstatning_for_plast

[121] Seehusen, J. (2014). TU. *Snart Kommer Treprodukter i Bilen*. Accessed: 15.11.2018 https://www.tu.no/artikler/snart-kommer-treprodukter-i-bilen/228535

much biocomposite exists on the Norwegian market, however as the European car markets are very similar, there is reason to believe this share will be similar.[122] However, the high concentration of electric vehicles on the roads in Norway could cause differences. Electric cars have the aim to be lighter in order to travel further, so we can perhaps expect an increased use of biocomposites on the Norwegian car market in the future.

[122] Mazda (2014). *Mazda Utvecklar Bioplast for Karossdeler*. Accessed: 15.11.2018. https://www.mazda.se/nyheter/miljo/mazda-utvecklar-bioplast-for-karossdelar/

11 Waste Management Systems

This chapter will investigate the Norwegian waste management infrastructure for municipal waste and suitability for bio-based and biodegradable plastics. Products at their end-of-life are disposed of in 4 main processes: recycling, in-vessel composting, incineration with energy recovery, or anaerobic digestion with biogas and fertilizer production. The challenges that bio-based and biodegradable products can cause at these different sites will be highlighted in this chapter.

In Norway the responsibility for household waste collection and disposal are organized in two different categories:

- Household waste
- Waste similar to household waste (waste from retail, public administration, service entities, offices, including administration part from industry)

The Norwegian household waste collection system varies from area to area. The responsibility of implementing waste handling systems is left to intermunicipal companies on behalf of each municipality, and the choices made regarding which type of waste handling system is implemented, are different, i.e. not all municipalities have a separate collection for food waste or plastic packaging waste. Municipal waste from municipal and private entities is handled in a free market situation and each waste collector can offer a different solution. The downstream market for waste treatment is in many cases the same.

75 % of Norway's population has source-separated collection of food waste in their municipality. The source-separated food waste will in some areas go to composting facilities, while the remaining amount is sent to biogas facilities across Norway or exported to Sweden/Denmark. Norway has roughly 80 composting plants and 39 biogas plants, though not all of these receive food waste from households. Household waste is only delivered to a select few, while the other plants receive garden waste, sewage sludge or other organic matter. Composting plants were earlier the main way of discarding food waste however the number of biogas plants has significantly increased over the last decade.

Table 6 shows the treatment methods of organic waste in Norway. This shows the division between food waste sent to biogas plants and composting plants. 65,8 % of the total amount of collected food waste is sent to anaerobic digestion with biogas.

Table 6 - Treatment methods for food waste and wet organic waste

Treatment methods according to SSB's division	Food waste (1000 tons)	Percentage of total
Biogas production	158	65,8 %
In-vessel composting	82	34,2 %
Total	240	100 %

11.1 Material Recycling

11.1.1 Plastics Recycling in Norway

Plastic packaging from households is in most municipalities collected through a separate collection system before it is bailed and sent to Germany for sorting and ultimately recycling. The value chain for the disposal of plastic packaging is developed and managed by Green Dot Norway based on an extended producer responsibility scheme. This scheme includes all plastic packaging, regardless of material types.

Most plastic packaging can be recycled and used in the production of new products. According to Green Dot Norway, about 80 % of the collected plastic packaging is sorted for recycling, however only 38 % of this is actually recycled.[123]

Plastic packaging in Norway goes through the same system of collection, except for PET bottles. Norway's PET stream is exceptional due to the fully incorporated return system that has been in place for many years. 88 % of all PET bottles sold within the system are returned by the consumers. One of the advantages to this system is the quality of the PET fraction. A 100 % sorting efficiency is difficult to achieve in practice and there will always be contaminations; from other types of plastic, or from other materials altogether. Contaminations will impact the quality of the recycled material and will, in turn, determine what products the recyclate can be used in.

11.1.2 Bio-based and Biodegradable Plastic in Plastic Recycling Systems

Bio-based raw materials/feedstock can be used to produce conventional plastic qualities such as PE, PP and PET, which are fully recyclable. These 'drop-in' bio-based plastics can be recycled together with conventional plastics produced from fossil sources. The PlantBottle™ developed by CocaCola Company is a fully recyclable bottle made from a mix of fossil plastic and bio-based plastic as mentioned earlier.

