Biodegradable Plastics: Breaking Down the Facts

Production, composition and environmental impact

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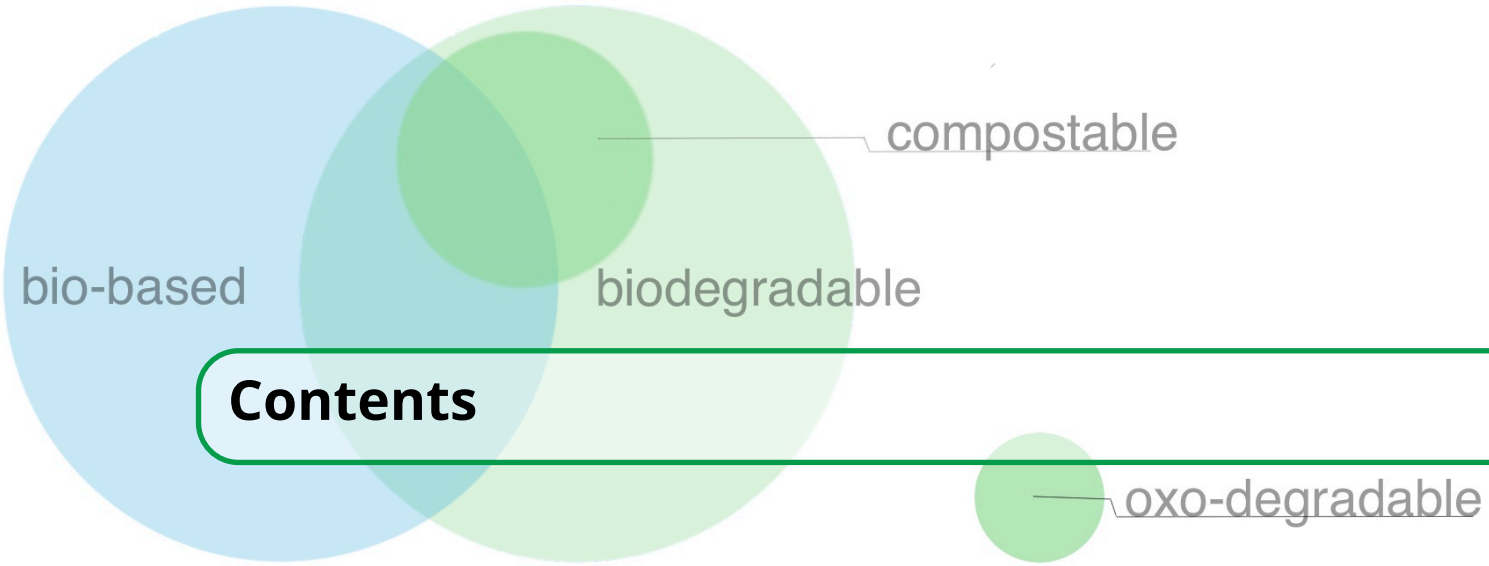

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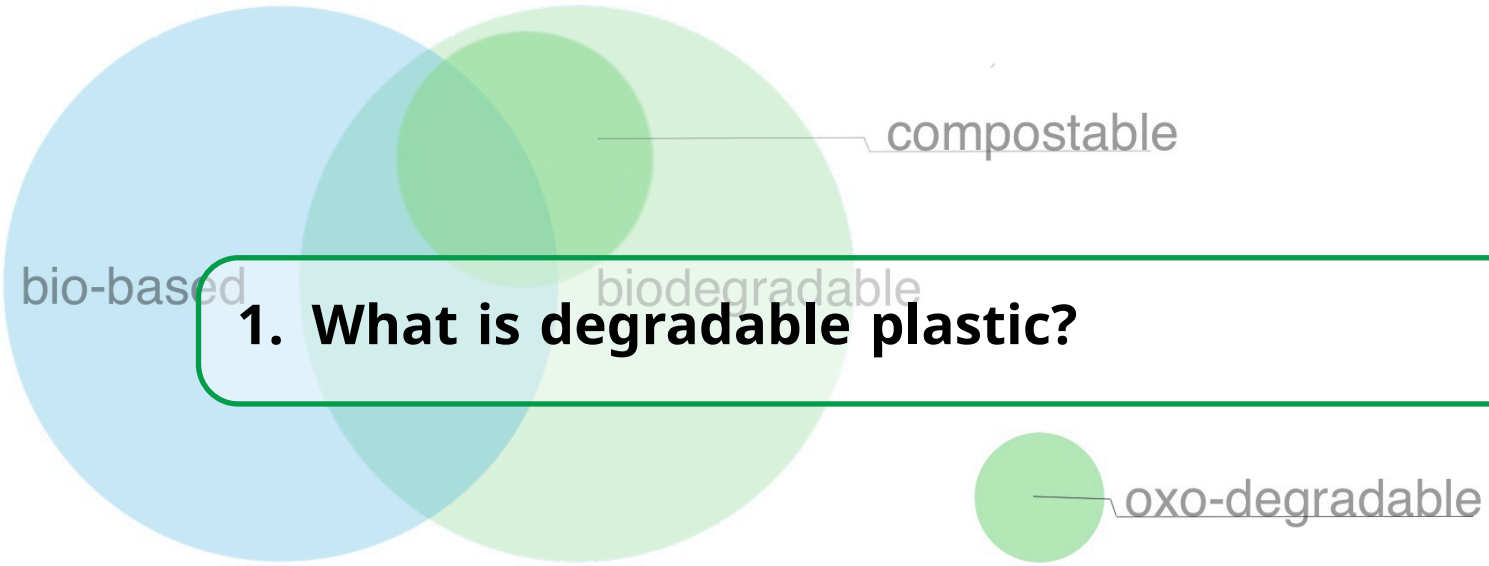


1. What is degradable plastic?

Marine plastic litter has drawn society's attention to the excessive use of disposable single use plastics (SUPs) [1], and its negative impact on the environment and human health. In addition, the rapid increase of SUPs globally is accelerating climate change due to the amount of greenhouse gas emissions from its entire lifecycle, according to a 2019 report[1].

The global annual usage of plastic exceeded 300 million tonnes in 2015, and nearly half was used to make SUPs[2], which are designed to be used for a short time before being thrown away. Policymakers across the globe have employed various national and regional regulatory approaches to address plastic pollution, to which SUPs are a major contribution. By 2018, the United Nations summarized that 127 countries have introduced legislation to regulate plastic bags, 27 countries have banned specific SUPs, materials or production levels, and 63 countries have mandates for extended producer responsibility for SUPs[3]. Of the specific plastic bag material composition requirements, 35 have given the green light for degradable plastics, incentivized the production, import, or use of oxo-biodegradable, biodegradable and/or compostable SUPs. Different types of degradable plastics have been highlighted in the mainstream media since then, often as an exciting breakthrough material to solve the plastic crisis.

China is one of the countries with the largest plastic production and consumption in the world, and announced a ban on non-degradable SUPs in major cities by the end of 2020 and across the country by 2025, although degradable SUPs are exempt from the ban[4]. Once again, degradable plastics are promoted as a "green" alternative. However, what is "degradable" plastic? What are its environmental impacts? Do we need to develop an alternative waste disposal strategy for disposable plastics? Can we really tackle plastic pollution by switching to degradable plastic? Many questions still need to be addressed before accepting degradable plastic as an eco-friendly solution to conventional plastic.

Considerable confusion exists in the field of degradable plastic, and different terms are often used incorrectly in public communications. The two general mechanisms for

[1] Single use plastics (SUPs) include different types of products, such as, plastic bags, food and beverage packaging, straws, containers, cups and cutlery, which are typically used once before being thrown away.

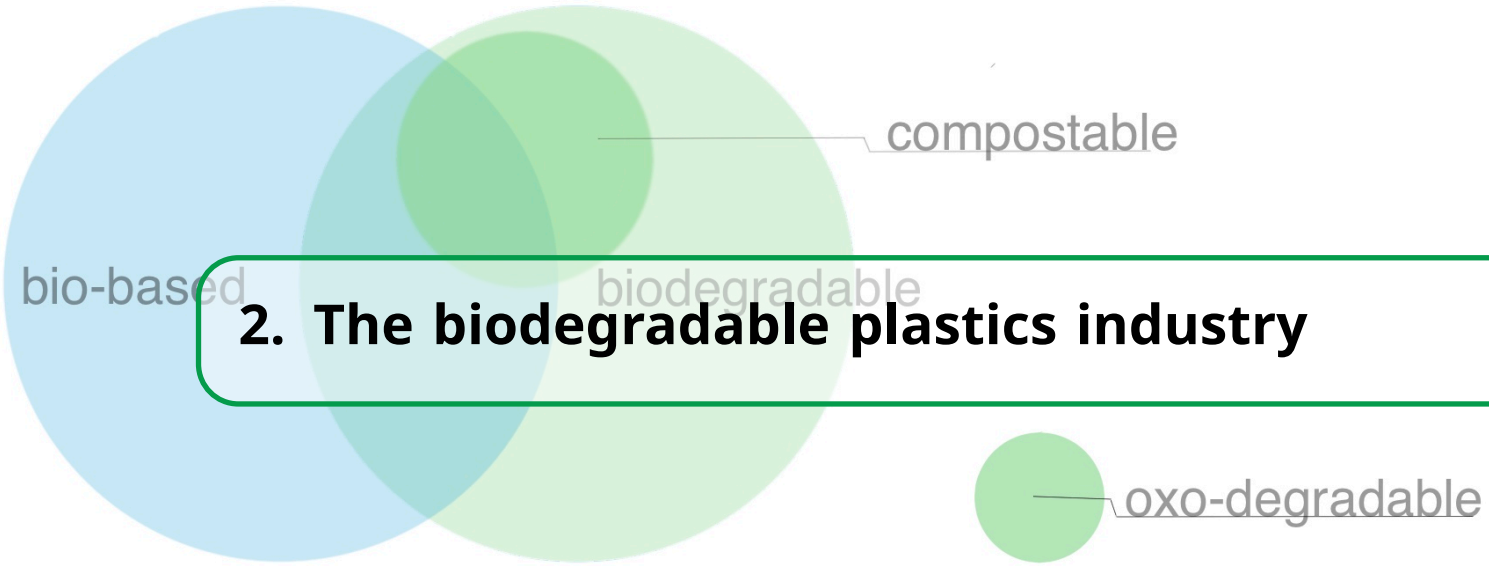
degradable plastics are (i) photo- and oxo-degradation and (ii) biodegradation[5]. Photo-degradable and oxo-degradable plastics are typically made from conventional plastics with some additives, which helps the products to fragment rapidly under ultraviolet radiation (sunlight) and oxygen[6]. The theory was that plastic would be degraded into carbon dioxide and water by microorganisms. However, studies have shown that photo- and oxo-degradable plastic does not biodegrade within a reasonable time period [2] , but leads to the accumulation of incompletely degraded plastics in the environment. Biodegradable plastics, on the other hand, consist of various polymers from different origins with different chemical structures and properties, and each requires specific conditions to fully biodegrade. There are more than 20 kinds of biodegradable plastics, including polymers from natural biomass, polymers produced from bacterial productions, polymers chemically synthesized using agricultural resources, and polymers chemically synthesized using fossil-fuel resources (for examples, see Table 8.1). The different types of degradable plastics, even photo- and oxo-degradable plastics, are often marketed as “green”, “eco-friendly” and “natural”, or generally described as “biodegradable” materials.

Another term that is often used is “bioplastic”, which includes bio-based plastics and biodegradable plastics, but the use of different names and the lack of clear terminology can be confusing for consumers. Bio-based plastics are made fully or partially from biological resources, and may not necessarily be biodegradable – nearly half of the bioplastics produced are not biodegradable. Despite the fact that these terms have been used for more than a decade, most consumers would presume a material is biodegradable when it reads “derived from plants”[8].

In an effort to solve the plastic crisis, a number of governments and big brands have favored degradable plastics, especially biodegradable plastics. The use of biodegradable plastics is predicted to increase rapidly, with an expanding range of applications. It is more urgent than ever to properly discuss the emerging issues concerning the use of biodegradable plastics.

Greenpeace has reviewed the production and application of biodegradable plastics, how they are managed in different parts of the world, and how they are marketed by big brands. A comprehensive understanding of bioplastics will help us evaluate whether the use of biodegradable plastics have any positive impacts, and how they should be regulated while society is transitioning towards a circular economy.

[2] “Defining a ‘reasonable’ time frame might differ from product to product depending also on the use of the product and its impact on the environment; the environmental impact is correlated with the time taken for complete breakdown of the polymer.” [7]



2. The biodegradable plastics industry

2.1 How biodegradable plastics are made

Global production capacity for bioplastics reached 2.11 million tonnes in 2019, of which 55.5% is biodegradable plastics, roughly 1.17 millions tonnes[9]. Polylactic acid (PLA) is probably the most well known biodegradable plastic, but more than 20 groups of biodegradable plastic polymers exist. Of those 20, only 3 groups are produced on a commercial production scale: (i) starch blends; (ii) PLA; and (iii) polybutylene-based polymers, which include PBS (short for polybutylene succinate) and PBAT (short for polybutylene adipate terephthalate), which are mostly fossil fuel based. Nearly 95% of production capacity for biodegradable plastics is among these 3 groups.

The production capacity of **starch blends** was approximately 450 thousand tonnes in 2019. Starch is inexpensive and readily available compared to other natural polymers with additional biodegradability, making it a popular material to develop biodegradable plastics. However, due to its poor water resistance and low strength[10], starch is often blended with other polymers to achieve needed mechanical properties. The commercial development of starch blends have gone through several phases. Early stage starch blends are to fill conventional non-degradable plastics (such as polyethylene or polypropylene) with starch, with the aim of increasing degradability as well as reducing cost. This type of starch blend is only partially biodegradable. Thermoplastic starch (TPS) [1] was developed in response to the need for a material that would fully biodegrade. Current starch blends are mainly TPS blending with other types of biodegradable plastics, though partially biodegradable starch blends still remain in many countries, often marketed as the “biodegradable starch plastic”.

PLA is relatively cheap with several attractive mechanical properties compared to other biodegradable polymers, which has made it a popular material. As of 2019, production capacity of PLA was approximately 290 thousand tonnes.

Both starch blends and PLA production heavily rely on plant feedstocks, such as cas-

[1]Thermoplastic starches (TPS) are chemically modified from natural starch. Natural starch can be processed by heating and adding different types of plasticizers, in order to improve properties for industrial use.

sava, potato, corn, and sugar cane[11]. Other feedstock sources have been researched and explored, such as agricultural byproducts[11], cellulosic materials[12], or greenhouse gases (i.e. carbon dioxide and methane)[12], but the technology is still under development and agricultural products look set to remain as the main feedstock for starch blends and PLA in the near future.

PBS/PBAT are fossil-based biodegradable polymers, with a current production capacity of 370 thousand tonnes. In theory, PBS can be 100% bio-based, and PBAT can be 50% bio-based[13]. However, bio-based equivalence for both polymers is under development, and a majority of PBS/PBAT currently produced are still fossil-based[14].

