LIFECYCLE OF BIOPLASTICS AND THEIR ROLE IN SUSTAINABLE DEVELOPMENT

Lappeenranta–Lahti University of Technology LUT

Chemical Engineering Bachelor's thesis

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Kemiantekniikka

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Biomuovien elinkaari ja asema kestävässä kehityksessä

Kemiantekniikan kandidaatintyö

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Tämän opinnäytetyön tarkoituksena on tarkastella erilaisten biomuovien elinkaaria sekä biomuovien asemaa kestävässä kehityksessä. Biomuovin elinkaarta tarkastellaan tuotannon ja kierrätyksen näkökulmasta, sillä nämä ovat ympäristön kannalta merkittävimmät näkökohdat. Biomuovien kestävyyttä tarkastellaan nykyisiin muoveihin kohdistuvien ongelmien kautta.

Tämän opinnäytetyön aihe on tärkeä, sillä muoveista aiheutuvat saasteet ovat tällä hetkellä suuri ympäristöongelma ja lisääntyvä muovin tuotanto pakottaa meidät etsimään vaihtoehtoisia ratkaisuja perinteisten muovien käytölle. Biomuovit ovat osoittautuneet lupaavaksi ympäristöystävälliseksi vaihtoehdoiksi perinteisten muovien paikalle, mutta niiden osuus muovituotannosta on edelleen erittäin pieni ja biomuoveihin kohdistunut tutkinta on ollut vähäistä.

Biomuoveilla on ympäristöystävällisempiä ominaisuuksia perinteisiin muoveihin verrattuna, mutta niillä ei voida vielä ratkaise kaikkia muovituotannon ongelmia. Biomuovien hiilijalanjälki on huomattavasti pienempi kuin perinteisten muovien, mutta niiden valmistus on myös kalliimpaa. Nykyisillä biomuoveilla on huonommat fysikaaliset ominaisuudet kuin perinteisillä muoveilla, joka rajaa niiden käyttöä. Biomuovien ottaminen laajempaan käyttöön olisi askel kohti kestävää kehitystä, mutta on silti tärkeää jatkaa biomuovien tutkimista, jotta tulevaisuudessa voidaan tuottaa entistä kestävämpää ja ympäristöystävällisempää biomuovia.

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

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Chemical Engineering

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Lifecycle of bioplastics and their role in sustainable development

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31 pages and 8 figures

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Keywords: Plastic, sustainability, environment, plastic recycling, plastic pollution

This bachelor's thesis aims to review the lifecycle of different bioplastics and the current state of plastic pollution. The bioplastic lifecycle will be examined from production and recycling perspectives as these are environmentally the most significant aspects. The sustainability of bioplastics will be examined through current plastic problems.

The topic of this thesis is significant since plastic pollution is currently a major environmental problem and increasing plastic production forces us to look for alternative plastic products. Bioplastics have shown promise to be a better environmental alternative, but their share of plastic production is still extremely low, and they still need to be researched further.

Bioplastics have clear advantages compared to conventional plastics in environmental aspects, but they do not currently solve all the problems with plastic production. Bioplastics have a significantly smaller carbon footprint, but they are also more expensive to produce. Current bioplastics have inferior physical properties compared to conventional plastics. In conclusion, adopting bioplastics into wider use would be a more sustainable solution, but it is still important to keep researching further into bioplastics to produce even more sustainable and more durable bioplastics.

LIST OF ABBREVIATIONS

AA	Adipic acid
BDO	Butanediol
DP	Direct polycondensation
NHC	N-heterocyclic carbene
PA	Polyamide
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PE	Polyethylene
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PLA	Polylactic acid
PP	Polypropylene
PTA	Terephthalic acid
PTT	Polytrimethylene terephthalate
ROP	Ring-opening polymerization

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1 Introduction

Plastic production and plastic waste have sparked many conversations in last ten years, but what is the state of plastic production and pollution. In 2014 plastic production was already 311 million tons, and it has been predicted to triple by 2050, according to Antoine Frérot (2016, 5). Plastic has its effects on the environment, from production all the way to recycling. Total carbon footprint of plastics accounted for 4.5 % of global greenhouse gas emissions in 2015, and the plastic waste often ends up in nature and harms ecosystems. The total bioplastic production was only 2.11 MT which counts as one percent of the plastic field; even though the bioplastics account for only a small proportion of all plastic made, it has been predicted to increase in the future (European bioplastic, 2020). Alongside the massive growth of plastic production, bioplastic production has also increased (Niaounakis, 2013, 55). If bioplastics are a better option than conventional plastics, why haven't we adopted them into more extensive use?

As plastic production keeps rising and conventional plastics do not seem to be a sustainable solution, there is a need to look for a solution to this problem. Biobased plastics are either biobased, biodegradable, or both, which may be the solution to current problems with plastics. Production and recycling of bioplastics differ from traditional plastics, making them more environmentally friendly. Production and recycling of bioplastics produce less CO_2 than conventional plastics. Even though bioplastics seem a way better option environmentally than conventional plastics, they have inferior physical properties. (Niaounakis, 2013, 2–4.) There is still a lot of research that needs to be done with bioplastics, which may be due to the lack of their use.

This bachelor's thesis focus on what is the role of bioplastics in sustainable development. Bioplastics have not being researched much and they still need to be improved. The goal of this thesis is to gather information from the production and recycling of bioplastics and compare the lifecycle of bioplastics to current problems of plastic pollution. The research questions of the thesis relate to the production, recycling of bioplastics and are bioplastics a sustainable solution to combat plastic waste. The thesis uses a literature review as the research method.

2 Bioplastics

Bioplastic is a broad concept that includes multiple types of plastics. Term bioplastic can be used for plastics that have been made from bio-based ingredients, plastics that are biodegradable, or both. Similarly, just like conventional plastics are made from polymers, bio-based bioplastics are made from biopolymers. If bioplastic is made from biopolymer, it does not have to be biodegradable to be counted as bioplastic. (Niaounakis, 2013, 2.) A bio-based polymer is made from carbon sources, such as vegetable oils or corn starch (De Clercq et al., 2017, 2). Plastics made from bio-based ingredients can also be divided into two categories. First-generation biomasses, which means ingredients to produce polymers are from consumable ingredients such as sugarcanes. Second-generation biomasses are from non-consumable ingredients such as cellulose. While ingredients for biopolymers grow, they absorb CO_2, which lowers their carbon footprint. Biopolymers have also been studied to emit less CO_2 back into the atmosphere compared to conventional plastics when incinerated. (Niaounakis, 2013, 283.) Second-generation biomasses have been proven to be a great solution to mitigate climate effects due to being able to use the waste of other processes instead of them going into waste (Repo et al., 2012, 1).