New bio-based plastics, such as PLA, cannot be recycled together with any of the conventional plastics. The recycling of PLA is possible, although not commercially done yet.[124] PLA is not sorted into any plastic fractions at the sorting plants that receive Norwegian plastic today but goes to incineration with energy recovery. If PLA were to be introduced on a large scale in Norway, then a separate recycling stream for PLA could be introduced. However, there are still challenges with introducing such a stream to existing sorting plants today as space is limited and the plants are at capacity in terms of individual streams.

The interference of biodegradable plastics amongst fossil-based plastics gives a contamination that reduces the quality of the recyclate. Biodegradable plastics should be marked with information indicating where they should be disposed of, e.g. the general waste bin.

It is possible that the NIR sorting technology at the sorting plants can be programmed to sort out biodegradable plastics to avoid contamination of the other fractions. It is also possible that

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[123] NRK (2018). *Bare en Tredjedel av all Plast blir Gjenvunnet*. Accessed 15.11.2018 https://www.nrk.no/viten/bare-en-tredjedel-av-all-plast-blir-gjenvunnet-1.14155047

[124] European Bioplastics (2018). *Mechanical recycling.* Accessed 23.11.18. https://www.european-bioplastics.org/bioplastics/waste-management/recycling/

the biodegradable material could be separated in the washing process, post sorting, if the density varies from the fossil-based plastics. As the biodegradable content on the market so far has been very low, it seems like the operators have not taken much action so far.

The effects of very small quantities of bio-based or biodegradable plastics in fossil-based plastic recycling systems are not measurable today.[125] There is no clear answer as to what level of bio-based or biodegradable plastics are acceptable in the recycled material. A study conducted by Wageningen Food and Biobased Research indicates that up to 10 % of starch-based film and up to 10 % of PLA film in the film fraction (LDPE material) has no significant effect on mechanical properties, however, another study commissioned by Plastic Recyclers Europe indicates a 2% limit.[126]

The estimations given on various websites come from a wide range of stakeholders that may not be impartial in the debate. More research is needed on this and we must be careful when making estimations without the correct knowledge. Furthermore, it is important to stress the sensitivity of the market for recycled material. According to leading operators, just the perception from the demand side, e.g. the perceived uncertainty about the biodegradable content of the materials, might harm the whole market for secondary materials.

11.2 Biogas Production

11.2.1 Biogas Production in Norway

The majority of source-separated food waste in Norway (65,8 %) is sent to biogas plants. Biogas is used to produce heat and power but is predominantly upgraded to biomethane which can be used to power motor vehicles. Biomethane produced from degradable waste products such as food waste has a minimal climate footprint and can replace diesel as fuel.

The remaining nutrient resources from the organic matter, the digestate, can be utilized as fertilizer for agriculture or to produce soil. A large portion of the nutritional resources from the organic matter are preserved. This process is therefore considered as the optimal utilization of food waste.

Biological treatment of food waste in biogas plants has a relatively short history in Norway but has quickly become the most common method of treatment for source-separated food waste. Norway has per today ca. 40 biogas plants, where most of them convert sewage sludge to biogas and a digestate that is used in soil improvers. In total, these plants produce biogas corresponding to approximately 600 GWh per year. The plants have the overall capacity to produce 600 000 tonnes of digestate that can be used as input in soil production.

11.2.2 Types of Biogas Plants

Biogas processes are anaerobic degradation of organic matter which is a natural process that takes place in environments with the absence of oxygen (bogs, landfills and fertilizer mounds).

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[125] Oever et al. (2017). *Bio-based and Biodegradable Plastics – Facts and Figures*. Rapport no. 1722. Accessed 15.11 2018.
https://www.wur.nl/upload_mm/1/e/7/01452551-06c5-4dc3-b278-173da53356bb_170421%20Report%20Bio-based%20Plastic%20Facts.pdf
[126] ibid

During the process, micro-organisms transform organic waste into biogas and digestate. The biogas produced is primarily methane and carbon dioxide. There may also be small amounts of nitrogen, oxygen and odorous gases.

When the organic matter first enters the wet biogas plant, it runs through a pre-treatment process that is intended to remove foreign objects, grind the waste and ensure that the substrate becomes available to microorganisms.[127] Foreign objects can get caught in the equipment used in the plant and could potentially damage it. This pre-treatment process is challenging and demands expensive and robust equipment. The material removed in the pre-treatment process is called the reject, and this will largely constitute bags of which the food waste has been collected in, and impurities from incorrect sorting..