Polyhydroxyalkanoates (PHAs) are another important group of biodegradable polymers. Current PHA production capacity is only 25 thousand tonnes. The major restriction for the wide commercialization and industrialization of PHA is the high cost of production[15], though European Bioplastics expect a significant increase in PHA production in the coming years[9]. PHAs are produced from microbial fermentation mainly using sugar or oil, although industrial waste streams have been studied as cheaper carbon sources, including agricultural waste, wastewater, food waste, used cooking oil and waste biogas[16].

Besides four major biodegradable polymers mentioned above, there are many other types of biodegradable plastics, including the water soluble PVOH (short for polyvinyl alcohol), the CO_2 derived PPC (short for propylene carbonate) and the good blending material PCL (polycaprolactone). There are reports of new materials from the biodegradable polymer field, but these materials will require many years of research and development to be used commercially.

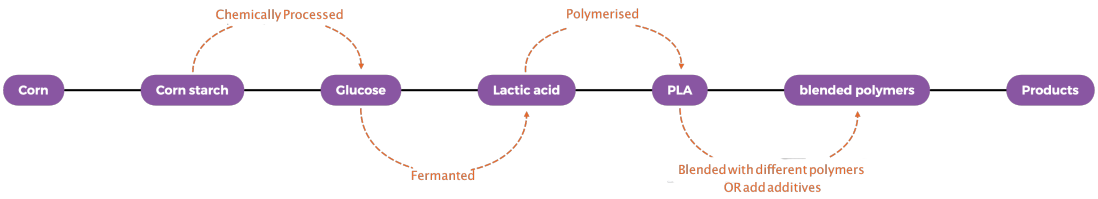


Figure 2.1: An example of biodegradable plastic supply chain

Box 2.1 The biodegradable plastics supply chain
Biodegradable plastics are synthetic chemical polymers with a supply chain that involves the polymer processing sector and the agricultural sector. Using cornstarch polylactic acid (PLA) as an example, its supply chain includes:

- Feedstock manufacture (corn farming)
- Raw material manufacture (starch extraction)
- Intermediate manufacture (starch hydrolysis into glucose)
- Platform chemical manufacture (lactic acid production)
- Material production (conversion of polylactic acid polymer), and
- Market product manufacture (mold polymers into packaging)

It is often a global supply chain spanning multiple continents and countries, involving a number of companies. ■

2.2 Who is making biodegradable plastics?

Companies in Europe, the United States, and Japan have commercialized production of biodegradable polymers, and production has shifted to Asia, due to the low cost and convenience of feedstock acquisition. Many companies have emerged in Asian countries, especially in China and Thailand[17], which are financed by local investments or companies from the Global North.

Starch blends: Italian company Novamont is the leader in the starch blends sector, having an annual production capacity of 150,000 tonnes. Novamont operates four production plants across Italy, mainly using cereal starch and oil crops as feedstocks[18]. The company claims that a sustainable supply chain is essential for its operations and that the production of its raw materials does not hijack high biodiversity and high carbon reserves in soil[19], but limited publicly accessible information could be obtained to evaluate its claims.

PLA: American company NatureWorks leads the PLA sector, operating a manufacturing facility in the midwestern state of Nebraska, with a production capacity of 150,000 tonnes[20]. NatureWorks uses crops growing within 50 miles of its US production facility. To ensure feedstock sustainability and responsibility, the company announced that by 2020, 100% of its feedstock will be certified by the International Sustainability & Carbon Certification System (ISCC), an independent third-party sustainability certification system[21]. Total Corbion PLA currently operates the world's second largest PLA plant in Rayong, Thailand. The plant was opened in 2019, with an annual capacity of 75,000 tonnes, using non-genetically modified sugarcane sourced locally in Thailand as feedstocks[22]. In early 2020, the company announced its plan for a second PLA plant based in Grandpuits, France, with an annual capacity of 100,000 tonnes[23]. The remaining major PLA producers are mostly located in China, Most of the companies are fairly small with an annual production capacity between 10,000 - 50,000 tonnes. Jiangsu Yunyoucheng operates the largest PLA plant in China, with an annual capacity of 50,000 tonnes[24]. However, a Chinese company called Anhui Fengyuan recently announced a production plan for PLA that would reach "15 million tonnes by 2020, and 35 million tonnes by 2030"[25], which, if achieved, would be 100 times greater than current global PLA capacity. Anhui Fengyuan also mentioned its plan to import corn from Brazil as the main PLA feedstock. Currently no public information is available to evaluate the sustainability and responsibility of feedstock sourcing by Chinese PLA producers.

PBS/PBAT: German chemical giant BASF leads the production of PBS/PBAT, operating a plant with annual production capacity of 74,000 tonnes[26], producing petrochemical-based biodegradable plastic. In addition, BASF, in early 2020, announced a collaboration with Chinese chemical manufacturer Red Avenue New Materials Group, planning to build another 60,000 tonnes plant in Shanghai, China[27]. The production of PBS/PBAT has bloomed in China, with an annual total amount of approximately 200,000 tonnes, making

up half of the global capacity. Guangzhou Jinfa is the leading Chinese company producing petrochemical-based PBAT[24]. Japanese chemical company Showa Denko was the first to commercially produce PBS. However, due to the high cost and low market share for biodegradable plastics over the last few years, Showa Denko closed its 20,000 tonne PBS production line in 2016[28]. Mitsubishi Chemical Corporation is the major Japanese company producing PBS polymers. Its PBS plant is located in Rayong, Thailand, with an annual capacity of 30,000 tonnes. Mitsubishi uses corn-derived bio-based monomers and petrochemical compounds to make PBS[29].

PHA: A number of companies used to produce PHA, but later exited from the sector due to the lack of market. American company Metabolix closed its 50,000 tonne PHA production line in 2012, and sold its technology to Korean company CJ CheilJedang in 2016[30]. Italian company Bio-on announced bankruptcy in 2019[31]. American company Danmier Scientific is the major PHA producer and produces bacteria-fermented PHA using canola oil[32]. Danimer's PHA plant is located in Kentucky, US, and it is working on bringing the technology to a commercial scale. The company plans to source canola oil from the southeast US according to Danimer's marketing manager. Chinese company Tianjin Guoyun is another important player, with an annual production capacity of 10,000 tonnes.

The above mentioned companies are the major suppliers for packaging companies or consumer goods brands to produce market products such as snack packaging, plastic bags and other single-use biodegradable plastics. Most companies sell their polymers as an intermediate product with a blended formulation, and provide customers on-the-shelf solutions, meaning polymer producers would alter the blend ratio of different types of biodegradable polymers and chemical additives in order to meet the requirements from the end user. The PLA plastic bag bought from Walmart might be slightly different from the PLA bag we bought from Carrefour in terms of chemical combination.

2.3 Where biodegradable plastics are used

Europe and North America are two major markets for biodegradable plastics, but the demand for biodegradable plastics is growing rapidly in Asia, especially in China and India, due to plastic restriction policies[33].

Packaging is the primary use for biodegradable plastics and accounted for 59% of the biodegradable plastics made in 2019[34]. Biodegradable packaging is currently a fraction (0.5%) of total plastic packaging produced. Flexible packaging used nearly 500,000 tonnes of biodegradable plastics. Large multinationals in the consumer-packaged goods, retailer and food service sector have also made progress or declared intentions to dramatically scale biodegradable plastic usage, which drives the demand for biodegradable packaging for fresh produce, food cutlery, and compostable bags. In 2017, 164,000 tonnes of biodegradable food packaging and food ware were produced. This number is forecasted to increase by 10% by 2022[35]. The demand for food packaging and single-use plastic has increased because of the the COVID-19 pandemic, and companies have sought biodegradable alternatives for food packaging and single-use cutlery[36]. Demand for compostable bags was 72,000 tonnes in 2017, and is forecast to increase by 9% by 2022[35]. In addition, several e-commerce giants have also encouraged a switch to biodegradable packaging, driving the biodegradable demand in online goods and food delivery. In China alone, if online sectors meet the policy requirement by switching 50% of their online delivery packaging[37] and 20% of food delivery packaging to biodegradables, more than 700,000 tonnes would be added to the demand of biodegradable plastics. In addition, a January 2020 policy[4] bans the use of non-degradable plastics in online delivery by 2025. If companies do not develop ambitious plastic reduction plans, and instead simply switch from conventional plastics to biodegradable plastics, China's online delivery industry would produce an estimated 5

million tonnes of biodegradable plastic waste per year by 2025 [2].

Agriculture and horticulture used 14% of all biodegradable plastics manufactured in 2019[34]. Agricultural mulching film is used to improve crop yield in many countries. Traditional mulching film is difficult to collect from the field and can lead to severe plastic pollution in the soil. Biodegradable mulching film has, therefore, been tested and developed to be an alternative. Though its soil biodegradability and impacts are not yet fully understood, many countries have applied it to a larger scale. BASF projected that global demand for biodegradable mulching films would reach 2 million tonnes per year, with 100,000 tonnes within Europe[38]. China has the largest mulching area, using up to 2.5 million tonnes of mulching films per year. With a presumed 10% annual switching rate to biodegradable, China alone would need more than 200,000 tonnes of biodegradable mulching films per year[39].

2.4 An uncertain future for biodegradable plastics

IHS Markit forecasts that the demand of biodegradable plastics will increase to 550,000 tonnes globally by 2023[40]. In comparison, Chinese market predictions are more ambitious, with an estimation of biodegradable plastics demand in China reaching 2.38 million tonnes by 2025[39], and 640,000 tonnes for PBAT alone[41]. Prof. Wen from Tsinghua University in China estimated that a cumulative amount of 22 million tonnes of biodegradable plastics will be needed over the next 5 years to replace single-use items according to the new Chinese plastic ban[42].

Legislation relating to single-use plastic is driving the demand for biodegradable plastics according to a recent calculation. In China, 36 companies have planned or constructed new biodegradable plastic projects, with an added capacity of more than 4.4 million tonnes[39], a sevenfold increase since 2019[43].

Despite the blooming development in biodegradable manufacture, the use of biodegradable plastics has faced a number of challenges, which have limited production and application. The global production data are only available to a limited extent, but European Bioplastics has stated that Asia has been the major production hub in the world. China produced 138,000 tonnes of biodegradable polymers in 2018[44], which is only 30% of the built capacity. The reasons behind low capacity utilization rate for the biodegradable plastics industry have been the elephant in the room for the industry, which have never been addressed or resolved despite the promotion of the biodegradable materials. It includes:

1. **Cost and agricultural feedstocks**: the cost of biodegradable plastics manufacturing is more than double compared to that of conventional plastics, making its price less competitive on the market. Conventional plastics have become cheaper with the dropping price of crude oil, leading to a bigger price difference[45]. Technology barriers remain to make biodegradable plastics cheaper, and feedstocks are a large portion of the cost. Roughly one-third of biodegradable plastics are made from petrochemicals, and the industry is moving towards bio-based feedstocks. Current bio-based feedstocks are still mainly agricultural products such as corn, potato, and cassava. To utilize agricultural products, especially food crops, on a large industrial scale could potentially bring problems such as whether industrial utilization is competing with food supply in the region, how to ensure companies responsibly acquire feedstocks when the business nature is to lower cost, or how to ensure the sustainability of bioplastics through the entire complex supply chain.

[2] This calculation assumes no reduction in overall plastics use and that conventional plastics used in online delivery are replaced by biodegradable plastics.

2. **Physical properties and chemical additives**: None of the current commercial biodegradable polymers are used solely to make products mainly due to cost and mechanical characteristics. To meet product needs, different types of polymers are normally blended together in different ratios, with chemical additives often added. What are the chemical additives? Do they have negative impacts on our health and the environment? How to properly evaluate the risks added with these chemicals and produce the true “green” and “eco-friendly” biodegradable products is the second challenge for the industry.

3. **Biodegradation and waste management facilities**: The biodegradation of “biodegradable” plastics is not straightforward. Biodegradable plastic products do not have a clear definition nor a universal label, making it difficult for consumers to distinguish biodegradable and conventional plastics. In addition, product descriptions often use false, misleading or unproven information. The *in-situ* biodegradation of biodegradable plastics would require tightly controlled waste management and proper facilities, which do not exist in many countries. Without the support of disposal infrastructure, biodegradable plastics would not help to solve the plastic pollution crisis.

With all these challenges still valid, one should not be too optimistic for the development of biodegradable plastics.

3. Agricultural feedstock and the supply chain

Biodegradable plastics are products from the chemical industry characterized by a long supply chain, and feedstock often sourced from the Global South. Past Greenpeace investigations have disclosed management challenges for a long supply chain that lacks transparency. The palm oil industry has brought deforestation, biodiversity loss, and agricultural land misuse in South East Asia[46]. The electronics industry has produced soil and water pollution and labor abuse[47]. Biodegradable plastic is a growing industry and it is difficult to evaluate or project the environmental and social impacts without enough information. However, it is clear that both data tracking and sustainability criteria schemes are not sufficient for the management of this emerging sector.

More than two-thirds of the biodegradable plastics produced rely on agricultural plant feedstock, which is projected to remain the major feedstock for the next a few years, if not longer. Only a few leading companies[48] reveal their source of feedstock and commit to responsible and sustainable sourcing – in many countries, disclosing the source of feedstock is voluntary. Multi-stakeholder associations have been established to monitor the feedstock sustainability, including the International Sustainability & Carbon Certification System (ISCC), the Roundtable on Sustainable Biomaterials (RSB) and the Bioplastic Feedstock Alliance (BFA). These are voluntary certification schemes without wide global recognition or certifying according to existing international standards.

The absence of international agreement and recognition for feedstock governance regarding biodegradable plastics is a potential problem. Although some international conventions have covered aspects of the industrial usage of biomass, they are not comprehensively linked to cover risks brought by the development of biomass feedstock for biodegradable plastics. The use of biomass for biodegradable plastics could bring more opportunities together with risks, especially for developing countries. Developing countries are more vulnerable to the potential risks due to a general deficiency in sustainable management. The European Union has developed relatively comprehensive sustainable regulations, but current schemes have not extended from biofuel feedstock to the plastics industry[49].

Box 3.1 Sustainability feedstock sourcing [50]
The evaluation of feedstock sustainability needs to take environmental, social and economical aspects into account.

Environmental sustainability
Focuses on negative environmental impacts of crop land use, such as whether agricultural land is scarce in the region, if the production of plastic feedstock would lead to competition with cultivated land, or if agricultural activities may lead to deforestation or biodiversity loss and contribute to more carbon emission and the climate crisis. Other considerations are whether agricultural activities result in water stress, and create water and soil pollution; And whether feedstock production takes place in the soil with high carbon reserves (such as forests or wetlands) that would significantly increase the carbon footprint of the final plastic product.

Social sustainability
Concerns are mainly about food security and land use. One concern is that large-scale industrial usage of food crops would compete with the food supply and increase the food price, which would impact food access for people on low incomes. Though the increasing demand of bio-resources could bring more income for small farmers, large-scale industrial plantations are normally preferred because of the lower cost. Questions remain with regards to whether corporations would pursue lower costs and ignore the negative impacts such as labor rights, soil pollution, and social injustice.