Non-biodegradable bioplastics are currently more popular type of bioplastic since they have similar properties with conventional plastics. Biodegradable bioplastics are currently research more than conventional plastics since plastic pollution has been getting increasingly worse. Today many plastic applications require durable plastics and since biodegradable plastics are not currently durable enough, biobased plastics are good for those applications. Even though biobased plastics can be used to replace conventional plastics it only slows down the current escalation of problems. Biobased non-biodegradable plastics do release less CO_2 into the atmosphere, but the pollution and lack of recycling is still a huge problem. Currently most bio-based plastics are produced from first-generation biomasses which is not preferrable since they could be used somewhere else. (Andreeßen et al., 2018, 3.)

The most common bio-based plastics are starch blends, PLA, PA, bio-PET, and bio-PE figure 1, which are bio versions of petroleum-based plastics. Around 58,1 % of bioplastics are biodegradable. (European bioplastic, 2020.)

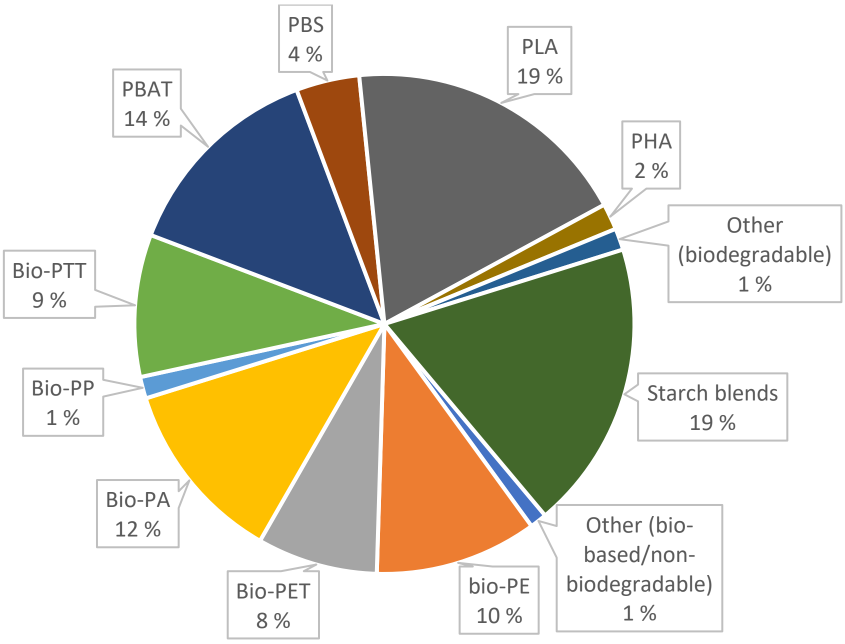

Figure 1. Distribution of bioplastic production in accordance with European bioplastic, 2020

Bioplastics are used a lot in food packaging industry (Peelman et al., 2013, 1). Bio-based plastics have their perks compared to conventional plastics when it comes to sustainability, but they also have their weaknesses. Bioplastics have different physical properties compared to traditional plastics, and the production cost of bioplastics is also higher than conventional plastics. Physical properties of bioplastics are often inferior compared to traditional plastics, for example, lower heat resistance, which makes them hard to implement in use. The cost of bioplastic production could be decreased by increasing bioplastic production. (Niaounakis, 2013, 2.) Bioplastic production has been predicted to triple in next five years, figure 2. (European bioplastic, 2020.)