After conversion to biogas, one is left with liquid digestate that has a high level of plant nutrients, especially nitrogen. The digestate can therefore be used directly as fertilizer or processed into other fertilizer and soil products.

11.2.3 Bio-based and Biodegradable Material in Biogas Plants

Food waste from Norwegian households is source-separated into mainly two types of plastic bags. One is made from conventional plastics (with or without bio-based content) and can be recycled, while the other is certified compostable according to EN 13432. There are also paper bags being used in some areas, however this is less common.

Bio-based and biodegradable packaging is growing in scale and there is little knowledge amongst producers and consumers that this type of packaging creates challenges in the biogas plants. There are several factors at play here:

1) Compostable bags will not break down in a biogas plant where the average treatment period of organic matter is 15-25 days. Some more modern facilities will have even shorter treatment periods.

2) There will always be contaminations in the food waste that is collected. Analyses performed over many years by Mepex show that waste bags constitute ca. 2 wt-% of the food waste fraction on average, and other contaminations (plastic, metal, glass, etc.), ca. 6 wt-%. The waste must therefore be treated in advance to remove these contaminations and to prevent foreign objects in the final products.

3) Foreign objects in the digestate can cause mechanical trouble to the equipment used in agriculture after spreading the digestate on fields.

Regardless of what material the bag is made of, or whether a product is biodegradable or compostable, or made from fossil resources, the objects will be removed in the pre-treatment process of the waste. The level of contaminations and the amount of waste bags used to collect food waste is the reasoning behind why such a pre-treatment process must be in place.

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[127] Avfall Norge (2017). *Kvalitet på substrat til biogassanlegg.* Rapport 09/2017. Accessed 15.11 2018. https://s3-eu-west-1.amazonaws.com/avfall-norge-no/dokumenter/Kvalitet-i-biogassubstrat-2017-1.pdf

In the pre-treatment process the bags are ripped open and shredded and the removal of the entire bag is challenging. The removal rate is high, though some particles (to be regarded as microplastics when under 5 mm) will follow the process and mix in with the digestate.[128]

Biodegradable bags and other biodegradable products that are not removed in the pre-treatment process, will in the treatment process turn to slimy flakes in the digestate. When the farmers spread liquid digestate on their land, these slimy flakes will settle on the ground and will seal the channels in the spraying equipment. It is not unambiguously predictable what will happen to the pieces of plastic that are spread across the agricultural land, but some parts are biodegradable, and these will degrade over time.

Packaging products that are certified according to NS-EN 13432 that end up in an anaerobic biodegradation plants are not likely to degrade as the processes that occur in these plants are not like those in the test facilities. The average residence time is 20 days, however this varies between plants depending on their capacity and active processes. There are discussions on further reducing the residence time to save costs. The processes that take place after the treatment process will vary between plants and are therefore not always in accordance with those second-stage processes established in test facilities.

Microplastics have become a severe challenge and it has become apparent that there is a high risk that bags used for the collection of food waste will give rise to microplastics in the digestate. Bags to collect waste are used in Norwegian households and the debate is whether biodegradable bags that could degrade if scattered in the soil are preferred over fossil-based PE or bio-PE bags that will take a longer time to degrade. There are also issues tied to visible plastics, and not only those on a micro scale. Either way, other plastic products that are unwelcome in the food waste fraction will enhance the problems that arise following the use of bags for food waste.

11.3 Composting

11.3.1 Composting in Norway

Biological treatment of food waste in composting plants was the preferred solution for treatment of source-separated food waste in Norway in the 80s and 90s. The development was to a large extent ruled by authorities which gradually introduced a ban on the landfilling of wet organic matter at the same time as source separation and recycling was marketed as the main strategy for handling food waste.

Many of the composting plants established in the 90s were simple, low-technology facilities and several of them have been discontinued. There are still many composting plants in Norway that compost sewage sludge, food waste and/or organic waste from gardens/parks.