Economic sustainability
Bio-based feedstock costs 2-5 times, or even more, than petrochemical feedstock. More research and innovation are needed to increase efficiency and lower the cost. Currently for plastic production, using biomass feedstock would be difficult to be economically sustainable without significantly increasing the final product price or relying on government subsidy. ■

In comparison to the petrochemical-based plastics, the production of bio-based plastics is small. The bioplastics industry claims the production of feedstock only used up to 0.02% of current agricultural land[9]. Feedstock production has largely been located in just a few countries. Although 0.02% is a small fraction of the global agricultural land, we need to pay more attention to where this 0.02% of land is located, and whether it is concentrated within only a few regions. Without more information, it is difficult to evaluate the impacts of growing feedstock for use in biodegradable plastics. The biodegradable plastic industry is predicted to grow as more countries, including China, promote the use of biodegradable plastics. Because the industry is growing, management of feedstock acquisition is urgent.

Box 3.2 Global agricultural land

If you think: "Why don't we change to biodegradable plastic to solve the plastic crisis?", please read the following calculation.

Globally, plastic packaging could use up to 146 million tonnes of plastic a year[2], and if it is all replaced by biodegradable plastics, presumably PLA as it is cheaper to produce with a relatively good conversation rate from feedstock.

To produce 146 million tonnes of PLA would require 348,940,000 tonnes of corn as feedstock, which uses 54,020,000 ha of land. To put this into a real-world scale, the amount of corn used equals to 32% of global annual corn production, or more than all corn produced in the US this year. To grow this amount of corn would use 1% of global agricultural land.

Calculation and data source:
Producing 1 tonnes of PLA requires 2.39 tonnes of corn, which uses 0.37 ha of land according to the Institute for Bioplastics and Biocomposites (ifBB)[51].
Global agricultural land in 2016 was 4.87 billion ha according to Hannah Ritchie and Max Roser (2013)[52].
Global corn production in 2018/2019 was 1.09 billion tonnes, and the US corn production in 2019/20 by far was over 345 million tonnes, as listed in statista[53].

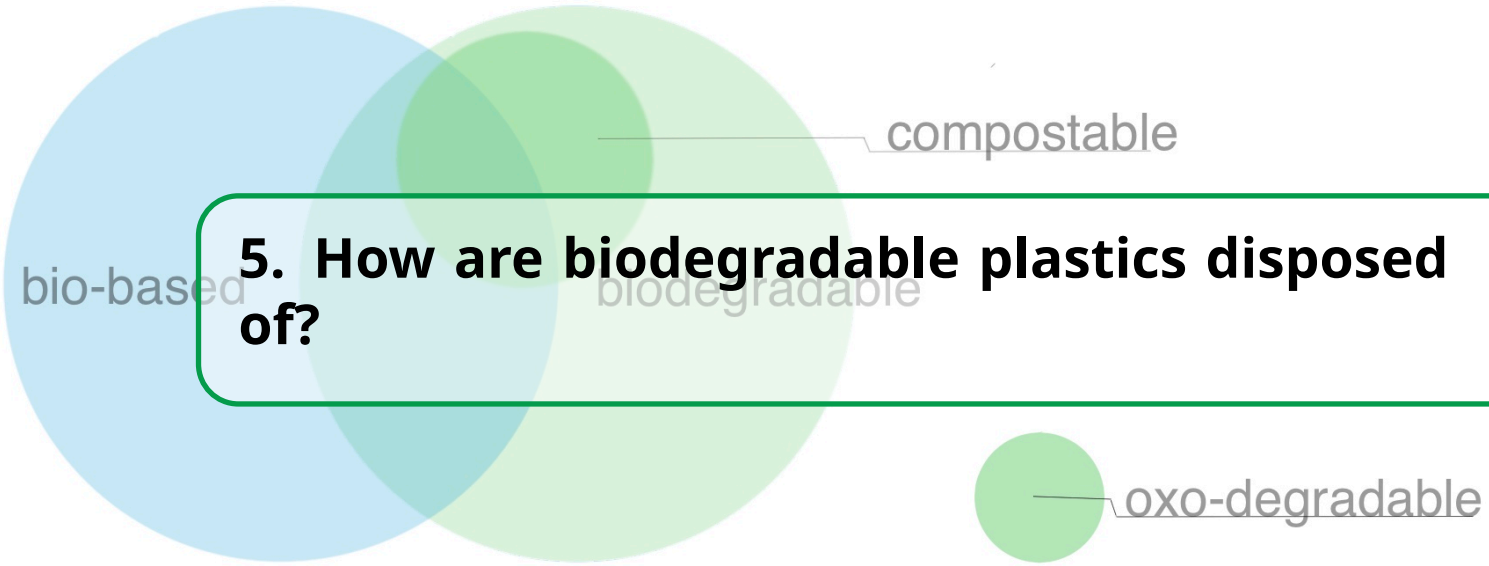
■

4. Safe and toxic-free production

Many people assume that biodegradable plastics are safe because they are made from natural raw materials, but studies have suggested that there are safety concerns regarding biodegradable plastics. Although most biodegradable plastics are made from plant materials, the manufacturing process involves chemicals such as additives and plasticizers. A recent study analyzing bio-based and/or biodegradable plastic products in the European market found that 80% of tested products contained more than 1,000 chemicals, and 67% of tested products contained hazardous chemicals[54].

Here we look at PFAS (per/poly fluoro alkyl substances) as an example. PFAS is a group of fluorinated chemical compounds that are used to impart water- and grease-resistance to single-use products[55]. Our understanding regarding the health effects of fluorinated chemicals is limited, but research suggests that many of these chemicals are hazardous to human and environmental health. Among PFAS substances, the most well-studied are perfluorooctanesulfonic acid (PFOS), which is a possible human carcinogen, and perfluorooctanoic acid (PFOA), which is a persistent organic pollutant[56]. Although the risks are not fully understood, PFAS chemicals are widely used in food packaging, with only a few countries restricting their use[57]. A US non-profit organization, Center for Environmental Health (CEH), tested 130 products from the US market in 2018 and found fluorinated PFAS compounds in a number of single-use products, including compostable and biodegradable foodwares[58]. In 2019, the California Environmental Protection Agency (EPA) inspected food-related packaging to gain a better understanding of the presence of PFASs, the impacts and the availability and feasibility of alternatives[59]. It is still unclear if the hazardous chemicals in the packaging may contaminate the content inside, but they could contaminate the compost if entering into the composting process[60]. Chemical examinations of several American compost facilities have tested PFAS-positive in the final compost products[61,62,63].

Chemical testing for biodegradable and/or compostable plastics include food-safety tests (for food packaging) and ecotoxicity tests[64], but the test list is limited to heavy metals and known organic pollutants. Most known and unknown hazardous chemicals are not included on the list. The production and use of biodegradable plastics requires better regulations of chemical use, which will require chemical disclosure from manufacturers as well as a more comprehensive chemical regulatory framework and testing strategy[65].



5. How are biodegradable plastics disposed of?

The urgent question surrounding the disposal of biodegradable plastics is whether "biodegradable" applies to real life situations or whether it is a misleading statement. Biodegradable products on the market require specific waste treatment at the end of life. To fully biodegrade, a plastic product also needs to be designed, used, and properly disposed of through its entire life cycle. This depends upon biodegradable plastics being easy to distinguish from non-biodegradable plastics. Biodegradable plastics look very similar to conventional plastics, so authorised testing and clear labels are important.

5.1 Biodegradable standards and certification systems need improvements

Because it is difficult for consumers to distinguish the biodegradability of a material, it is extremely important for authorities to provide definitions of biodegradability and biodegradation, and for international testing methodologies to be developed. In addition to national and international standards, certification schemes would ensure third-party verification of biodegradability, which support companies and governments to regulate and manage the quality of products. A unified label and clear naming guidance could direct consumers to choose certain products. Biodegradable plastics markets have developed in Europe and North America, and those regions therefore have advanced standards and certification systems in place. The most broadly recognized biodegradable standards include European EN standards, the American Society for Testing and Materials (ASTM) standards in the US, and ISO standards by the International Organization for Standardization[66]. Based on these standards, the Biodegradable Products Institute (BPI) and the US Compostable Council (USCC) developed the BPI certification program in the US. European Bioplastics has developed the certification scheme in Europe, with testing performed by DIN CERTCO in Germany and TÜV in Austria and Belgium. Each certification scheme has developed its own label for biodegradable products, which are the most globally recognized biodegradable labels.

The biodegradation of each plastic requires specific conditions. The BPI certification scheme only certifies industrial compostable plastics. The European certification scheme certifies plastics under categories of "industrial compostable", "home compostable", "marine

biodegradable", "soil biodegradable" and "fresh water biodegradable", but not all categories have matching international standards.

R **Composting** is a controlled process of breaking down organic waste into compost, which can be integrated with soil. It can occur in a home composter or an industrial composting facility. Materials that can decompose in an industrial composting facility are not necessarily able to break down in a home composter because of the difference of temperature and mechanical mixing process, and types and quantities of microorganisms present[67] .

Even though international standards and certification schemes are the best way to guarantee plastic biodegradability, recent studies have indicated that these standards or testing cannot reflect the real world situation and therefore cannot ensure biodegradation after use[66]. For instance, a number of composters from Europe[68] and the US[69] have reported the gap between their operation period and the time needed for compostable plastics to fully decompose. Even certified products cannot guarantee full biodegradation in their facility. The same problem is revealed for "marine biodegradable", "soil biodegradable" and "fresh water biodegradable" plastics. Variabilities such as temperature, exposure to sunlight, and oxygen levels are important factors for the biodegradation process. Biodegradability tests conducted in lab-simulated environments may not always not reflect variabilities. For example, the marine biodegradable plastic test requires a testing temperature of 20°C[70] - 30°C[71], but sea water in some parts of the world will not reach 20°C - 30°C. Consequently, lab testing is not always fully reliable to estimate the biodegradation rate and required time for biodegradable plastics in the ocean when conditions are different from the lab[72]. The lab testing and certification process could tell us if the tested plastic could biodegrade under lab conditions, but cannot answer the question that everyone is eager to know "Can this biodegradable plastic I bought really biodegrade in my town?"

5.2 Consumers need clear information and guidance

In addition to the complicated terms and definitions around biodegradable plastics, the product descriptions for biodegradable plastics are often misleading. Consumers in some countries have to correctly identify biodegradable plastics from those with fake labels[73]. Consumers generally do not know the difference between "bio-based", "biodegradable" and "compostable", and research has suggested that confusion surrounding the true meaning of "biodegradable" would encourage littering[74]. On the other hand, corporates who produce and use biodegradable plastics often promote their products being "eco-friendly", "biodegradable in the nature", "green" and "sourced from natural materials", which exaggerate the benefit of biodegradable plastics, but manufacturers often provide limited information regarding how the products should be disposed of after use.

Without clear information of how biodegradable packaging should be disposed of, under what conditions and how long it can biodegrade, it is unlikely that biodegradable plastic waste will end up in the correct place to be processed. Due to the ambiguous meaning of "biodegradable", some countries have tightened up the laws on these terms, forbidding companies to claim their products are "biodegradable" without scientific evidence. Labeling and naming biodegradable plastics are not regulated in many parts of the world.

Existing certification schemes do not provide sufficient guidance for consumers. Consumers International evaluated existing labels for compostability, biodegradability, reliability, relevance, clarity, transparency and accessibility, and concluded that labels show a significant discrepancy between labelling and available infrastructure in the region. Discrepancy in labeling does not guide consumers towards proper disposal of biodegradable

plastic[75]. With an increasing number of consumers eager to seek more environmentally friendly products, the market for biodegradable plastics requires better and more effective regulatory approaches to ensure that consumers access products and services that provide real benefit to the environment.

5.3 Are there enough compost facilities to treat biodegradables?

Biodegradable plastics are claimed to be able to divert waste from landfill and reduce non-degradable plastic waste. However, these benefits are standing on the assumption that biodegradable plastics would eventually biodegrade in an acceptable time frame. Currently 83% of the biodegradable plastic used for packaging is "industrially compostable"[76], which requires processing under industrial composting conditions, with a temperature higher than 50°C and carefully managed humidity conditions.

Globally, up to 2 billion tonnes of municipal solid waste are produced each year, of which more than 50% is organic waste[77]. Composting organic waste could effectively direct waste from the landfill, and organically recycle the waste into nutrients for the soil[78]. Despite all the benefits, composting is only a small fraction (5.5%) of waste treatment capacity globally[77]. Europe has been developing composting capacities since the Landfill Directive 1999/31/EC[79], and becoming the leading composting region. Still, composting only represents 10% of its waste disposal capacity by 2016[77]. The 2019 statistic suggests that only seven countries among the 21 European countries have enough composting facilities to treat all organic waste generated within the country[80]. Composting capacity is even more scarce in the US and China, representing 3%[81] and 4%[82] of entire waste disposal capacity, respectively.

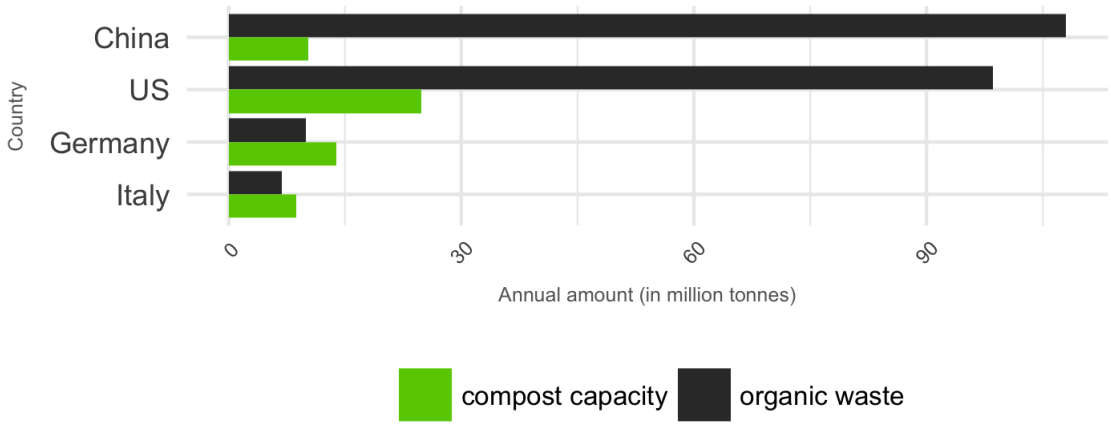


Figure 5.1: The difference between organic waste and compost capacity – a comparison between selected nations.

Data source:
Italy composting data (2016): `https://www.compost.it/wp-content/uploads/2019/08/CIC-Key-Data-2018-ENG_web-version_protetto.pdf/` ;
Germany composting data (2015): `https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/abfallwirtschaft_2018_en_bf.pdf`;
China composting data (2018): `www.stats.gov.cn/tjsj/ndsj/2019/indexch.htm`, and China's organic waste only includes food waste;
US composting data (2018): `https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials`
For the most up-to-date figures, please refer to the national statistics in each country.