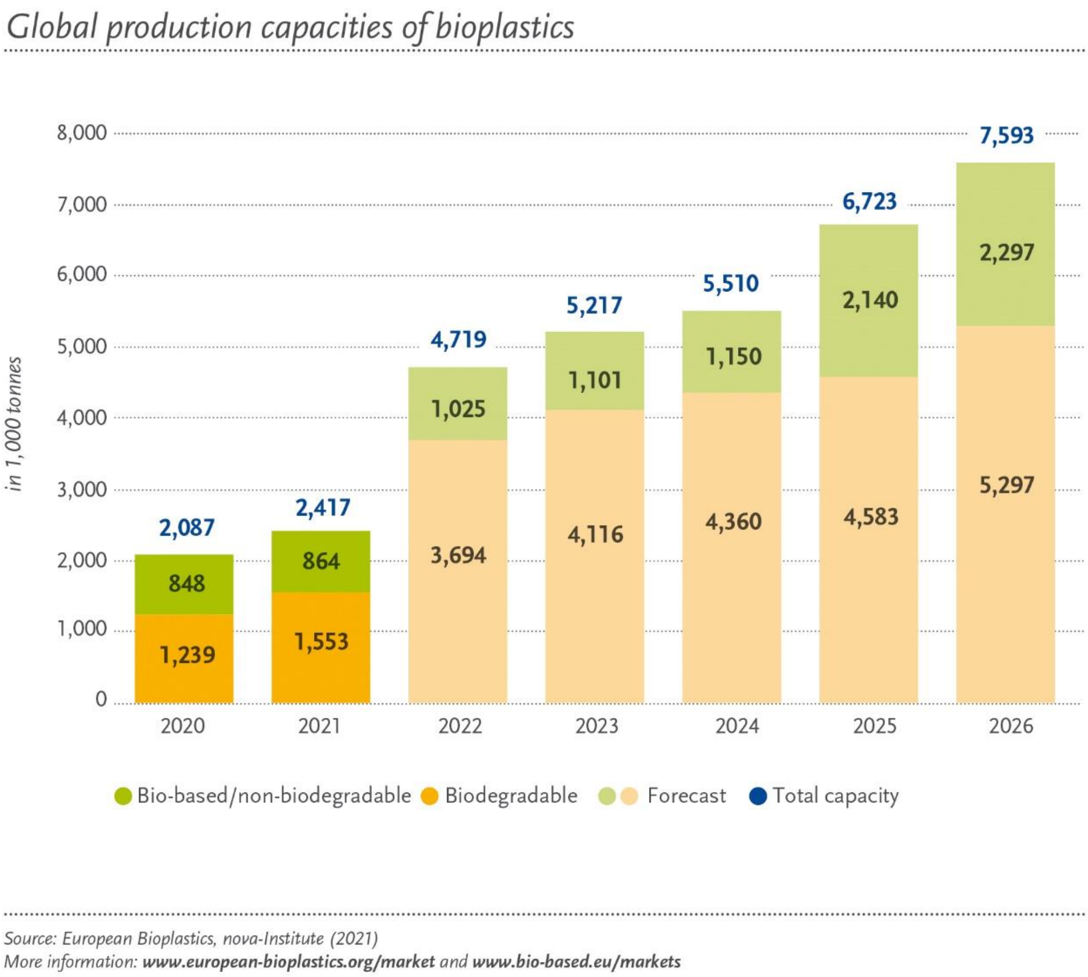

Figure 2 Predicted grow of bioplastics according to European bioplastic, 2020

Examples of bioplastics and their production are discussed below.

2.1 Polylactic acid

Polylactic acid is bio-based and biodegradable bioplastic. Polylactic acid (PLA) is produced from a monomer of lactic acid, and there are two possible production routes figure 3. (Sin et al., 2012, 71–72.)

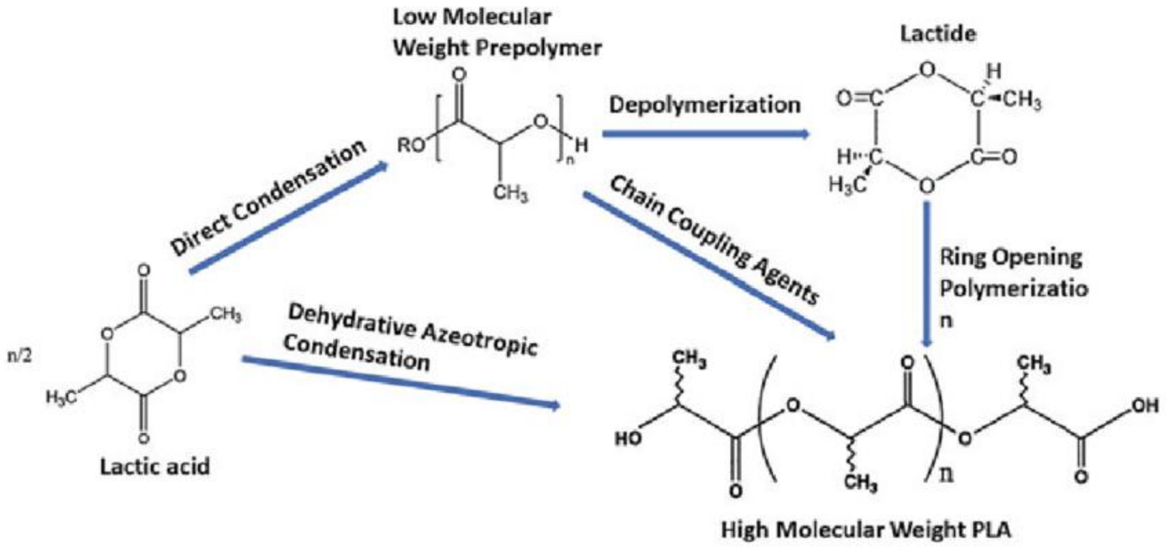

Figure 3 Production routes of PLA (Sharif et al., 2019, 6).

PLA can be made with direct polycondensation (DP) route or the more common ring-opening polymerization (ROP) route. Lactic acid is obtained from the fermentation of sugar, and the lactic acid is first converted to lactide acid and, in the end, to PLA. PLA produced with ROP is referred to as polylactide and through DP polylactic acid. Even though these PLA products have different terms, both of them are used interchangeably. Although DP is more straightforward way to polymerize monomer lactic acid, the yield of PLA ends up having low molecular weight and therefore it has weaker mechanical properties. Because PLA produced with DP has limited applications, the ROP route has been adopted by most industries. (Sin et al., 2012, 71–72.)

2.1.1 Production of polylactic acid

In ring-opening polymerization of the lactide, coordination of the lactide with the acidic metal of Lewis results in electrophilic activation of the lactide due to the attack of the nucleophilic alkoxide group on the metal. The attack results in forming an intermediate, which collapse causes ring-opening to occur. Collapse of the intermediate forms an alkoxide which includes one unit of lactide. The propagation occurs with the subsequent lactide coordinations and the alkoxide insertion continues until the metal alkoxide bond is broken by termination reactions. (Di Lorenzo & Androsch, 2018, 76–77.)

The polymerization reaction starts with electrophilic activation of lactide that can be achieved with either Lewis acid catalyst or brönsted acid. The activation results into formation of intermediate oxo-carbenium ion, which activates monomer poised for nucleophilic attack. in next part, oxocarbenium ion is attacked by the initiator or the growing polymer which forms new tetrahedral intermediate. Tetrahedral intermediate collapses after proton transfer, which adds new lactide unit into polymer chain and produces new ring-opening. (Di Lorenzo & Androsch, 2018, 76–77.)

High molecular weight can be obtained with nucleophilic activation of the end of the polymer chain. Ring-opening polymerization can be catalyzed by nucleophilic catalyst. In nucleophilic catalyzed reaction, free carbene acts as a nucleophile which attacks lactide's carbonyl group. Attack of the carbene results in a zwitterionic intermediate. The collapse of formed intermediate results in ring-opening and new intermediate. After the alcohol additive deprotonates the new intermediate, the intermediate releases an alkoxide that attacks the acylium ion present in the reaction, to form a second zwitterionic tetrahedral intermediate. The collapse of the new intermediate releases NHC catalyst. Chain propagation is achieved when the subsequent nucleophilic activation of a second monomers which is the captured by the alcoholic end group that was formed in polymer initiation The polymerization continues this way until all of the lactide monomer has reacted. (Di Lorenzo & Androsch, 2018, 76–77.)

2.2 Bio-polyethylene

Bio-PE is a bio-based non-biodegradable bioplastic. As the name bio-based polyethylene implies bio-PE is produced from bio-based ethylene. Ethylene can be found in nature, but industrially produced ethylene is used for bio-PE. Ethylene can be produced from ethanol by chemical dehydration process. Just like petroleum-based PE, bio-PE can be used in large wide range of applications. Bio-PE can be used in food packaging, cosmetics, or agricultural purposes. Bagasse is a byproduct of the process, but it can be combusted to produce heat and power. Using the bagasse for power minimizes the waste and the surplus of power can be sold to the grid. (Shen et al., 2010, 12.)