[128] NRK (2018). *De skulle gjenvinne matavfall – nå risikerer de en million i bot.* Accessed 15.11.2018. https://www.nrk.no/troms/de-skulle-gjenvinne-matavfall-_-na-risikerer-de-en-million-i-bot-for-plastforsopling-1.14232250

11.3.2 The Composting Processes

Aerobic decomposition of organic matter is a natural, oxygen-intensive process that involves microorganisms converting organic matter into stable compost and heat. The composting process requires moisture, bacteria and enzymes. The final product from composting plants is a compost that can be used as a soil enhancer directly on agricultural land, in green areas and in private gardens. A large part of the compost produced ends up in soil production.

Like biogas plants, most composting plants also have a pre-treatment process to remove foreign objects. This can be combined with post-treatment to remove more of these objects.

11.3.3 Bio-based and Biodegradable Material in Composting Plants

As mentioned earlier, food waste is sorted into mainly two types of plastic bags; those made from conventional plastics (with or without bio-based content) or those made using compostable plastics. As with biogas plants, regardless of what material the bag is made of, the bags will mainly be removed in the pre-treatment process. Due to the level of contamination in the food waste (7-8 wt-% according to analyses performed by Mepex) there must be a pre-treatment process in place to remove these.

Special conditions are required for a compostable product to biodegrade in a composting facility. Compostable plastic can under defined aerobic conditions, break down to CO_2, water and minerals as stated in chapter 5. The test facilities used to certify products according to EN 13432 set a 6-month biodegradation period that is far longer than the actual processing time in industrial composting plants in Norway, where a plant's active phase normally lasting 3-6 weeks and post composting stabilization lasting 2-3 months. Even though serious manufacturers of compostable plastics must certify their plastic materials will biodegrade according to the NS-EN 13432 standard for industrial composting, this certification is irrelevant in Norway as only a selected few composting plants will accept them. These are:

- Origo: Composting plant at Skibotn in Troms, Avfallsservice
- SIMAS: Sogn Interkommunale Miljø og Avfallsselskap
- HIM: Haugaland Interkommunale Miljøverk IKS (will only accept a certain type of popcorn boxes)

There are roughly 15-20 composting plants that accept food waste, and at the 3 specific plants listed above, the addition of compostable plastic items must be under controlled conditions and not as part of the food waste fraction. These will accept a clean, uncontaminated fraction of compostable plastics which can be added to the plant separately. Our understanding is that there is a separate process for compostable products, however there is no documented positive effect of this, and these processes have in large been developed due to demand from suppliers. The criteria for accepting compostable products are strict. Festivals and large-scale events which have had disposable, compostable plastics and which have been able to separate these products from other general waste, are able to send these to the selected composting plants that will accept them.

The environmental benefits of composting compostable plastics are low, and it is uncertain if the end products will give a positive effect to the compost. Compost is less attractive to consumers in Norway today than the digestate from biogas plants. This will be further discussed in the next sub-chapter.

11.4 Biogas Versus Composting in Norway

There is a lot of uncertainty of what types of other bio-based and biodegradable plastic items enter biogas plants and what volumes there are. Mepex has throughout the years performed many analyses on food waste from households and found few traces of bio-based and biodegradable plastic in this fraction so far. However there has been limited focus on this material type during these analyses so it can have gone unnoticed.

The most significant difference between composting and biogas processes is that microorganisms that ensure degradation under anaerobic conditions don't have access to oxygen (biogas production), while oxygen is a prerequisite for microorganisms that create aerobic degradation (composting). Thus, there are completely different conditions for degradation in the two processes, and there is little evidence that implies that a compostable product will also break down in biogas production. Rather, they pose more challenges than they are useful.

As there are clear environmental advantages to biogas compared to composting, many Norwegian municipalities deliver collected food waste to biogas plants. Many new biogas plants have been established over the last decade, while existing plants have been upgraded to expand their capacity. Many of the old composting plants have been shut down or are used to compost organic matter from parks and gardens. It is expected that this development will continue. There is little information that indicates that new composting plants for food waste will be established in Norway.

The intention of producing compostable products is good, however the number of treatment plants in Norway that will accept these products is limited and the number is declining. Effort is placed on the establishment of biogas plants instead of composting facilities. LCA analyses have shown that biogas plants have the overall best utilization of food waste, henceforth the compostable quality given to certain biodegradable products has little purpose in Norway. Compostable biodegradable products do not fit into the downstream solutions Norway has today other than for energy recovery.