Box 5.1 How many composting facilities still needed
In China, approximately 96% of waste treatment is landfill and incineration. The remaining 4% is other forms of waste treatment, including composting, which amounts to a total daily treatment capacity of 28,102 tonnes. However, around 290,000 tonnes of food waste is generated daily[83], creating a composting capacity discrepancy of more than 260,000 tonnes per day, which means China would still need 535 more composting facilities (consider that a composter could treat 500 tonnes of waste per day) to be fully capable of treating all organic waste. There would not be enough facilities to treat the emerging biodegradable plastic waste. ■

Not all composting facilities are able to accept compostable plastics. A 2018 US composting survey found that only half of the surveyed facilities could accept compostable plastic waste[84]. Compostable garbage bags have been permitted by local governments to collect organic waste in countries including Germany, Italy, and the Netherlands, and there has been an increase in the collection rate of organic waste. However, after years of operation, some composting facilities have raised concerns about accepting and treating compostable plastics[68,69]. The major reasons for concerns include:

1. Generally, kitchen waste takes six weeks to become compost, but additional time is required for compostable plastics to fully break down. The time discrepancy makes it difficult to ensure full biodegradation of compostable plastics in the facility[85].

2. Compostable and conventional plastics are not easy to distinguish. Composting firms worry that the acceptance of compostable plastics would introduce more conventional plastics into the facility and introduce contamination into the final products[86].

3. Accepting and treating compostable plastics does not add value[87]. Compostable plastics, if not fully biodegradable, would be treated as contaminants in the final product[87].

Because of the uncertainties surrounding biodegradation, advice from the US compost council is that composters should field test compostable products to ensure the product will disintegrate in their specific system[88].

Without statistics about use and disposal of biodegradable and compostable plastics, it is difficult to estimate the percentage of compostable plastics being safely processed at the end of life. However, global waste collection rates need improvements because only a few regions within certain countries could reach 100% collection; in some low-income countries the waste collection rate is only 39%[88]. The low efficiency of waste collection and management is a major reason that plastic waste is becoming a serious environmental pollution problem[89]. What's more, biodegradable plastics, as a new waste type, have not been included in most current waste management systems. For questions regarding the disposal of biodegradable plastics, the US EPA answered "contact your garbage/recycling company or local government to find out"[90]. Japan, which is a country that is considered to have one of the the best waste sorting schemes, has not included biodegradable plastics in its comprehensive waste sorting guidebooks[91]. Similarly in China, it is still unclear how biodegradable plastics should be disposed of in the current waste sorting system. It is valid to conclude that consumers in most regions, as an important player in the waste collection system, are not fully aware how to dispose of biodegradable plastics after use.

5.4 Other end-of-life options for biodegradable plastics

The use of biodegradable plastics often encounters the question: Can I recycle biodegradable plastics?, The simple answer is: No. Although biodegradable plastics, in theory, are valuable to recycle, current biodegradable plastics are not designed to be recycled, nor do dedicated recycling channels exist. Globally, accumulated plastic waste amounted to 6.3 billion tonnes in 2015, of which only 9% was recycled[2]. The plastic industry claims that all types of plastic can be recycled, but most plastics are not actually recycled due to poor product design using hard-to-recycle materials, low profit for recycling, and low collection rates of waste plastic packaging. Introducing biodegradable plastics into the system will make recycling more challenging.

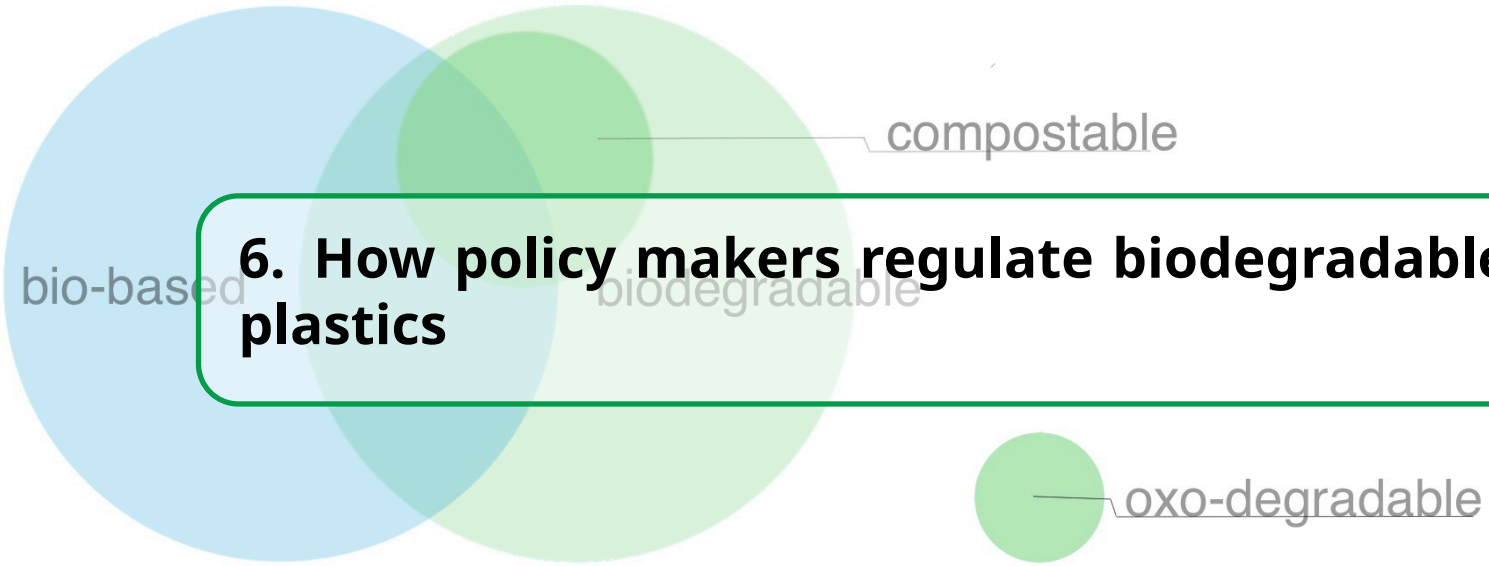
For example, polyethylene terephthalate (PET) has the highest recycling rate among all plastic types. If PET were to be mixed with compostable PLA, 0.1% of PLA would reduce the transparency of recycled plastic, and make the mixture opaque; 0.3% of PLA would lead to a yellowing of the resulting product[92], and if the PLA content increase to 2-5%, different melting points for PLA would possibly form clusters, hampering further operations[93]. Because of such manufacturing complications, accepting biodegradables into recycling schemes would risk the quality of recycled content.

Incineration is another major waste treatment process, especially in the high-income regions such as North America, Australia and northern Europe. Incineration plants are designed to burn garbage and generate power. Biodegradable plastics are not as efficient at generating energy in comparison to petrochemical-based counterparts. The energy that can be produced by combusting waste can be calculated by the calorific value of a certain type of waste. Biodegradable plastics have an average calorific value of 19.6MJ/kg, which is nearly one-third of conventional plastics (40MJ/kg). The estimated energy produced by combusting one kilo of biodegradable and conventional plastic waste is 4.51MJ and 9.2MJ, respectively[94]. Though burning biodegradable plastic waste would result in lower carbon emissions, it is not an efficient waste-to-energy source. Besides, the concerns and debates about environmental and healthy risks brought by incinerations to the surrounding neighborhood have been ongoing for more than a decade[95], which should be considered for the development and use of incineration technology in any region.

More than 40% of global waste is sent to landfill or is open dumped in many low-income countries. Without support from a functioning waste sorting system, biodegradable plastics are likely to end up in landfills. Whether biodegradable plastics could break down in a landfill is still unclear due to complex environmental conditions. In a modern landfill, garbage is compressed to minimize space use, which squeezes the oxygen out. Without the presence of oxygen, the natural biodegradation process would be extremely slow[96]. Experiments have found no change in the appearance of compostable plastics after 12 months in landfill[97]. Even though biodegradation could occur, uncontrolled biodegradation in landfill would release large amounts of greenhouse gases, including methane and carbon dioxide. Methane contributes significantly to climate change[98]. According to the US EPA, landfill generates methane representing 15% of all anthropological activities in the country[99]. To summarize, landfill should not be the destiny for biodegradable plastics.

If our waste system and disposal strategy do not significantly change, SUPs, biodegradable or not, could persist in the environment. The fate of biodegradable plastics in different ecosystems is difficult to predict because of the variability of conditions in different environments. Research suggests that some biodegradable plastic products can fully break down within two years in seawater[100], yet some biodegradable plastic that had been buried in soil for three years was still functional[101]. The reasons that SUPs are a major contribution to plastic waste are because they are produced and used in large quantities, are expensive to recycle and difficult to collect. Promoting biodegradable plastics for large-scale use without proper management and regulations will drive environmental,

social and economic problems. The use of biodegradable plastics requires strict regulations and legal guidance, from feedstock farming to waste disposal. In the next chapter, we compare policy and regulations among the major regions using biodegradable plastics, in the hope to summarize good practices that could be applied more broadly.



6. How policy makers regulate biodegradable plastics

The development of the biodegradable plastics market and industry largely benefits from restrictions on the use of single-use plastics around the world. Regulatory work has developed with different timeframes around the world, and some countries have had more experience to regulate biodegradable plastics. Europe and the US are the major biodegradable plastics producers and have made the most progress in regulations and legal frameworks. Many Asian countries are growing markets for biodegradable plastics, despite the lack of waste collection schemes and treatment facilities..

The biodegradable plastics market is growing rapidly without adequate legislation and loopholes exist, such as lack of international agreement, recognised criteria for sustainable feedstock, and the absence of a comprehensive approach to safely manage chemicals used in the manufacturing process. The development of regulations and standards does not match the speed of market growth, which reflects in the lack of universal labeling and naming guidelines for biodegradable plastics, leading to confusion between real and fake products. Misleading green claims and the complexity of biodegradable products make appropriate disposal of waste difficult. Additionally, it is very rare to see legal requirements that stipulate end-of-life procedures for biodegradable plastics.

6.1 Europe

Besides banning a series of SUPs, the European Union plans to prevent plastic pollution through an increase in reuse and recycling. The “Circular Economy Action Plan” released in 2015 urges the European economy to transit from linear production to a circular model, improving the resource efficiency to reduce waste. The “EU Strategy for Plastics in the Circular Economy” in 2018 emphasized that plastic products should be designed to enable a greater durability, reuse and high-quality recycling. The plastic strategy also suggested that all plastic packaging on the EU market to become reusable or can be recycled cost effectively by 2030. The SUP directive passed in 2019 banned the use of ten common marine litter products within the EU, setting recycling targets and mandating minimum content of recycled plastic in plastic beverage bottles, as well as extending the plastic pollution responsibilities to producers.

Though recognising the potential use of biodegradable plastics, the European Commission also recognised the absence of market regulations, lack of consumer education, and the lack of waste management strategies. Without properly addressing these shortcomings, the promotion of biodegradable plastics would result in worse plastic pollution, and bring new problems for plastic recycling systems[102]. Therefore, the EU has proposed to conduct more research to assess where the biodegradable applications could provide genuine environmental benefits, planning to develop a policy framework by 2021 for the management of biodegradable plastics[103], including sourcing, labelling, standards and certification systems for biodegradability and waste collection. The European standard EN 13432 is widely used among European countries to determine the compostability of plastic packaging.

The European Commission's Joint Research Centre recognises the importance of data collection and monitoring of the emerging bio-based industry[104], which is essential to ensure development within safe ecological limits[105]. The bio-based chemicals sector is highly complex, with hundreds of different routes from biomass feedstock to the final bio-based products, making data collection and tracking difficult. Though many European statistics have recorded biomass production in Europe, current data still represents a significant gap to describe the following steps in the chemical industry[106].

Countries within Europe demonstrate different attitudes towards biodegradable plastics. The UK government has released a call for evidence on standards for bio-based and biodegradable plastics, seeking evidence from scientists, manufacturers and the research community on the sustainability, wider impacts and end-of-life destinations of these new materials. The UK parliament reported that compostable plastics have been introduced without appropriate infrastructure or consumer understanding to manage the compostable waste, therefore, it does not support a general increase in the use of industrially compostable packaging at this stage[107]. Financial instruments such as taxes and charges on plastic products and the deposit return scheme were implemented in the UK to reduce plastic waste. One of the most successful cases in the UK is the 5p charge (about 0.05 USD) on plastic carrier bags introduced in 2015, which has successfully reduced 80% of plastic bag usage in England[108]. As a follow up, an increase in plastic bag fee to 10p will apply from 2021[109]. The UK government also plans to impose a tax on plastic packaging using less than 30% recycled content[110]. For beverage containers, the UK plans to apply a full scale deposit return scheme to improve recycling rate and quality[111].

By comparison, Italy is more supportive to the use of biodegradable plastics, with a focus on compostable plastic bags. Italy has developed a relative complete policy framework in the past decade regarding compostable plastics. The production of compostable plastics has increased by 60% in the past five years[112] with the global largest starch blend manufacturer in the country. Italy implemented a ban on single use plastic bags in 2012[113], illegalising the sale and use of non-biodegradable plastic bags in the supermarket, and encouraging the use of compostable plastic bags, cloth and paper bags as alternatives. In 2017, the ban extended to fresh food packaging in the supermarket[114]. An extended producer responsibility scheme "Biorepak" focusing on compostable plastics has been developed[115]. Among countries that allow compostable bags for bio-waste, Italy demonstrated a particularly interesting case study with a noteworthy increase of organic waste collection rate in large-scale cities.

Box 6.1 Case study - Italy
The zero waste movement has a strong influence of waste sorting work in Italy. One of the key threads is to increase the quality of organic waste collection and improve its

organic recycling rate[116]. Milan, as the first metropolis implementing a full scale curb-side waste separation scheme, has successfully increased organic waste collection[117]. The use of compostable bags played a key role in the success of the collection scheme, but the success is much more than just using compostable bags. The success of Milan's waste sorting scheme is standing upon the policy framework and the development of waste sorting and compostable systems:

1. **The local government gradually improves waste collection methodology**: Milan firstly switched black rubbish bags to transparent bags in 2012 to make the contents clearly identifiable; then divided organic waste into garden waste and kitchen waste for different collections (higher fermentability of food scraps) and volume (garden waste is much more bulky); followed by modifying the size and structure of garbage bins, and optimisation of the collection frequency to prevent the fermentation process and reduce odor; also, it encouraged citizens to use compostable bags for organic waste collection, to make the system user friendly and maximise participation.

2. **Standards exist for compostable plastic bags**: Italy (and many countries in Europe) allows the use of compostable bags that are certified according to EU standard EN 13432. Additionally, the single use plastic bag ban implemented in 2012 has largely stopped the production of non-biodegradable plastic bags, reducing the risk of contamination at the waste disposal and treatment stages.

3. **Waste disposal and treatment facilities are ample**[118]: Italy has more than 300 composting facilities around the country, presenting 8 million tonnes of annual compost capacity, which is enough to serve around 80% of the Italian population. Two major techniques in Italy include composting and anaerobic digestion (AD); all AD processes are followed by post compost processes to maximize the decomposition rate. For both techniques, pre-separation and post-separation of non-organic matters are applied to eliminate any potential contaminations. These pre- and post- separations could minimize the contamination in the final compost product, which is not a procedure carried out by all composters around the world. Moreover, the promotion for the final composted products by national and regional institutions (for example with subsidies to farmers using compost as a tool to fight desertification and climate change) created a healthy market for the composting industry to operate.

4. **Public education and outreach**: individuals are a very important component in the waste sorting process. According to Zero Waste Europe, the education and outreach needs to start two months prior to the new policy implementation, including door-to-door, booklets and information boosting, which is an important contribution to a successful result[118]. The education campaign could be carried out by the local government, together with local NGOs, to maximize the impact.