2.2.1 Production of bio-polyethylene

Ethanol needed for ethylene production is often from sugarcanes, which means it is produced from first-generation biomass (Wheals et al., 1999, 1). Sugarcane is treated in sugar mill, where it is cleaned, sliced, and shredded figure 4 (Shen et al., 2010, 12).

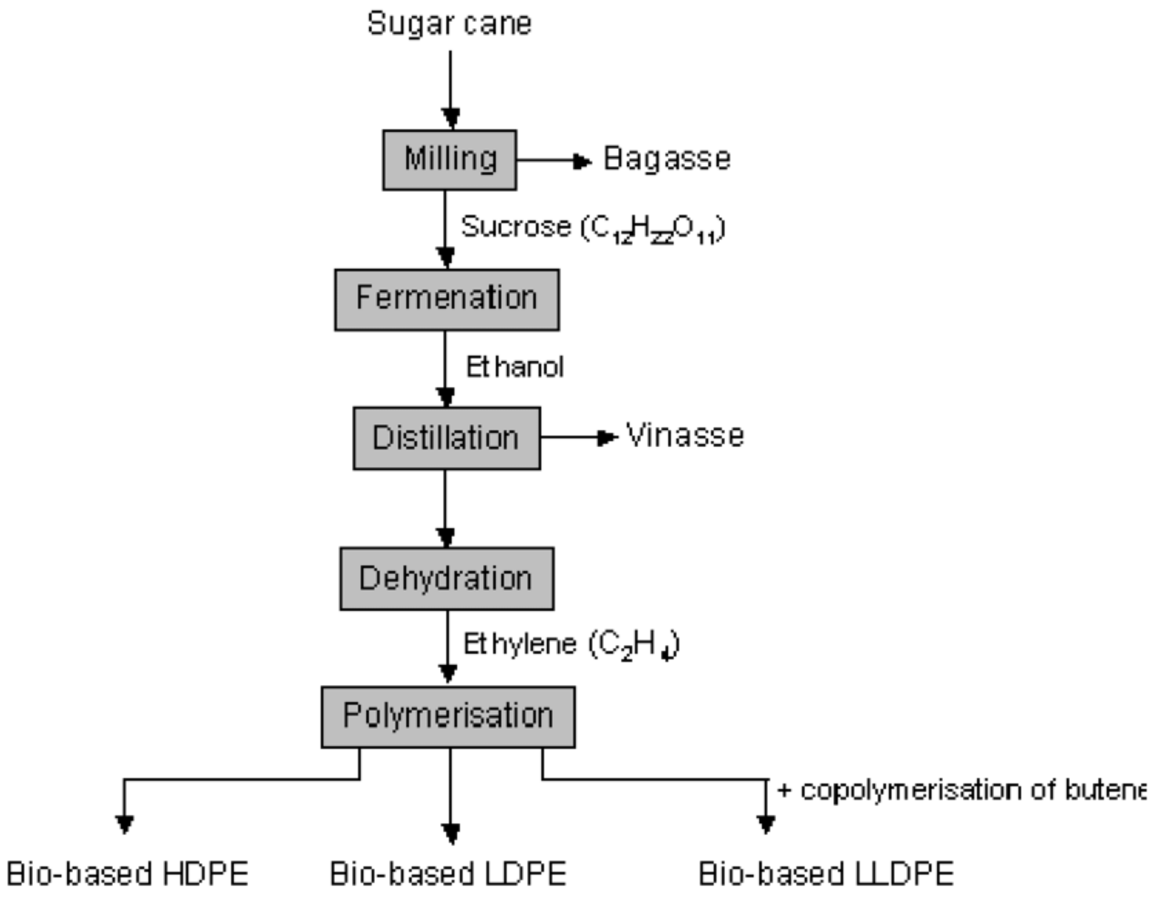

Figure 4 Production route of different biobased PE plastics (Shen et al., 2009, 133).

Treatment of sugarcane produces sugarcane juices and bagasse. Ethyle is produced by fermenting the sugarcane juices under anaerobic conditions. (Shen et al., 2010, 12.) Before producing ethylene, ethanol must be distilled to produce a constant-boiling mixture of hydrous ethanol with strength of 95.5 % (Wheals et al., 1999, 2). To produce ethylene, distilled ethanol is dehydrated at 300-600 °C in the presence of heterogeneous catalysts (Shen et al., 2010, 12). Bio-PE is produced from ethylene by polymerization (Mendieta et al., 2019, 3). In gas-phase polymerization gas-phase supplies the monomer and removes the heat from polymerization. Titanium based catalyst and aluminum alkyl-based co-catalyst are used in polymerization. (Kusolsongtawee et al., 2018, 3.)

2.3 Polybutylene terephthalate

Polybutylene terephthalate (PBAT) is biodegradable bioplastic which has better physical properties compared to most biodegradable bioplastics. Better physical properties are due to it aromatic unit in the molecule chain. PBAT has physical properties similar to non-biodegradable bio-PA which ensures a large scale of use. PBAT is used in different types of plastic bags, packaging, mulch film and many other applications. (Jian et al., 2020, 2–3.)

2.3.1 Polybutylene terephthalate production

PBAT is produced with the polycondensation reaction of adipic acid (AA), butanediol (BDO) and terephthalic acid (PTA) figure 5 (Jian et al., 2020, 2).