Nevertheless, if such materials are used, they must be disposed of in the residual waste fraction that is sent to energy recovery. Hence, the materials must be clearly labelled for the consumer to sort them correctly. If biodegradable plastics were to be introduced at large scale to the Norwegian market, it would create a lot of confusion amongst consumers if they were to learn that biodegradable plastics were to be sorted as food waste.

Today's sorting rates already indicate that some consumers are not motivated and/or confused as to which bin plastic products should be disposed of in. There is a mismatch between how the products are marked and how they are handled downstream. This mismatch is portrayed in the media creating confusion amongst consumers as to where, e.g. plastic crisp packets with an aluminium or paper coating, should be disposed of. They are marked as plastic, however they are sent to incineration together with the residual waste. Sorting information will also vary between municipalities depending on the downstream waste handling systems in place. Information like this from many sources confuses the consumer. If the sorting of a new fraction is introduced, it is likely that a lot of fully recyclable fossil-based plastics would be lost in the food waste or residual waste fractions due to incorrect sorting.

11.5 Energy Recovery

Norway has 20 Waste-to-Energy recovery facilities where the majority of Norway's municipal solid residual waste is sent. There is some export, mainly to Sweden. Only a small amount of waste without biodegradable content is sent to landfill. The energy produced at these facilities is used to produce heat and power. In addition to this, two cement kilns receive pre-treated waste.

The pre-treatment process in biological treatment plants will remove most biodegradable plastics as these are defined as contaminants. They will also be removed from plastic recycling streams in sorting centres. In all cases in Norway at present, biodegradable plastics will end up in incineration plants.

11.6 European Waste Management Solutions

In Northern Europe certain fractions have been banned from landfilling for several years. In the UK taxes have reduced the amount sent to landfill, however both the UK, Southern and Eastern Europe still landfill a large share of their plastic waste.

Many countries still limit their plastic collection from households to bottles or rigid plastics. On the other end, some municipalities in Germany include other plastic products in addition to packaging in their plastic packaging collection. Both the Netherlands and Norway have experience from central sorting of residual waste, including plastic waste from households. So far results show that these plants increase the volumes sorted for recycling. New EU targets for plastic packaging will probably boost collection and sorting of plastic packaging in Europe. Combined with Chinese import bans, Europe is obligated to boost recycling in Europe too.

Regarding food waste, it seems that composting is the most common treatment method in Southern Europe, while biogas is more common in the North. Compostable plastics, often produced in Italy, are very much promoted by Italy within the EU. In Northern Europe, these materials are mainly considered as material for energy recovery.

It is possible that there will be an increase in the number of international products on the Norwegian market in the future. These products could be made from materials that are not supported in the Norwegian waste management system. It is therefore necessary to evaluate the import of these products, and whether restrictions on material types should be implemented to prevent contamination of recycling streams.

12 Appendix

12.1 Bio-based and/or Biodegradable Plastic Producers

	Brand name	Type of plastic	Production location	Production capacity (ktonnes / year)
Arkema SA	Rilsan®	PA	France, USA, China	N/A
Avantium	YXY	PEF	Belgium	Expected to be 50 by 2023
BASF	ecoflex®	PBAT	Germany	74+
	ecovio®	PBAT & PLA blend		
Braskem	I'm green™	Bio-PE	Brazil	200
DuPont	Hytrel® RS	polyester-polyether copolymer	Switzerland	N/A
	Zytel® RS	PA (Nylons)		
	Sorona® EP	Bio-PTT		
Danimer Scientific (formerly Meridian)	Nodax™	PHA	Georgia, USA + Kentucky in 2019	~90
FKuR	Biograde	Cellulose Acetate	N/A	N/A
		Bio-PP		
Greendot holdings	Terratek®	Starch blend	N/A	N/A
NatureWorks	Ingeo	PLA	USA	200
Novamont	Mater-Bi	Mater-Bi	Italy	100

Plant PET Tech Collaborative	PlantBottle™	PET	N/A	N/A
Plantic Tech	Plantic	PE / PET copolymers	Australia + Germany	N/A
Total Corbion	Luminy®	PLA	Thailand	75
Yield10 Bioscience Inc. (formerly Metabolix)	Mirel	PHA	Spain	N/A
	Mvera	PHB		