In summary, the successful waste collecting case of Italy is not a simple switch from non-biodegradable plastic bags to compostable bags, it is a result of government determination, a step-by-step amelioration in waste collection practices, an insurance from waste collection and treatment, and a campaign to raise public awareness.

■

6.2 The United States

Hundreds of cities in the US, and California, New York, and other six states have imposed a ban on the use of single use plastics[119]. Several authorities have explicitly stated that single

use biodegradable and/or compostable plastics are also included in the ban. For instance, the city of Los Angeles[120] and the city of Portland[121] have banned the use of plastic or PLA straws in restaurants unless specifically requested by a customer. The authorities in both cities have emphasized that there are no existing facilities to ensure the biodegradation of such materials, and compostable plastics, including PLA products are not recommended in the region.

The highlights of biodegradable plastic management in the US is the legislation regarding labeling of biodegradable products. California in 2011[122], and Maryland in 2018[123], have criminalized the use of misleadings terms such as "biodegradable".

Box 6.2 Case study - California
California has restricted environmental marketing claims on plastic products. Since the California Law (SB 567)[124], the term "biodegradable", "degradable", or "decomposable" cannot be used on plastic products due to their ambiguity. The terms can be misleading for consumers, implying products will break down or decompose in a landfill or other environment. For specific terms "compostable" and " marine biodegradable", products are required to meet specific ASTM standards, and be certified by the recognized third-party certification organizations. Plastic products labelled "home compostable" need to obtain the Vincotte OK Compost HOME certification. A compostable plastic bag needs to bear a clear label, and shall not display any recycling symbol, such as a chasing arrow resin identification code.

The plastics manufacturer ENSO Plastics was sued in 2011, claiming its products were "both biodegradable and recyclable". Two companies using ENSO Plastics to package their bottled water were also sued[125]. ENSO Plastics was charged a penalty of USD$18,000 fine, and was required to remove all "biodegradable and recyclable" claims, and notify their customers[126].

The supermarket chain Walmart was also charged USD$1 million for selling bottled water with misleading labels, claiming the packaging was "biodegradable in the natural environment"[127]. The lawsuit prompted Walmart to create company policies to forbid on-shelf products with false biodegradability claims.

The supermarket chain Costco and the coffee company JBR, Inc., were sued for selling plastic coffee pods, labeled with '97% biodegradable' and 'biodegradable', which led to a combined civil penalties and costs of USD$500,000 for two companies in 2018[128].

The same year, the e-commerce giant Amazon agreed to pay more than USD$1.5 million for selling plastic products misleadingly labeled as "biodegradable" or using similar terms[129].

■

6.3 China

China has banned ultra-thin plastic bags since 2007 and requires retailers to charge for plastic carrier bags. A new plastic ban in 2020[4] restricts the production and use of multiple single use plastics, including packaging from the emerging e-commerce sector. The new plastic ban encourages the use of "reusable, recyclable, and degradable" alternatives, such as "degradable" plastic bags, cutlery, and packaging. Following the national announcement, 28 provincial governments have also released local plastic bans, and several have stated that they will promote degradable plastics. Chinese central government has shown a strong determination to reduce plastic waste, but lacked a detailed action plan. Discussing policies and practices to improve the plastic reduction pathway and the management of SUPs with

other countries and applying these lessons in China is essential to strengthen Chinese policy regarding plastic pollution.

In summary, to tackle plastic pollution will require a systematic change and combined regulatory efforts, which cannot be replaced by simply switching to degradable alternatives. The use of degradable plastics in China still requires substantial regulatory improvements around naming and labeling, standards, market governance, waste disposal and treatment, feedstock sourcing, supply chain monitoring and chemical safety.

Firstly, a clear definition of "degradable plastics" is needed by consumers and industry. Currently "degradable plastics" is defined in a 2006 standard (GB/T 20197-2006), which include oxo-degradation, thermal-degradation, photo-degradation, biodegradation, and compostable plastics as "degradable plastics". Although a new industry guideline[130] was published In 2020 to clarify "degradable plastics" into six categories, the guideline is not a national standard. It is unclear what "degradable plastic" is permitted in the 2020 plastic ban.

Secondly, clear and consistent instructions for labelling, supporting standards and third-party certification systems are essential. Recently, the Standardization Administration of China has released several standards for compostable plastic carrier bags (GB/T 38082-2019), soil-biodegradable mulching film (GB/T 35795-2017), and compostable delivery packaging (GB/T 38727-2020), which is an important step in development. To ensure that products on the market meet the standardised requirements, regulations will be required for labeling and authorized certification schemes. Currently all types of degradable plastics, ranging from oxo-degradable, photo-degradable, to compostable plastics, remain in the market, with many false claims that a product is fully biodegradable in the natural environment.

Thirdly, "biodegradable" is actually "biodegradable under certain conditions", which requires the development of specific waste disposal and management strategy. The biggest loophole for the current Chinese plastic plan is the lack of discussion around waste disposal and treatment capacities. The majority of current "real" biodegradable plastics are industrial compostable plastics, but China does not have enough composting facilities to support the end-of-life treatment, nor the collection system for compostable waste. The lack of facilities have not been addressed in the latest policy planning, and incineration remains to be the major waste treatment method in development according to the 13th Five-Year Plan[131].

Fourthly, sustainable feedstock sourcing is essential. Biodegradable plastics use agricultural products such as corn, potato and sugarcane, but manufacturers in China have not shared enough information publicly about their supply chain. To ensure the healthy development of the biodegradable plastic industry, it is essential to enforce regulations on feedstock management as well as requirements for a sustainable and responsible supply chain.

Finally, a safe and clean manufacturing process will ensure product safety. The production of biodegradable plastics involves countless chemicals, including hazardous chemicals. Without comprehensive and effective chemical management, it will be difficult to prevent the potential environmental and health risks of biodegradable plastics. Addressing the use of chemicals by the Chinese government, and governments around the world, is essential to ensure the safety of biodegradable plastics.

Box 6.3 Case study - The first biodegradable promotion in China

Background:

The province of Jilin introduced the first provincial plastic ban in China in 2014[132], banned the sale of non-degradable single-use plastic bags and cutlery, and promoted degradable alternatives. The county of Nanle, Henan province, introduced a local ban in 2018[133], forbid the use of non-degradable single-use plastics that rely on fossil-fuel feedstock, and promoted degradable single-use plastics among public procurement, retailers, and agriculture.

Both local governments have provided tax compensation to boost the development of regional production. Changchun Economic zone formed the first PLA production industrial cluster in China in 2015[134], gathered 12 PLA manufacture and product molding companies, which was planned to supply PLA products for the region. Nanle bio-based material industrial cluster was formed in 2016, with 15 companies in the complex covering the entire supply chain, from the raw material production to platform chemical synthetic to the end product[135].

The effectiveness of plastic bans:

In 2019, a Chinese NGO, Zero Waste Alliance, conducted field research in both regions, and their results could partially reflect the impact of the bans.

Changchun, Jilin[136]: Though Jilin has published the local standards for PLA and biodegradable packaging in 2018 and made efforts to regulate products on the market, the investigation found a substantial portion of non-biodegradable bags or fake biodegradable bags in the market. Consumers and shops could not easily distinguish biodegradable bags. Most interviewed citizens throw biodegradable bags into their residual rubbish bin. Furthermore, the main waste treatment in Jilin province is landfill (60% of processed waste), and there are no plans to expand compost capacity[82]. On the production side, out of 9 companies that were attracted to the region, 3 were bankrupt, 3 eased production, and only 3 are still operating, relying on exporting products overseas.

Nanle, Henan[137]: Two-thirds of the interviewed shops provide conventional plastic bags. Biodegradable bags were provided in Nanle by the sole supplier and because the bags were a special green color they were easy to recognise. Shops and consumers have reported that biodegradable bags have a high price and are poor quality. Nanle did not specifically plan waste disposal after use or increase its composting capacity. There were 13 companies involved in production in 2019, but 95% of products are for export overseas. Also, it was reported that PLA pallets (the plastic polymer for making end products) were imported from overseas because local manufacturing had technical obstacles.

In Changchun and Nanle, described above, the governments replaced non-biodegradable single-use plastics with biodegradable alternatives, but did not manage to prevent single-use plastics. A simple material switch will not solve waste management problems brought by the overconsumption of materials. Biodegradable waste will lead to environmental pollution if it is not properly disposed of and treated. Biodegradable plastics products have not been widely used because of their high price and poor performance, and the difficulty in distinguishing between real and fake products. The lessons learned from Changchun and Nanle are valuable for the wider use of biodegradable plastic products throughout China.

■

7. Is “eco-friendly” packaging really biodegradable?

Big corporations are the key users of plastic packaging, who are able to control and change the way of packaging through purchasing and supplier collaboration, to completely transfer the design of packaging that helps achieve plastic reduction. With growing attention towards plastic pollution and more national regulations on SUPs, many corporates have adopted plastic reduction plans into their environmental and social responsibility, looking for more sustainable plastic packaging. Corporate plastic plans mainly comprise four parts, to reduce virgin plastic usage, to increase recycling rate and recycled content usage, to use alternative materials and to develop the reuse and refill systems. For "alternative materials”, bioplastic (including bio-based non-biodegradable plastics and biodegradable plastics) and paper are the most common materials. Almost all companies would use terms like “green”, “plastic made from plants”, and “sustainable” to describe their new packaging products though each choice of bioplastics is very different. In this chapter, we compared the “green” packaging from major global brands in different sectors, and how the plastic reduction approach varies among brands.

7.1 Fast-Moving Consumer Goods Companies (FMCG)

Many FMCG companies have committed to reduce the amount of plastic that they use. Coca-Cola put more efforts on recycling, by expanding packaging collections systems and increasing the use of recycled content. Pepsi uses a combination of biodegradable materials and recycled content in its packaging. Danone, on the other hand, put its focus on optimizing extended producer responsibility (EPR) and deposit return schemes (DRS). The use of bioplastic among fast-moving consumer goods companies is largely contributed by non-biodegradable plastic bottles. Some companies have invested in biodegradable flexible packaging, such as snack bags, tea bags, and sachets

7.2 Retailers

Retailers play a major part in providing a plastic-free shopping experience for consumers. As the largest providers of plastic carrier bags, one option would be for retailers to stop

Table 7.1: Fast-moving consumer goods companies and bioplastics

Company	Type of bioplastic used	Biodegradable?
The CocaCola Company	PlantBottle™ was released in 2011, made from a blend of petroleum-based materials and up to 30 percent plant-based materials[138].	Partially bio-based and non-biodegradable.
Pepsi Co	Partnered with biotechnology firm Danimer Scientific to develop biodegradable film resins to be used for next-generation snacks packaging[139] (Danimer's Nodax™ PHA bioplastic).	PHA is biodegradable, but there is no information about condition and time required for the actual biodegradation for this particular product.
Danone	Will introduce the first 75% bio-based bottle at commercial scale by 2021, aim to offer consumers bottles made from 100 % bioplastic[140].	Partially bio-based and non-biodegradable.
Nestlé	Partnered with biotechnology firm Danimer Scientific to develop biodegradable plastic bottles[141] (Danimer's Nodax™ PHA bioplastic).	PHA is biodegradable, but there is no information about condition and time required for the actual biodegradation.
Mars, Incorporated	Launched the compostable wrapper for vegan GALAXY® bars in the UK[142].	Compostable wrappers could potentially biodegradable with commercial composting facilities in place.
Unilever	Use plant-based, compostable material in one third of its branded tea bags. Apply seaweed sachets in sauce packaging, and pilot at a small scale in the UK for food delivery[143].	Compostable tea bags could potentially biodegradable with commercial composting facilities in place. The company claims seaweed-based material can naturally biodegrade in approximately six weeks[144].
Procter & Gamble	Using plastic resins and packaging material from the resin producer Braskem SA, who mainly produce bio-based PE, which is made with ethanol derived from Brazilian sugarcane[145].	Bio-based and non-biodegradable.

offering plastic bags to consumers and instead provide reusable options or encourage customers to take their own bags. Beyond plastic bags, retailers could act as gatekeepers for products sold in store, by providing packaging guidelines and encouraging brands to choose sustainable ways of packaging. The UK retailers, such as Iceland[146], Morrisons[147], and Tesco[148] have informed suppliers that packaging will be a key part of their decision-making process to determine which products are sold in stores. Their suppliers need to use recyclable packaging, remove unnecessary packaging, adopt easy-to-recycle materials, and increase recycled content when possible. A retail store is also a crucial space for in-store customer education, offering unpackaged products, and testing reuse and refill models. Globally, zero-waste stores have become a trend, where consumers are encouraged to bring own reusable containers to purchase loose and non-packaged goods[149]. Several retail brands have started pilot programmes to adopt reusable containers in the supply chain, such as Carrefour in France[150], and Tesco in the UK[151], both collaborating with American company Loop to trial reusable containers. Retailers are also an important part of extended producer responsibility schemes, and should be encouraged to set up deposit return schemes or related instruments to assist local recycling programmes.

Major global retailers have adopted policies that promote environmental and social responsibility, which include seeking sustainable materials for product packaging. Though many retailers have committed that “all packaging will be recyclable, compostable or reusable by 2025”, each demonstrates different focus in their implementation and practices in place. Tesco in the UK has stated that current waste management cannot deal with biodegradable and/or compostable plastics (including PLA), therefore, do not recommend use of those materials for the suppliers, while Costco clearly promotes biodegradable/compostable materials around the world. American company Kroger.Co has partnered with TerryCycle to explore the recycling possibility for flexible packaging[152] instead of switching to biodegradable and/or compostable materials.

In comparison, the effort at implementing delivery models using reusables is less noticeable. Though many retailers are looking into ways to reduce the amount of plastic packaging they use and some are to trial reusable or zero packaging options, we hope the reusable and packaging-free options will go further and faster, so that customers have more choices to purchase products that are not wrapped in single-use packaging.

Table 7.2: Retailers and bioplastics

Company	Type of bioplastic used	Biodegradable?
Tesco	2020 Tesco published preferred packaging materials list for own brand packaging in UK, and categorised all compostable/PLA & biodegradable materials as “red” - not to be used as customers as cannot easily recycle[148].	
Carrefour	Carrefour Romania uses biodegradable bags produced by Florin Pogonaru[153]. Carrefour in Malaysia & Singapore use biodegradable plastic bags sourced from tapioca[154].	Could potentially biodegradable with commercial composting facilities in place.
Costco	Costco continues to expand the use of compostable packaging[155]: • Replaced straws in all US locations with compostable plastic or paper straws. • In Japan, provided compostable packaging for all food court packaging. • In Korea, provided compostable packaging for all food court cups and straws. • Used compostable fresh meat packaging in Mexico and in some US locations. • Used compostable bags in the Canada fresh meat department.	Could potentially biodegradable with commercial composting facilities in place.
7-11	Packaging for all Onigiri sold in Japan will switch to a blend of petroleum-based materials and plant-based materials[156]. Plastic bags are made from 30% plant based plastic[157].	Partially bio-based and non-biodegradable.
FamilyMart	FamilyMart in Japan has adopted bioplastic (PLA) containers for salad offerings[158].	PLA could potentially biodegradable with commercial composting facilities in place.