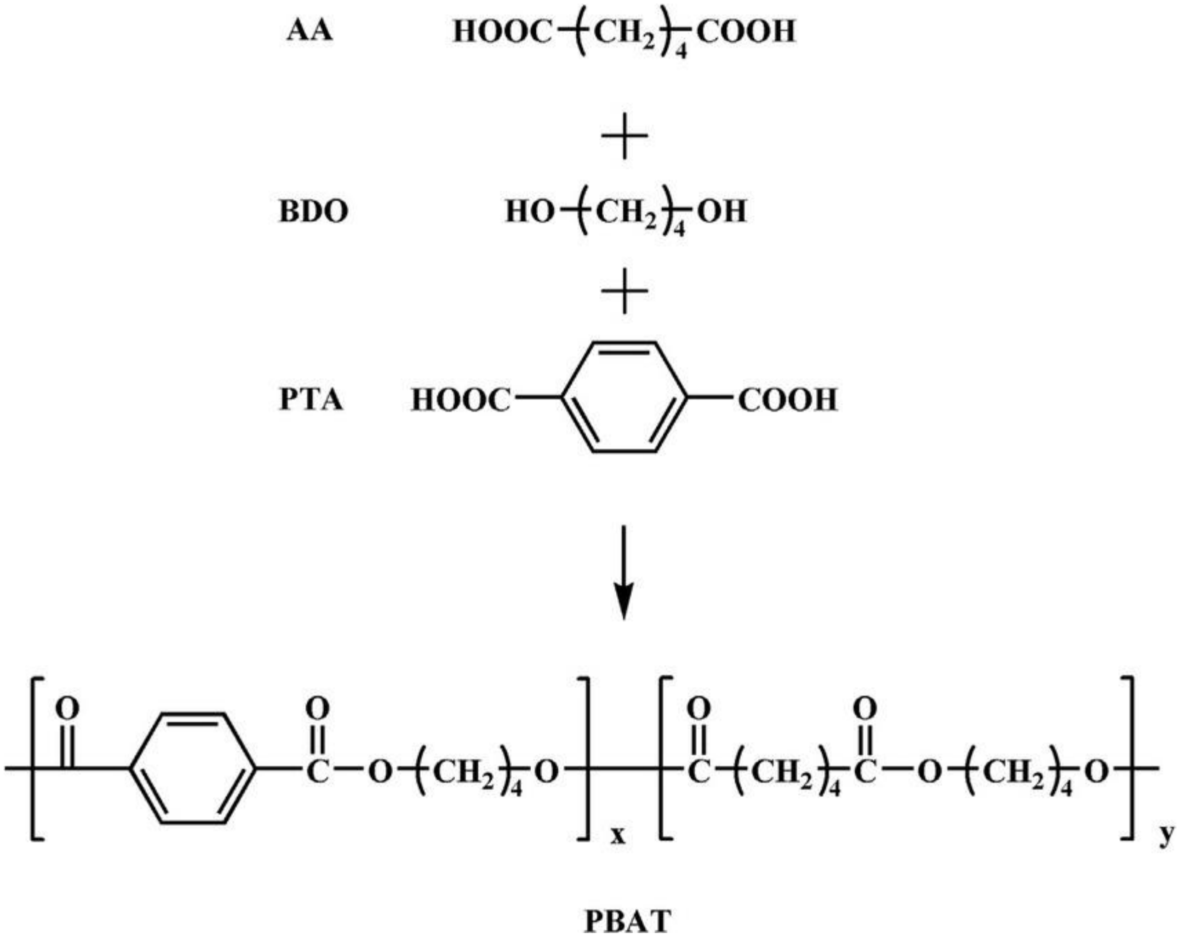

Figure 5 Reactants and schematic diagram of PBAT synthesis (Jian et al., 2020, 2).

The polycondensation rection in the presence of catalyst based in organometallic compounds. In polymerization process nucleating agents are used to improve crystallization behavior of PHAB and to avoid tack. inorganic compounds such as chalk are often used as nucleating agents. Sometimes phosphorous compounds are added in polymerization reaction to stabilize colour, but it also reduces condensation rate. Long chain branching the backbone of polymer increases its product's heat resistance. Long chain branching can be obtained by using multifunctional monomers as branching agents. (Jian et al., 2020, 2–3.)

2.4 Bio-polyethylene terephthalate

Bio-PET or bio-polyethylene terephthalates is bio-based non-biodegradable bioplastic. Bio-PET has similar physical properties compared to conventional PET. Bio-PET is produced from terephthalic acid and ethylene glycol. Most bio-PET are currently not entirely bio-based since bio-based terephthalic acid production is not currently beneficial. Biomasses for ethylene glycol are mostly obtained from sugarcanes or corn starch. Main uses of Bio-PET are textiles and plastic packaging like water bottles. (Andreeßen et al., 2018)

2.4.1 Bio-polyethylene terephthalate production

Bio-PET is produced with polycondensations of terephthalic acid and ethylene glycol figure 6 (Storz, 2014, 9–10).

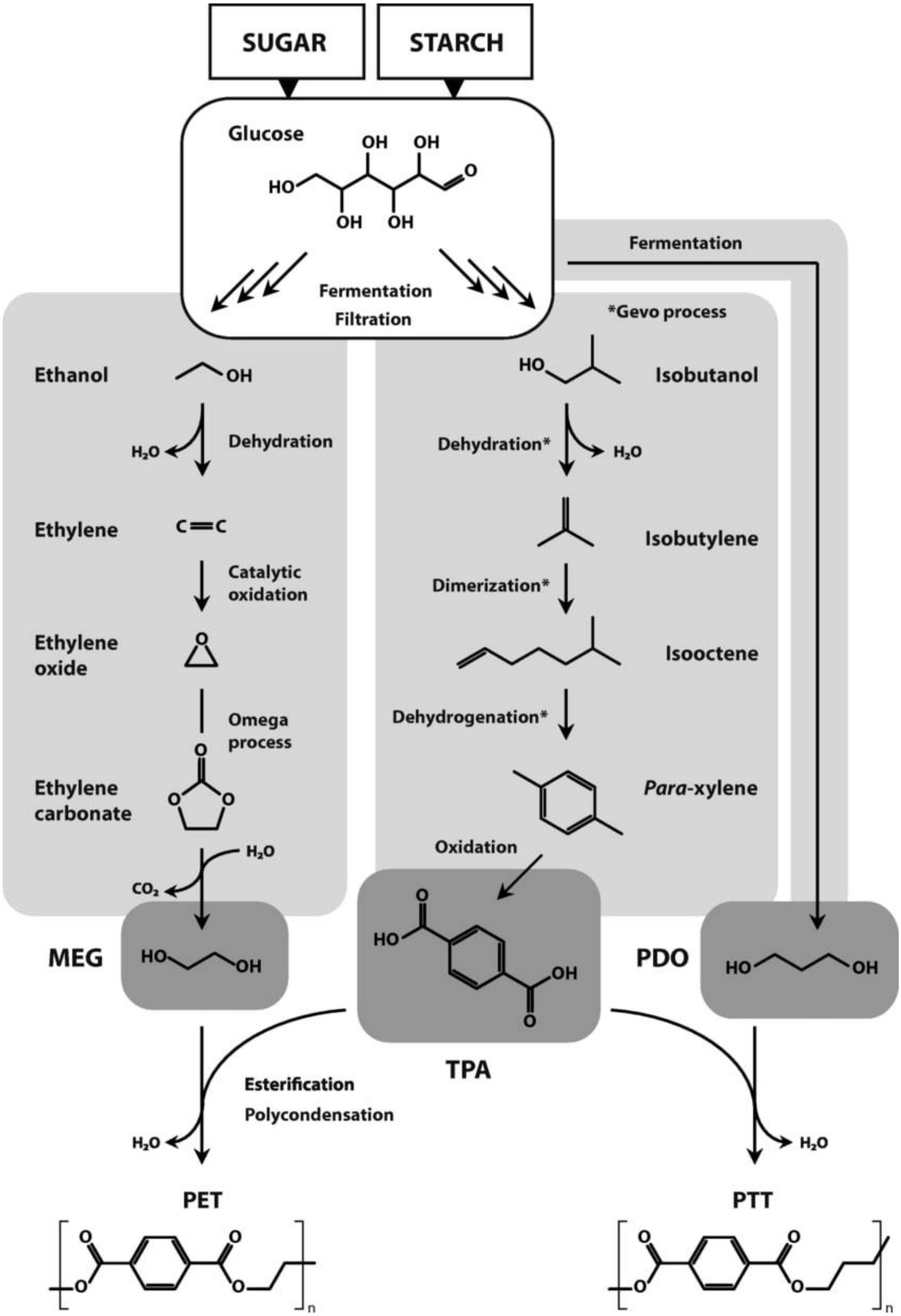

Figure 6 Bio-PET production route (Andreeßen et al., 2018)

Bio ethylene glycol can be produced from bio-ethanol. First bio-ethylene is produced from bio-ethanol, then oxidation of ethylene produces bio-ethylene oxide. Bio-ethylene glycol can be produced with reaction between water and bio-ethylene oxide. Producing bio-terephthalic acid is not as easy process. Bio-terephthalic acid can be produced from bio-based isobutanol. In bio-terephtalic acid production bio-isobutanol is transformed into bio-TPA with catalytical conversation steps with isobutylene and paraxylene. PET production starts with esterification of terephthalic acid and ethylene glycol. After esterification PET is formed with transesterification reaction. Chain extension can be added to production route to produce high-viscosity PET. (Storz, 2014, 9–10)

3 Problems with plastic

Plastic problems can be divided into three categories, problems which occur at the manufacturing, recycling, and problems with their physical properties. Manufacturing and recycling are important subjects to look when examining sustainability of plastics. Problems in manufacturing come from sourcing the materials and the carbon emissions from the production. Possibly the biggest problem of plastics is the recycling aspect. Even though recycling of plastic has its problems large amount of plastics do not even reach the correct recycling facilities and just end up in nature. It is not always just the negligence which causes plastics to avoid recycling for example some clothes contain plastics which polymers could end up into water by the result of friction in the washing machine and some products contain plastics that are impossible to recycle like cosmetic items that contain primary microplastics. (Rocha-Santos et al., 2020.) (Guerranti et al., 2019, 3.)

3.1 Problems with plastic production

In 2014, 311 million tonnes of plastic was produced which consumed 6 % of earths oil consumption. The plastic production has been predicted to double by the year 2034 and triple by the year 2050 when the plastic production would account 20 % of world yearly oil consumption. (Frérot 2016, 5.) Oil is nonrenewable which means soon it will be impossible to keep producing plastic from oil with this rate. Oil prices have also been rising which leads to higher production costs. (Vroman & Tighzert 2009, 1.)

3.2 Problems with plastic recycling

The biggest problem of plastic recycling is the low recycling rate. For example, in the USA only 9.1 % of plastic waste was recycled properly in 2015 (Johnson, 2019). Even though the plastics recycling produces CO_2 it is still better to recycle the waste than throw it away. The unrecycled plastics also cause financial problems, in 2017 it was estimated that 80-120 billion dollars' worth of plastic packaging material is lost yearly. (Linder, 2017, 1.) Incineration should be last solution when it comes to plastic recycling, since there are other more sustainable methods. Yet some places use incineration as preferred method of recycling as the resulting energy is easy to sell for financial gain. (Panda et al., 2009, 5.)

3.3 Problems plastic cause in nature

Between 1950 and 2015, 6.3 billion tons of plastic waste was generated and only 21 % of them was properly treated which means 5 billion tons of plastic ended up into landfills or somewhere else in nature (Geyer et al., 2020, 1). In 2010 alone 9 million tons of plastic waste ended up into the ocean. Polyethylene is one of the most used plastics around the world and it is used in plastic bags. A plastic bag made from PET takes decades to decompose in the nature or landfills. (Lukyanova et al., 2020, 1.) Plastic waste produces large garbage islands into the oceans such as the Pacific trash vortex. Pacific trash vortex has been estimated to be threat to for about 600 different species due them consuming plastic. Plastics break into smaller pieces in ocean and produce harmful micro and nanoplastics. (Eisberg, 2017.)

Plastics pose a danger to marine life. Fishes could entangle into microplastics, or they can ingest them. Entanglement could hurt fishes a lot it can cause tissue damage, breathing and feeding difficulties or even death of some marine groups. Ingestion of small plastics is harmful for fishes for example it can cause intestinal inflammation, endocrine distribution, and physical injuries. (Santos de Moura & Vianna, 2020, 2.) Plastics also cause danger to some turtles. Endangered leatherback turtle may mistake floating plastic bag for a jellyfish, causing it to eat plastic Figure 7. Almost 40 % of opened leatherback turtles had plastic in their stomach. (Campbell, 2018, 1.)

Figure 7 Plastic waste often end up in the ocean. (Australasian Bioplastic association, 2017)

3.3.1 Micro- and nanoplastics

Microplastics can be divided into two categories primary microplastics, which means the plastic was produced to be microscopical and secondary microplastics which are the result of large plastics pieces breaking down. (Guerranti et al., 2019, 3.) Micro- and nanoplastics have been found in different foods like seafood, beer, and table salt. All the effects that nanoparticles can cause are not yet to be figured out but for example it has been studied, that consuming nanoparticles could suppress iron intake. (EFSA, 2016, 21.)