7.3 E-commerce

The increase in popularity of Internet retail has brought new packaging waste problems. Single-use packaging in the e-commerce sector includes plastic parcels, cardboard boxes, food containers and single-use cutlery. China stands out as one of the largest e-commerce markets with one billion users, 1.6 millions tonnes of plastic waste generated from food delivery in 2017[159], and 8.37 millions tonnes of paper waste and 850,000 tonnes of plastic packaging waste in 2018 from parcel delivery[160]. The use of online shopping has grown rapidly across the globe during the COVID-19 pandemic, bringing packaging issues to wider attention.

China announced several policies to solve packaging waste problems from the e-commerce sector. The use of electronic waybills instead of paper ones, and reusable courier containers have become common practices in logistics companies in China. Globally, online shopping and delivery companies have also started to reduce packaging waste, optimising box selections to better fit product sizes and weight, reducing tape usage, and initiating recycling plans at different scales. Companies sometimes also work with suppliers and shops, make packaging guidelines to reduce waste with brand producers. Despite efforts, a substantial amount of hard-to-recycle plastic packaging is used for delivery.

Single-use plastics from the food delivery industry often contain single-use food containers, plastic bags, and cutlery. Many online food order platforms have canceled the “free cutlery” option from the mobile app, and charge customers for single use cutlery. However, as many restaurants collaborating with the online platforms still give out cutlery for free, there is not enough information to evaluate the effectiveness of such change. Globally, the common plastic packaging change is to switch to paper or biodegradable materials.

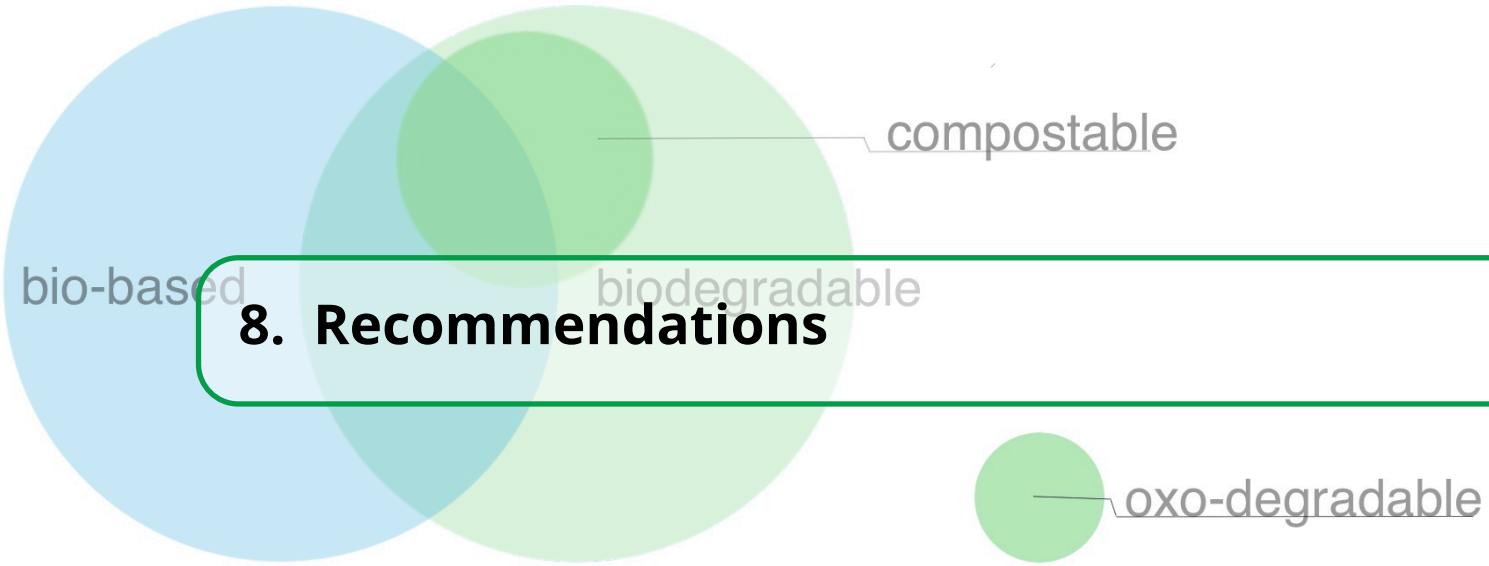
Overall, though many companies from different sectors have announced a transition to more “eco-friendly” and “green” packaging, a large portion of “green” plastic packaging is either non-biodegradable or requires industrial composting that does not exist in many parts of the world. Only a few companies considered the local waste capacity for their choice of packaging material.

A simple switch to bio-based non-biodegradable plastics or single-use compostable plastic will not stop plastic pollution. To address plastic pollution, plastic usage must be reduced by 50% by 2040[168]. Corporations around the globe must reduce plastic packaging in a more ambitious way, not only by reducing excessive and unnecessary packaging, but also by developing effective reuse and refill systems.

Globally, more than 250 corporate companies in the plastic supply chain have made a commitment to reduce plastic usage[168]. However, it is rare to see Chinese brands committing to reduce their use of plastic. National policy is an important instrument to urge the commercial sector to make positive environmental changes. Policies could include a plastic ban, tax incentives, requirements on public procurement, and to build up an EPR scheme to ask plastic producers and users to pay for the end-of-life waste management. Many such schemes and incentives have proved to be effective in reducing the use of plastic.

Table 7.3: E-commerce companies and bioplastics

Industry	Company	Type of bioplastic used	Biodegradable?
Online shopping and parcel delivery	Alibaba	The company will replace 50% of delivery packaging and 100% of fillings with biodegradable materials by 2020[161].	Could potentially be biodegradable with commercial composting facilities in place.
Online shopping and parcel delivery	JD.com Inc.	In 2016, used "full-biodegradable" (the term for compostable in China) bags for fresh food delivery. The company will replace 50% of plastic packaging with biodegradable materials[162] in the JD logistic.	Could potentially biodegradable with commercial composting facilities in place.
Online shopping and parcel delivery	Amazon.com Inc	Amazon sets environmental marking guidelines for products sold on Amazon.com. Environmental marketing claims on the product packaging and product detail page must meet all US federal laws and state/local laws. A general biodegradable claim should not be made, and compostable can only be used on products meeting the applicable ASTM standards or Vincotte certification standards[163].	
Online food service	Uber Eats	In partnership with Enviropack, providing biodegradable and/or compostable packaging to restaurants.	Could potentially biodegradable with commercial composting facilities in place.
Online food service	Delivery hero/Food panda	Invested in biodegradable plastic manufacturer Bio-Lotions[164], which will provide biodegradable plastic packaging and cutlery.	The company claims that products use natural raw materials and are biodegradable, but there is no information about condition and time required for the actual biodegradation for this particular product[165].
Online food service	Just Eat	Collaborates with a British packaging company and uses a seaweed-based material called Notpla, that makes paper containers with Notpla liners and Notpla sauce sachets[166].	The company claims seaweed-based Notpla can naturally biodegrade in home composters in approximately six weeks[144].
Online food service	Meituan	Piloting the use of "full-biodegradable" (the term for compostable in China) bags in China[167].	Could potentially biodegradable with commercial composting facilities in place.



8. Recommendations

The call for a reduction in the use of plastic grows louder each day. Unfortunately, there is no single solution and switching to biodegradable materials or any other single-use material will not be the silver bullet. Widespread plastic pollution is a result of systematic problems that include over-consuming behavior, reliance on the single-use connivence, and a non-sustainable linear economic model that ignores end-of-life waste disposal. Plastic waste has become a serious pollution problem because of overuse and lack of adequate waste management. Without reduction from the source, and without careful consideration of waste disposal, it will be challenging to solve the problem.

The promotion and use of degradable and biodegradable plastics still face several challenges, including:

1. The gap between standards that test biodegradability and in-situ biodegradation.
2. The labels on biodegradable products lack legally binding requirements and can be confusing, which can mislead consumers.
3. Biodegradable plastics largely rely on agricultural resources and the lack of regulations on resource sustainability is likely to be a bottleneck for the development of the industry.
4. Biodegradable waste needs dedicated waste treatment facilities.
5. Biodegradable plastics face the challenge to be toxic free.

Greenpeace is calling the Chinese government to take action on the following:

Single-use plastics and products:

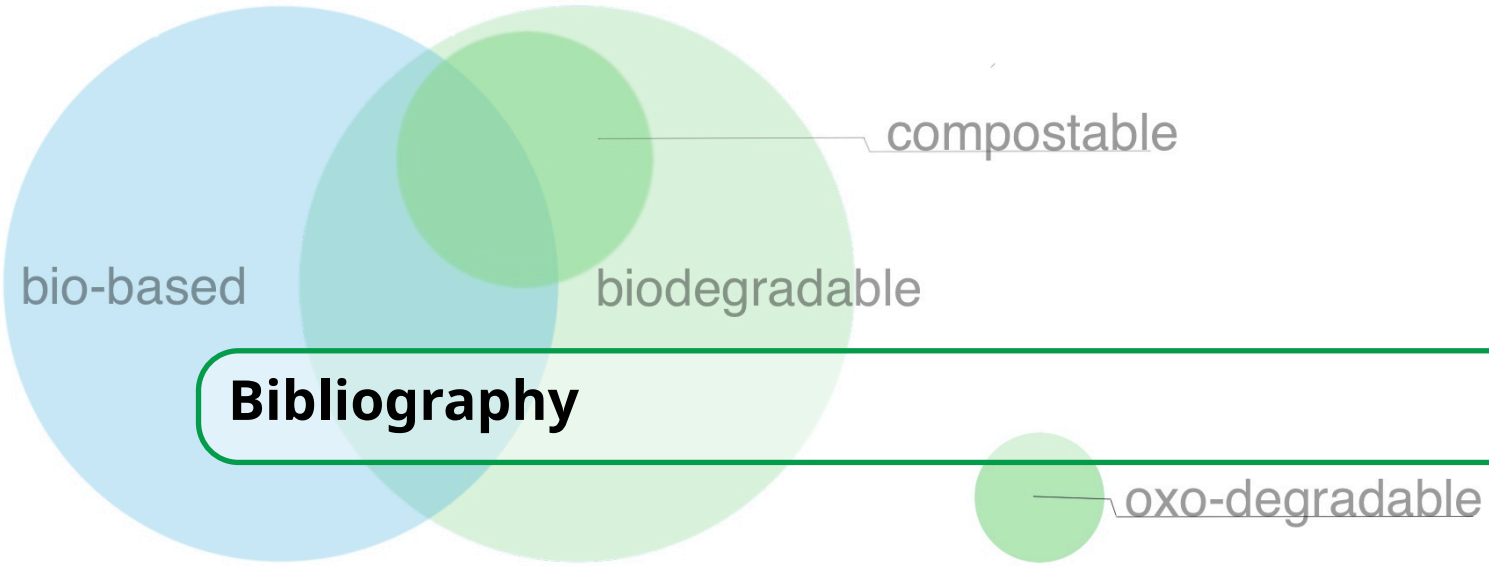
- Prioritize the plan for plastic usage reduction and the development of reusable and refillable models, expand extended producer responsibility schemes to plastic packaging.

Biodegradable plastics:

- Clearly define “degradable” and “biodegradable” plastics, regulate product labeling and forbid the use of ambiguous terms that can be confusing and misleading for consumers.
- Develop standards and a comprehensive certification scheme, which should include laboratory testing that reflects the biodegradability claims in real-world situations.
- Evaluate local waste disposal and treatment capacity before the promotion of biodegradable plastics, and ensure transparency of information.

Greenpeace is calling corporates to:

- Calculate and publicize plastic usage and footprint and make a clear plan to reduce the use of plastic instead of switching to alternative materials.
- Actively release information about the source and sustainability of plastic and bioplastic feedstock.
- Ensure clear labels are on products and avoid the use of misleading information.
- Guide consumers to properly dispose of packaging.
- Ensure the end-of-life options are locally available for plastic packaging.



Bibliography

[1] David Azoulay, Priscilla Villa, Yvette Arellano, Miriam Gordon, Doun Moon, Kathryn Miller, and Kristen Thompson. Plastic & Health. Technical report, Center for International Environmental Law, September 2019.

[2] Roland Geyer, Jenna R Jambeck, and Kara Lavender Law. Production, use, and fate of all plastics ever made. *Science Advances*, 3(7):e1700782, July 2017.

[3] United Nations Environment Programme. Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations. Technical report, December 2015.

[4] National Development and Reform Commission. Opinions of the National Development and Reform Commission and the Ministry of Ecological Environment on Further Strengthening the Treatment of Plastic Pollution, Fa Gai Huan Zi [2020] No. 80, 2020. URL `https://www.ndrc.gov.cn/xxgk/zcfb/tz/202001/t20200119_1219275.html`.

[5] Peter P Klemchuk. Degradable plastics: A critical review. *Polymer Degradation and Stability*, 27(2):183–202, 1990.

[6] Isabelle Vroman and Lan Tighzert. Biodegradable Polymers. *Materials*, 2(2):307–344, June 2009.

[7] European Commission. 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. Technical report, January 2018.

[8] Clare Goldsberry. Consumers confused by distinction between biobased and biodegradable plastics, February 2020. URL `www.plasticstoday.com/sustainability/consumers-confused-distinction-between-biobased-and-biodegradable-plastics`.

[9] European Bioplastics. Bioplastics Market Data, . URL `www.european-bioplastics.org/market/`. Accessed 20 Aug. 2020.

[10] Xiu-Li Wang, Ke-Ke Yang, and Yu-Zhong Wang. Properties of starch blends with biodegradable polymers. *Journal of Macromolecular Science, Part C*, 43(3):385–409, 2003. doi: 10.1081/MC-120023911.

[11] Emilio Pérez-Pacheco and Jorge Carlos Canto-Pinto and Víctor Manuel Moo-Huchin and Iván Alfredo Estrada-Mota and Raciel Javier Estrada-León and Luis Chel-Guerrero. *Composites from Renewable and Sustainable Materials*, chapter Thermoplastic Starch (TPS)-Cellulosic Fibers Composites: Mechanical Properties and Water Vapor Barrier: A Review. IntechOpen, November 2016. doi: 10.5772/62936.

[12] Julia Lovett and François de Bie. Sustainable Sourcing of Feedstocks for Bioplastics: Clarifying Sustainability Aspects Around Feedstock Use for the Production of Bioplastics. Technical report, Corbion Group Netherlands B.V., 2016. URL www.corbion.com/media/550170/corbion_whitepaper_feedstock_sourcing_11.pdf. Accessed 20 Aug. 2020.

[13] Florence Aeschelmann and Michael Carus. Biobased Building Blocks and Polymers in the World: Capacities, Production, and Applications–Status Quo and Trends Towards 2020. Technical report, nova-Institut GmbH, May 2015.

[14] PTT MCC Biochem. FAQs. URL www.pttmcc.com/new/faq.php. Accessed 20 Oct. 2020.

[15] Shi-zheng Qiu, Jia-yi Li, Jing-chen Yang, and Chang-li Liu. Research Progress of Low-cost Method of Synthetizing Polyhydroxyalkanoates (PHAs). *Biotechnology Bulletin*, 35 (9):45–52, 2019.