Nanoplastics are extremely small plastic particles with diameter less than 0.1 μm which are produced by the result of microplastics being broken down by sunlight. As the result of small size, nanoplastics can bind up to a thousand times more toxins than microplastics. It is feared that toxins can migrate into the organism after being ingested. A high amount of nanoplastics have been studied to have negative physical effects, and they are able to move up through the food chain. (Roscam Abbing, 2019, 49.)

4 Recycling of plastics

Even though some bioplastic can be discarded, they have valuable raw materials that would be wasted. There are also bioplastics that are nonbiodegradable such as PLA. When plastic is discarded, new plastic needs to be produced, which consumes renewable sources which could be used elsewhere. A large amount of power would be saved by not producing new biopolymers for biodegradable plastics. By recycling plastics, CO_2 emissions can also be reduced since there is less need to harvest new materials. There need to be enough biopolymers recycled, so recycling is practical, which is hard as bioplastics production is low. (Niaounakis, 2013, 151.) Once the plastic has reached the end of its life and been collected for recycling, there are four recycling route options figure 8 (Lamberti et al., 2020, 2).

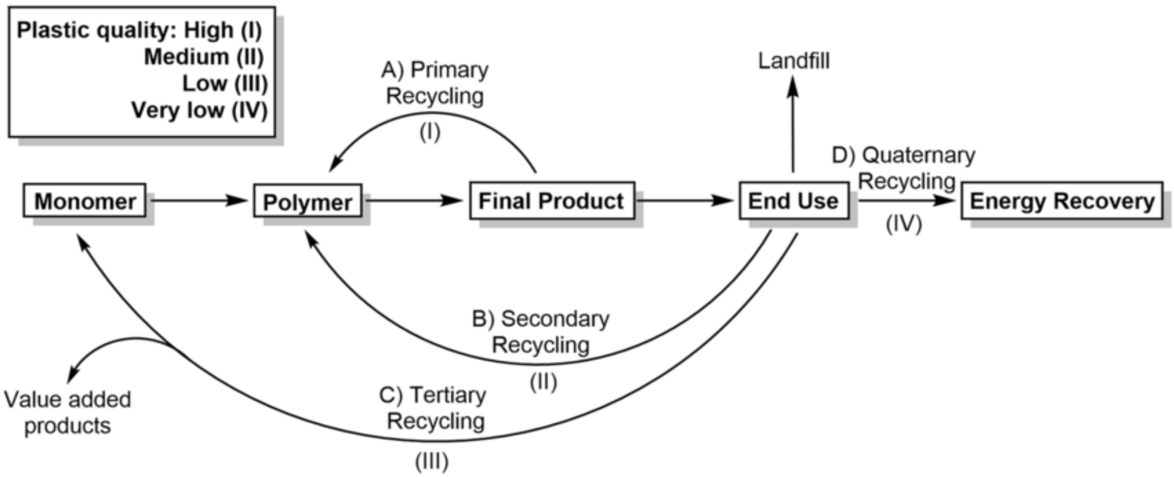

Figure 8 Plastic waste treatment options associated to necessary plastic quality. (Lamberti et al., 2020, 2.)

Even though recycling bioplastics is beneficial, adding new plastics in the current waste management requires some changes or better sorting systems since all plastics are not suitable for same recycling methods (Cornell, 2007, 1).

The classification of bioplastic recycling is summarized below.

4.1 Primary recycling

In primary recycling, plastic scraps with similar features to the original product are utilized to produce new products with similar properties. Plastics need to be clean to be used in primary recycling. Most of the waste used in primary recycling is process scrap. Household plastics are rarely used in primary recycling because of the demanding sorting process. (Al-Salem et al., 2009, 4.) Recuperation and restabilization are types of primary recycling (Niaounakis, 2013, 95).

4.1.1 Recuperation

In recuperation, plastic waste is grounded up and mixed with new virgin material, which is then introduced into the processing machinery. The direct processing of bioplastics in the extruder is possible to a limited extent due to their voluminous nature and poor flow property. Bioplastics are therefore treated by comminution. After comminution, flake-like bioplastic particles are agglomerated into highly compacted, free-flowing, and abrasion-resistant granules. It is crucial to keep the temperature under melting temperature in heat treatment required to produce agglomeration the produced granules need to have the same qualities as new material so they can be proportionately admixed.

4.1.2 Restabilization

It is common that reprocessing waste polymers leads to materials with inferior properties compared to the new material, which can be explained by the change of the chemical structure due to the degradation process. In restabilization, the material is protected from thermomechanical degradation during processing, and materials long-term stability throughout reuse is enhanced. Restabilization can be used to prevent further degradation process, but it can not recover already degraded materials. Without restabilization oxidative moieties or moisture could catalyze material to degrade even further. Different kind of processing and light stabilizers are being used to re-stabilize recycled biopolymers, including combinations of hindered phenols hindered amine stabilizers.

4.2 Secondary recycling

In secondary recycling or mechanical recycling plastic waste is recovered for re-use in manufacturing plastic products with mechanical process. In mechanical recycling polymers are left intact. Mechanical recycling can only be used for single polymer plastics, and the more complex the plastic and contaminate the plastic is, mechanical recycling gets more complicated. Mechanical recycling is not the preferred recycling method of miscellaneous bioplastics waste because most biodegradable bioplastics are aliphatic polyesters and therefore not suitable for this method. (Niaounakis, 2019, 4).

4.3 Tertiary recycling

Tertiary recycling or chemical recycling is used when plastics are converted back into smaller molecules and monomers, which can be used as feedstock to produce new chemicals and plastics. Chemical recycling means that the chemical structure of the material is change in the way that the original material can be made from produced chemicals. (Tukker, 2002, 3.) In chemical recycling chemical structure of the polymer is altered in non-catalytic thermal cracking (thermolysis). In thermolysis, plastic waste is treated under controlled temperatures without catalyst. Thermolysis can be seperated into three categories pyrolysis, gasification, and hydrogenation. In thermolysis, plastic waste is treated without catalyst but under controlled temperatures. (Al-Salem et al., 2009, 7.)

4.3.1 Pyrolysis

In pyrolysis plastic waste can be turned into clean and high calorific gas with conversion technology (Al-Salem et al., 2009, 7–8). Plastics have great properties for pyrolysis since plastics have very high volatile matter and ash content which is great for producing a large amount of liquid oil (Giulia et al., 2021, 11). In Pyrolysis, hydrocarbon content within waste is converted into gas or oil, which can be used without the need for fuel gas treatment.

Plastics are an excellent way to produce high calorific value gasses with pyrolysis. High calorific gasses produced can be used in a gas engine to produce heat and electricity or sold forward. In pyrolysis, the residual output of char can be utilized as a fuel for other petrochemical processes. Pyrolysis doesn’t require gas clean-up as flue gas is mainly treated before utilization. Pyrolysis has some advantages in environmental aspects as it provides an alternative solution to landfilling and reduces CO2 emissions. The most significant disadvantage of pyrolysis is the difficulty to handle char and treat the final product to a specific product. (Al-Salem et al., 2009, 7–8.)

4.3.2 Gasification

In gasification, plastic waste is turned into fuels or combustible gases. Gasification agent is used as a medium in gasification process (Yang & Chen, 2015, 253). It is possible to reduce the cost of the gasification, by using air as gasification agent instead of O_2. Even though the process is cheaper while using air, the calorific value of produced gasses is lowered because the presence of N_2 within air dilutes the effect on fuel gases. To reduce the amount of N_2 in the process, steam is introduced in a stoichiometric ratio. An ideal way to process plastic waste by gasification would produce high calorific values gases, completely combusted char, produced metal should be easy to separate from ash, and work with air. The gasification process is still being worked on to be more effective as today gasification processes produce large amount of char which requires to be processed further or being burnt. (Al-Salem et al., 2009, 10.)

4.3.3 Hydrogenation

In hydrogenation (hydrocracking), hydrogen is added by a chemical reaction through the unit operation. In hydrogenation, agglomerated plastic waste is depolymerizated and dechlorinated by keeping it between 350 and 400 °C. The overhead of the previous process is then partially condensed, which is then fed into a hydrotreater. Hydrotreater eliminates the HCL with formation water, and the resulting, after HCL elimination new Cl-free condensate and gas are mixed with depolymerisate for treatment in the viable cascade controller section. (Al-Salem et al., 2009, 13.)

4.4 Quaternary recycling

If the plastic cannot be recycled any other way, the final recycling step is energy recovery. Incineration process is used to harvest all the energy left in the plastic waste. Even though bioplastics aren't as energy rich as conventional plastics, heat energy produced from incineration can be used to produce heat, steam and electricity. (Al-Salem et al., 2009, 15–16.)

4.4.1 Energy recovery

Energy recovery or incineration is a viable solution for recycling waste polymers since hydrocarbon polymers replace fossil fuels which lowers the CO_2 burden on the environment. (Panda et al., 2009, 5.) After recovering the remaining energy of the plastic, its volume will also be reduced by 90-99%, which reduces the reliability on landfills. (Al-Salem et al., 2009, 15–16). Bioplastics release less CO_2 into the atmosphere in energy recovery (Niaounakis, 2013, 283).

5 Biodegradation

Biodegradation of a polymer is the combination of the enzymatic cleavage of its polymer chains into metabolic products of the microorganism responsible for the enzymes and abiotic reactions, which are photodegradation, oxidation, and hydrolysis. The present microorganisms, their distribution and growth conditions determine the biodegradation rate of plastic waste. For example, PLA has a very slow biodegradation rate in water, and it needs half a year until its properties drop significantly, when Starch based plastics have a fast degradation time which reduces the requirements of landfills way more. (do Val Siqueira et al., 2021, 1.) (Lamberti et al., 2020, 5.) Yet there is still need for more research for degradation periods and associated energy potential (Nachod er al., 2021, 2). A process called hydrolytic degradation is a process where moisture penetrates, for example, bioplastic, and breaks down the polers in the material. Bioplastics have a high molecular weight which means their hydrolysis rate is too slow to significantly reduce the burden when disposed on landfills. (Lamberti et al., 2020, 5.)

6 Conclusions

Bioplastic is a term that includes plastics that are bio-based, biodegradable or both. Only 42 % of bioplastics are biobased. Biobased plastics are made from biomasses which can be divided into two categories first- and second-generation biomasses. The latter of these being more sustainable since first-generation biomasses are consumable and second-generation biomasses are non-consumable. Bioplastics have more sustainable production compared to conventional plastics. Production of bioplastics produces less CO_2 emissions and they are also produced from renewable sources. Bio-based bioplastics have the most sustainable production since plants used to make biopolymers can absorb CO_2.

Bioplastic recycling is important since some biobased bioplastics are made to have same properties as conventional plastics and therefore, they have long degradation time. Recycling plastics is not just good for the environment but also financially beneficial since there is less need for new raw material. Some bioplastics are biodegradable and have a fast biodegradation time but still should be recycled to harvest energy and materials. Even though recycling bioplastics is important some current recycling methods are not optimized for bioplastics.

The recycling of bioplastics does not differ much compared to traditional plastics, but for example sorting systems need to be changed so bioplastics can be included in current recycling systems. Recycling plants remain the same recycling methods of conventional plastics even for bioplastics since bioplastics count is less as compared to conventional plastics, but the scenario would change if proportion of bioplastics increases in the future. However, the recycling product differs despite same recycling method are applied for bioplastics and conventional plastics. Even though the recycling methods are same the end product depends on the plastic and its properties, for example bioplastics emit less CO_2 while incinerated but also produces less energy. Biggest problem in plastic recycling is the low recycling rate, which even bioplastics cannot fix. Bioplastics do however reduce the problem of lack of recycling since biodegradable bioplastics cause way less harm when discarded into nature.

Bioplastics clearly have their strengths against conventional plastics, but they are not yet the perfect alternative. Bioplastics still need to be studied more to be as used as conventional plastics. Bioplastics have not been able to be produced with the same physical properties as traditional plastics. There needs to be more studies on how to make bioplastics more durable. The cost problem should be solved by increasing the production amount of bioplastics, but the process will be slow. Adopting bioplastics into wider use would be beneficial since it would be environmentally friendly, and it would encourage the research process. Bioplastics should be adopted especially to areas which produce the most unrecycled plastic waste. Bioplastics have production has been rising in recent years which could indicate that bioplastics can someday bypass petroleum-based plastics as the most used plastic.

7 References

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