[16] Tiago M. M. M. Amaro, Davide Rosa, Giuseppe Comi, and Lucilla Iacumin. Prospects for the use of whey for polyhydroxyalkanoate (pha) production. *Frontiers in Microbiology*, 10:992, 2019. ISSN 1664-302X. doi: 10.3389/fmicb.2019.00992. URL https://www.frontiersin.org/article/10.3389/fmicb.2019.00992.

[17] Thailand Board of Investment. Bioplastics. URL www.boi.go.th/upload/content/BioplasticsBrochure.pdf. Accessed 20 Oct. 2020.

[18] Novamont. Novamont Sustainability Report, 2018. URL www.novamont.com/public/BdS/Novamont_BdS18_Leaflet%20EN.pdf.

[19] Novamont. Our Pillars. URL www.novamont.it/eng/our-pillars-20. Accessed 20 Oct. 2020.

[20] NatureWorks. About NatureWorks. URL www.natureworksllc.com/About-NatureWorks. Accessed 1 Nov. 2020.

[21] NatureWorks. NatureWorks Announces 100 Percent Third-Party Certified Sustainable Feedstock by 2020, February 2019. URL www.natureworksllc.com/News-and-Events/Press-Releases/2019/2019-02-14-100-Percent-Sustainable-Feedstock-by-2020. Accessed 1 Nov. 2020.

[22] Total Corbion PLA. Total Corbion PLA Celebrates Opening of Bioplastics Plant, September 2019. URL biomassmagazine.com/articles/16463/total-corbion-pla-celebrates-opening-of-bioplastics-plant. Accessed 1 Nov. 2020.

[23] Total Corbion PLA. Total Corbion PLA Announces the First World-Scale PLA Plant in Europe, September 2020. URL www.total-corbion.com/news/total-corbion-pla-announces-the-first-world-scale-pla-plant-in-europe/. Accessed 1 Nov. 2020.

[24] Lin Yang, Jingwen Huang, Fengchun Zhou, and Cong Xue. Jinfakeji Benefits From the Rapid Growth of Chinese Biodegradable Market. Southwest Securities, September 2019. URL http://stock.tianyancha.com/ResearchReport/eastmoney/ef546deebbaed4f1a753b04d922367b6.pdf.

[25] Biodegradable Materials Research Institute. Anhui Fengyuan PLA Production Surge: Will Overtake Sinopec in 10 Years and Cover 20% Chinese Plastic Market, October 2020. URL mp.weixin.qq.com/s/oeyDdy6G_koYpeOn5rBo5w. Accessed 3 Dec. 2020.

[26] Plasticker. BASF Announces Major Bioplastics Production Expansion, April 2008. URL https://cutt.ly/HhHoPK1. Accessed 3 Dec. 2020.

[27] Red Avenue New Materials and BASF. BASF and Red Avenue New Materials Group Collaborate to Produce Certified Compostable Polyester (PBAT) in China, May 2020. URL www.rachem.com/en/news/xwmta/2020/0528/428.html. Accessed 3 Dec. 2020.

[28] Plasteurope.com. Showa Denko, November 2016. URL www.plasteurope.com/news/SHOWA_DENKO_t235564/. Accessed 20 Oct. 2020.

[29] PTT MCC Biochem. Nature to Nature, 2017. URL www.pttmcc.com/new/download/PTTMCC_Brochure_2017.pdf. Accessed 20 Oct. 2020.

[30] Alexander H. Tullo. PHA: A Biopolymer Whose Time Has Finally Come. *Chemical & Engineering News*, 97(35), September 2019. URL cen.acs.org/business/biobased-chemicals/PHA-biopolymer-whose-time-finally/97/i35.

[31] Bio-on. Bio-on Press Note, December 2019. URL www.bio-on.it/news.php. Accessed 20 Oct. 2020.

[32] Robert Arnason. Canola-Based Plastic May Hit Market Soon. The Western Producer, April 2019. URL www.producer.com/2019/04/canola-based-plastic-may-hit-market-soon/. Accessed 20 Oct. 2020.

[33] PlasticsToday. Biodegradable Plastics Market Rising 9.4% Yearly, April 2020. URL www.plasticstoday.com/packaging/biodegradable-plastics-market-rising-94-yearly. Accessed 20 Oct. 2020.

[34] European Bioplastics. Applications for Bioplastics, . URL www.european-bioplastics.org/market/applications-sectors/. Accessed 20 Oct. 2020.

[35] Nan Xie and Bo Zhang. Biodegradable Plastic Special Column: Industry Giants Are Planning for the Emerging Huge Market. Zhongtai Securities, June 2020. URL pg.jrj.com.cn/acc/Res/CN_RES/INDUS/2020/6/23/3799970f-677d-4365-bfb7-44d7f277a67d.pdf.

[36] Harvest Pack Solutions. Pandemic Leads to More Single-Use Plastic; Company on a Mission to Reduce Waste with Smart Food Packaging that Won't Harm the Environment. AP News, August 2020. URL apnews.com/press-release/accesswire/8c87be3a403f334f993df5d9f9956be7. Accessed 20 Oct. 2020.

[37] State Post Bureau. Guiding Opinions on Coordinating the Promotion of Green Packaging in the Express Industry, Guo You Fa [2017] No. 86, 2017. URL www.gov.cn/xinwen/2017-11/02/content_5236573.htm.

[38] BASF. Segment Profile. URL report.basf.com/2019/en/managements-report/segments/materials/segment-profile.html. Accessed 20 Oct. 2020.

[39] Wanpeng Liu. Standard Upgrade Series: Biodegradable Plastics Are Emerging to Fill in the Alternative Material Market. Huaan Research, June 2020. URL pdf.dfcfw.com/pdf/H3_AP202006301388397876_1.pdf.

[40] Marifaith Hackett. Biodegradable Polymers Market Value. IHS Markit, August 2018. URL ihsmarkit.com/research-analysis/biodegradable-polymers-market-value.html.

[41] Zhe Wang, Jiancong Yuan, and Boyang Chen. Industry of Petrochem and Biodegradable Plastic: "White Pollution" Control Is on the Agenda, the Time for Biodegradable Is Coming. CITIC Securities, January 2020. URL http://m.hibor.com.cn/wap_detail.aspx?id=8c3ed2f8e8f2a5f25c28abad7464db4a.

[42] Zongguo Wen. Interpretation and policy analysis of the new chinese plastic ban, 2020. PowerPoint Presentation.

[43] Cheng Gong and Aihua Shang. Degradable plastics: 100 billion market with policy support. Guosen Securities, October 2020. URL http://qccdata.qichacha.com/ReportData/PDF/46339cbc4b815ef981027c65fdedae50.pdf.

[44] Leading Industry Research. Analysis of the Production Capacity of China's Biodegradable Plastics Industry, the Product Categories, Production Capacities of Major Manufacturers in 2020, January 2020. URL www.leadingir.com/datacenter/view/4580.html. Accessed 20 Oct. 2020.

[45] Axel Barrett. Bioplastic Production Growth Pale Compared To Fossil Plastic Production Growth, December 2019. URL bioplasticsnews.com/2019/12/06/bioplastic-production-growth-fossil-plastic-production-growth/. Accessed 20 Oct. 2020.

[46] Greenpeace. Final Countdown: Now or Never to Reform the Palm Oil Industry. Technical report, September 2018. URL www.greenpeace.org/international/publication/18455/the-final-countdown-forests-indonesia-palm-oil/.

[47] Gary Cook and Elizabeth Jardim. Guide to Greener Electronics 2017. Technical report, Greenpeace, October 2017. URL www.greenpeace.org/usa/reports/greener-electronics-2017/.

[48] NatureWorks. Ingeo Feedstocks & Certifications: From Greenhouse Gas to Performance Materials, 2018. URL www.natureworksllc.com/~/media/Files/NatureWorks/What-is-Ingeo/Where-Ingeo-Comes-From/NatureWorks_Ingeo-feedstock-certification-options_pdf.pdf?la=en. Accessed 17 Nov. 2020.

[49] European Commission. Voluntary Schemes. URL ec.europa.eu/energy/topics/renewable-energy/biofuels/voluntary-schemes_en?redir=1. Accessed 20 Oct. 2020.

[50] Food and Agriculture Organization of the United Nations. Bioenergy, Food Security and Sustainability-Promoting an International Framework. Technical report, May 2008. URL www.fao.org/tempref/docrep/fao/meeting/013/k2498c.pdf.

[51] Hochschule Hannover. Biopolymers facts and statistics: 2019 Production capacities, processing routes, feedstock, land and water use. Technical report, Institute for Bioplastics and Biocomposites, 2019. URL https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren/f+s/Biopolymers-Facts-Statistics-2019.pdf.

[52] Hannah Ritchie and Max Roser. Land use. *Our World in Data*, 2013. URL https://ourworldindata.org/land-use.

[53] M. Shahbandeh. Corn - Statistics & Facts, October 2020. URL https://www.statista.com/topics/986/corn/#:~:text=Corn%20is%20the%20world's%20most,over%20345%20million%20metric%20tons. Accessed 20 Nov. 2020.

[54] Lisa Zimmermann, Andrea Dombrowski, Carolin Völker, and Martin Wagner. Are bioplastics and plant-based materials safer than conventional plastics? In vitro toxicity and chemical composition. *Environment International*, 145:106066, 2020.

[55] Minnesota Pollution Control Agency. Composting and PFAS. URL www.pca.state.mn.us/waste/composting-and-pfas. Accessed 30 Nov. 2020.

[56] United States Environmental Protection Agency. Technical Fact Sheet – Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA), November 2017. URL www.epa.gov/sites/production/files/2017-12/documents/ffrrofactsheet_contaminants_pfos_pfoa_11-20-17_508_0.pdf.

[57] Yan Huang. Not Waiting for the European Union, Denmark Is the First to Announce the Ban on Food Packaging PFAS. Tech News, September 2019. URL technews.tw/2019/09/04/danish-government-about-to-ban-pfas-in-food-package/. Accessed 30 Nov. 2020.

[58] Center for Environmental Health. Avoiding Hidden Hazards: A Purchaser's Guide to Safer Foodware. Technical report, April 2018. URL www.ceh.org/wp-content/uploads/2019/05/CEH-Disposable-Foodware-Report-final-1.31.pdf.

[59] California Environmental Protection Agency. Food Packaging with Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs), October 2019. URL dtsc.ca.gov/wp-content/uploads/sites/31/2019/10/Food-Packaging_Perfluoroalkyl-and-Polyfluoroalkyl-Substances-PFASs.pdf.

[60] Youn Jeong Choi, Rooney Kim Lazcano, Peyman Yousefi, Heather Trim, and Linda S Lee. Perfluoroalkyl Acid Characterization in U.S. Municipal Organic Solid Waste Composts. *Environmental Science & Technology Letters*, 6(6):372–377, May 2019.

[61] BioCycle. Managing PFAS Chemicals In Composting And Anaerobic Digestion, January 2020. URL www.biocycle.net/managing-pfas-chemicals-composting-anaerobic-digestion/. Accessed 7 Jun. 2020.

[62] Wood Environment & Infrastructure Solutions, Inc. Investigation of Per- and Polyfluoroalkyl Substances (PFAS) at Select Source Separated Organic Material and Yard Waste Sites, Minnesota. Technical report, September 2019. URL cdn.ymaws.com/www.compostingcouncil.org/resource/resmgr/documents/advocacy/pfas/pfas_report_minnesota.pdf.

[63] Erika Schreder and Jennifer Dickman. Take out toxics: Pfas chemicals in food packaging. Technical report, Safer Chemicals Healthy Families and Toxic-Free Future, 2019.

[64] Anu Kapanen. Ecotoxicity Assessment of Biodegradable Plastics and Sewage Sludge in Compost and in Soil. Technical report, VTT Technical Research Centre of Finland, 2012. URL helda.helsinki.fi/bitstream/handle/10138/37273/ecotoxic.pdf?sequence=1.

[65] EU Science Hub. Assessing potential risks from exposure to chemical mixtures - case study review, July 2016. URL ec.europa.eu/jrc/en/science-update/assessing-potential-risks-exposure-chemical-mixtures-case-study-review. Accessed 18 Oct. 2020.

[66] Kjeldsen, Annemette and Price, Marcus and Lilley, Charlotte and Guzniczak, Ewa and Archer, Ian. A Review of Standards for Biodegradable Plastics. Technical report, Industrial Biotechnology Innovation Centre, 2018. URL assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817684/review-standards-for-biodegradable-plastics-IBioIC.pdf.

[67] European Bioplastics. Home Composting Fact Sheet. Technical report, April 2015. URL docs.european-bioplastics.org/publications/bp/EUBP_BP_Home_composting.pdf.

[68] M. Kern and T. Turk and A. Hüttner and U. Koj. Fate Of Compostable Bags In Digester Field Trials. BioCycle, September 2018. URL www.biocycle.net/fate-compostable-bags-digester-field-trials/. Accessed 30 Oct. 2020.

[69] Cole Rosengren. Some Facilities Stop Accepting Compostable Packaging as Contamination Debate Persists. WasteDive, March 2018. URL www.wastedive.com/news/compostable-packaging-rexius-US-Composting-Council-Conference/550012/. Accessed 12 Oct. 2020.

[70] Joseph P. Greene. *Sustainable Plastics: Environmental Assessments of Biobased, Biodegradable, and Recycled Plastics*, chapter Appendix E: Marine Biodegradation Testing, pages 303–307. John Wiley & Sons, Ltd, August 2014. ISBN 9781118899595. doi: 10.1002/9781118899595. URL https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118899595.app5.

[71] TÜV AUSTRIA. Bio products – degradation in seawater, April 2019. URL https://cutt.ly/2hHoGz7.

[72] Jesse P. Harrison, Carl Boardman, Kenneth O'Callaghan, Anne-Marie Delort, and Jim Song. Biodegradability standards for carrier bags and plastic films in aquatic environments: a critical review. *Royal Society Open Science*, 5(5):171792, 2018. doi: 10.1098/rsos.171792.

[73] Clare Goldsberry. Fake Biodegradable Products Flood Market After India Bans Single-Use Plastics. Plastics Today, February 2020. URL www.plasticstoday.com/packaging/fake-biodegradable-products-flood-market-after-india-bans-single-use-plastics. Accessed 15 Oct. 2020.

[74] Versopub. Out of All Eco-Friendly Products, Biodegradable Ones May Be the Most Misunderstood, September 2020. URL www.versopub.com/out-of-all-eco-friendly-products-biodegradable-ones-may-be-the-most-misunderstood/. Accessed 7 Nov. 2020.

[75] Ellie Moss and Rebecca Harris. Can I Recycle This? A Global Mapping and Assessment of Standards, Labels and Claims on Plastic Packaging. Technical report, United Nations Environment Programme and Consumer International, 2020. URL www.oneplanetnetwork.org/resource/can-i-recycle-global-mapping-and-assessment-standards-labels-and-claims-plastic-packaging.

[76] Kjeld W. Meereboer, Manjusri Misra, and Amar K. Mohanty. Review of recent advances in the biodegradability of polyhydroxyalkanoate (pha) bioplastics and their composites. *Green Chem.*, 22:5519–5558, 2020. doi: 10.1039/D0GC01647K.

[77] Kaza, Silpa and Yao, Lisa C. and Bhada-Tata, Perinaz and Van Woerden, Frank. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Technical report, The World Bank, 2018. URL openknowledge.worldbank.org/handle/10986/30317.

[78] Modupe Stella Ayilara, Oluwaseyi Samuel Olanrewaju, Olubukola Oluranti Babalola, and Olu Odeyemi. Waste management through composting: Challenges and potentials. *Sustainability*, 12(11):4456, 2020. URL https://www.mdpi.com/2071-1050/12/11/4456.

[79] The Council of The European Union. Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste, July 1999. URL eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31999L0031.

[80] European Environment Agency. Bio-waste in Europe — turning challenges into opportunities. Technical report, January 2020.

[81] United States Environmental Protection Agency. National Overview: Facts and Figures on Materials, Wastes and Recycling, . URL www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#Recycling/Composting. Accessed 20 Oct. 2020.

[82] National Bureau of Statistics. China Statistical Yearbook, 2019. URL www.stats.gov.cn/tjsj/ndsj/2019/indexch.htm. Accessed 20 Oct. 2020.

[83] China Industry Information Network. China's food waste disposal and management industry analysis in 2019: Research on the Status Quo and Future Trends of Market Scale, 2019. URL www.chyxx.com/industry/201909/778203.html. Accessed 20 Oct. 2020.

[84] Nora Goldstein. Quantifying Existing Food Waste Composting Infrastructure in The U.S. BioCycle, November 2019. URL www.compostingcollaborative.org/wp-content/uploads/2018/11/Task3_rev181129.pdf.

[85] Compost Manufacturing Alliance LLC. Field Study: Foodservice Packaging as Compost Facility Feedstock. Foodservice Packaging Institute and Biodegradable Products Institute, October 2018. URL docs.wixstatic.com/ugd/1f2d68_c6e81abf2b7c4e8ba4bc015e9152224a.pdf.

[86] Hann, Simon and Scholes, Rosy and Molteno, Star and Hilton, Mark and Favoino, Enzo and Jakobsen, Line Geest. Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy. European Union, 2020. URL bioplasticsnews.com/wp-content/uploads/2020/06/kh0420187enn.en_.pdf.

[87] WtERT. Position Statement on the Disposal of Biodegradable Plastics Through Bio-Waste Treatment (Composting and Anaerobic Digestion), jun 2019. URL www.wtert.net/news/217/Position-Statement-on-the-disposal-of-biodegradable-plastics-through-bio-waste-treatment-(composting-and-anaerobic-digestion).html. Accessed 16 Nov. 2020.

[88] US Composting Council. Compostable Products. URL www.compostingcouncil.org/page/CompostableProducts. Accessed 20 Oct. 2020.

[89] Jenna R Jambeck, Roland Geyer, Chris Wilcox, Theodore R Siegler, Miriam Perryman, Anthony Andrady, Ramani Narayan, and Kara Lavender Law. Plastic waste inputs from land into the ocean. *Science*, 347(6223):768–771, February 2015.

[90] United States Environmental Protection Agency. Frequently asked questions about plastic recycling and composting. URL www.epa.gov/trash-free-waters/frequently-asked-questions-about-plastic-recycling-and-composting. Accessed 20 Oct. 2020.

[91] Nagano City. Guidelines for Disposal of Household Recyclables/Garbage. URL www.city.nagano.nagano.jp/uploaded/attachment/328145.pdf. Accessed 20 Oct. 2020.

[92] Éco Entreprises Québec. Fact Sheet: Impact of Packaging on Curbside Recycling Collection and Recycling System. URL www.eeq.ca/wp-content/uploads/PLA-bottles.pdf. Accessed 20 Oct. 2020.

[93] Luc Alaerts, Michael Augustinus, and Karel Van Acker. Impact of bio-based plastics on current recycling of plastics. *Sustainability*, 10(5), 2018. ISSN 2071-1050. doi: 10.3390/su10051487.

[94] Chet Chaffee and Bernard R. Yaros. Life cycle assessment for three types of grocery bags - recyclable plastic; compostable, biodegradable plastic; and recycled, recyclable paper. Technical report, 2014. URL monterey.org/Portals/0/Policies-Procedures/EnvironPrograms/Bags/BousteadLCA.pdf.

[95] Marie Donahue. Waste incineration: A dirty secret in how states define renewable energy. Technical report, Institute for Local Self-Reliance, 2018. URL https://ilsr.org/waste-incineration-renewable-energy/.

[96] Biodegradable Products Institute. The Myths of Biodegradation. URL bpiworld.org/page-190439. Accessed 20 Oct. 2020.

[97] Dana Adamcová and Magdalena Vaverková. Degradation of biodegradable/degradable plastics in municipal solid-waste landfill. *Polish Journal of Environmental Studies*, 23(4):1071–1078, 2014. ISSN 1230-1485. URL http://www.pjoes.com/Degradation-of-Biodegradable-Degradable-rnPlastics-in-Municipal-Solid-Waste-Landfill,89283,0,2.html.

[98] Global Methane Initiative. Global methane emissions and reduction opportunities. URL www.globalmethane.org/documents/GMI_Mitigation-Factsheet_Chinese.pdf. Accessed 20 Oct. 2020.

[99] United States Environmental Protection Agency. Basic Information about Landfill Gas, . URL www.epa.gov/lmop/basic-information-about-landfill-gas. Accessed 20 Oct. 2020.

[100] Katie Allen, Dianna Cohen, Alicia Culver, Anna Cummins, Sandra Curtis, Marcus Eriksen, Miriam Gordon, Angela Howe, Sego Jackson, Nick Lapis, Matt Prindiville, Bev Thorpe, and Stiv Wilson. Better alternatives now (ban) list 2.0. Technical report, 5 Gyres Institute, 2018. URL static1.squarespace.com/static/5522e85be4b0b65a7c78ac96/t/5a99d29d41920278291296a4/1520030386318/5Gyres+BAN+List+2018.pdf?_ga=2.96180060.1517479492.1576696218-904504388.1455000410.

[101] Alan Williams. Biodegradable Bags Can Hold a Full Load of Shopping Three Years After Being Discarded in the Environment, April 2019. URL https://www.plymouth.ac.uk/news/biodegradable-bags-can-hold-a-full-load-of-shopping-three-years-after-being-discarded-in-the-environment. Accessed 26 Oct. 2020.

[102] The European Parliament and The Council of The European Union. Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment, June 2019. URL https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32019L0904&from=EN.

[103] European Commission. Circular Economy Action Plan: For a cleaner and more competitive Europe, April 2020. URL https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf.

[104] European Commission. Bio-Based Industry in the EU, 2018. URL ec.europa.eu/knowledge4policy/visualisation/bio-based-industry-eu_en. Accessed 20 Oct. 2020.

[105] European Commission. Environment, 2018. URL ec.europa.eu/knowledge4policy/bioeconomy/topic/environment_en. Accessed 20 Oct. 2020.

[106] Claudia Parisi and Ronzon Tévécia. A global view of bio-based industries: Benchmarking and monitoring their economic importance and future development. Technical report, European Commission, 2016. URL publications.jrc.ec.europa.eu/repository/bitstream/JRC103038/lb-na-28376-en-n.pdf.

[107] House of Commons. Plastic Food and Drink Packaging, September 2019. URL publications.parliament.uk/pa/cm201719/cmselect/cmenvfru/2080/2080.pdf.

[108] Department for Environment Food, and Rural Affairs. Carrier Bags: Why There's a Charge, March 2020. URL www.gov.uk/government/publications/single-use-plastic-carrier-bags-why-were-introducing-the-charge/carrier-bags-why-theres-a-5p-charge.

[109] Department for Environment, Food & Rural Affairs and The Rt Hon George Eustice MP. Start of Ban on Plastic Straws, Stirrers and Cotton Buds, October 2020. URL www.gov.uk/government/news/start-of-ban-on-plastic-straws-stirrers-and-cotton-buds.

[110] HM Treasury and Department for Environment, Food & Rural Affairs. Plastic packaging tax, March 2020. URL www.gov.uk/government/consultations/plastic-packaging-tax.

[111] Department for Environment Food & Rural Affairs, Department of Agriculture, Environment and Rural Affairs (Northern Ireland, and Welsh Government. Introducing a Deposit Return Scheme (DRS) in England, Wales and Northern Ireland: Executive Summary and Next Steps, August 2019. URL www.gov.uk/government/consultations/introducing-a-deposit-return-scheme-drs-for-drinks-containers-bottles-and-cans/outcome/introducing-a-deposit-return-scheme-drs-in-england-wales-and-northern-ireland-executive-summary-and-next-steps.

[112] Liz Gyekye. Compostable materials market booms in Italy. Bio Market Insight, June 2020. URL biomarketinsights.com/compostable-materials-market-booms-in-italy/. Accessed 11 Oct. 2020.

[113] BBC News. Italy to Begin Ban on Plastic Bags in Shops, December 2010. URL www.bbc.com/news/world-europe-12097605. Accessed 3 Nov. 2020.

[114] Elisabetta Povoledo. Biodegradable Bags Cause Outrage in Italy. (It's Not Really About Bags.). New York Times, January 2018. URL www.nytimes.com/2018/01/08/world/europe/italy-plastic-bags.html?_r=0. Accessed 4 Nov. 2020.

[115] Greenreport. È nato Biorepack, il consorzio italiano per il recupero delle bioplastiche, May 2020. URL www.greenreport.it/news/economia-ecologica/e-nato-biorepack-il-consorzio-italiano-per-il-recupero-delle-bioplastiche/. Accessed 3 Nov. 2020.

[116] Enzo Favoino. On the Road to Zero Waste: Viability of Schemes for Organics in a City with Pop. Above 1 million, 2016. URL www.circulareconomy.lt/wp-content/uploads/2017/09/OK_FAVOINO_-_biowaste_in_Milan.pdf. Powerpoint Presentation.

[117] Enzo Favoino. Zero Waste Italy and Milan: Case Study. The Organic Stream Talk Show, February 2014. URL www.organicstream.org/2014/02/10/zero-waste-italy-and-milan-case-study/. Accessed 12 Oct. 2020.

[118] Italian Composting and Biogas Association. Annual Report on Biowaste Recycling. Technical report, November 2017. URL www.compost.it/wp-content/uploads/2019/08/Rapporto-CIC-2017-Eng-v-2.6-web-version.pdf.

[119] Sarah Gibbens. See the Complicated Landscape of Plastic Bans in the U.S. National Geographic, August 2019. URL www.nationalgeographic.com/environment/2019/08/map-shows-the-complicated-landscape-of-plastic-bans/. Accessed 12 Oct. 2020.

[120] City of Los Angeles. Plastic straws-on-request ordinance, 2019. URL https://www.lacitysan.org/san/faces/home. Accessed 20 Oct. 2020.

[121] City of Portland. Straw Ordinance, 2020. URL www.portlandmaine.gov/2558/Straw-Ordinance. Accessed 20 Oct. 2020.

[122] California Department of Justice. Quick Reference Guide to 'Biodegradable,' 'Compostable,' and Related Claims on Plastic Products in California. URL oag.ca.gov/sites/all/files/agweb/pdfs/environment/ag_website_environmental_claims.pdf. Accessed 22 Sep. 2020.

[123] Maryland General Assembly. Environment - Compostable, Degradable, and Biodegradable Plastic Products - Labeling. URL mgaleg.maryland.gov/mgawebsite/legislation/details/hb1349?ys=2017rs. Accessed 22 Sep. 2020.

[124] California Legislative Information. Plastic Products. California Public Resources Code, sec. 42355 - 42358.5, 2011. URL leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=PRC&division=30.&title=&part=3.&chapter=5.7.&article.

[125] Clare Goldsberry. California Sues to Stop Greenwashing; Biodegradable vs. Compostable Battle Rages on, November 2011. URL www.plasticstoday.com/california-sues-stop-greenwashing-biodegradable-vs-compostable-battle-rages. Accessed 22 Sep. 2020.

[126] Sheila Millar and JC Walker. 23 California DAs Obtain $1.5 Million Settlement for Deceptive Biodegradable Claims, August 2018. URL www.consumerprotectioncxn.com/2018/08/23-california-das-obtain-1-5-million-settlement-for-deceptive-biodegradable-claims/#:~:text=The%20California%20law%20prohibits%20businesses,set%20forth%20in%20the%20law. Accessed 22 Sep. 2020.

[127] Office of Alameda County District Attorney. DA Announces Settlement with Walmart Over 'Greenwashing' Claims, February 2017. URL www.alcoda.org/newsroom/2017/feb/walmart_settlement. Accessed 22 Sep. 2020.

[128] Office of Alameda County District Attorney. DA Nancy O'Malley Announces Settlement with Costco & SF Gourmet Coffee, March 2018. URL www.alcoda.org/newsroom/2018/mar/costco_and_sf_gourmet_coffee_settlement#more. Accessed 15 Oct. 2020.

[129] County of Monterey. District Attorney Announces Settlement With Amazon.com, Inc. for Sales of "Biodegradable" Plastic Items, August 2018. URL www.co.monterey.ca.us/home/showdocument?id=67593. Accessed 15 Nov. 2020.

[130] Chuxiao Zhao. Guidelines for classification and labeling of biodegradable plastic products released, September 2020. URL www.thepaper.cn/newsDetail_forward_9198024. Accessed 15 Nov. 2020.

[131] National Development and Reform Commission. Thirteenth Five-Year Plan" National Urban Domestic Waste Harmless Treatment Facilities Construction Plan, 2016. URL www.ndrc.gov.cn/xxgk/zcfb/ghwb/201701/W020190905497906455466.pdf.

[132] Jilin Daily. Jilin Province became the country's first "plastic ban" province, January 2015. URL www.gov.cn/xinwen/2015-01/05/content_2800263.htm. Accessed 15 Nov. 2020.

[133] nanle.gov. Nanle County Central Kindergarten held a mobilization meeting to control white pollution and promote the use of disposable degradable plastic products, April 2018. URL http://www.nanle.gov.cn/2018/0411/16964.html. Accessed 28 Nov. 2020.

[134] Jilin Daily. Changchun Development Zone: To build the core area of the domestic biological manufacturing industry, November 2015. URL ezone.mofcom.gov.cn/article/ab/201511/20151101194592.shtml. Accessed 28 Nov. 2020.

[135] Henan Province Nanle County Investment Promotion Bureau. National Bio-based Materials Industry Cluster—Welcome to Henan Nanle, April 2016. URL www.nanle.gov.cn/2016/0421/5120.html. Accessed 28 Nov. 2020.

[136] Caixuan Yue. High cost, low effectiveness, non-degradable-the effectiveness of the promotion of degradable plastics in Changchun City for five years. Zero Waste Alliance, March 2020. URL mp.weixin.qq.com/s/z2R-d-tR0OoqSdMYlai6TA. Accessed 10 Nov. 2020.

[137] Caixuan Yue. Low implementation and poor quality of bags-Nanle County uses biodegradable plastic bags to promote "plastic ban" report. Zero Waste Alliance, March 2020. URL mp.weixin.qq.com/s/FmB_SUA8SCl_l55BQMlSeA. Accessed 10 Nov. 2020.

[138] Packaging Digest. Coca-Cola Company Introduces Bioplastic Bottle, January 2014. URL www.packagingdigest.com/smart-packaging/coca-cola-company-introducesbioplastic-bottle.

[139] Pepsico. ESG Topics A-Z. URL www.pepsico.com/sustainability/esg-topics-a-z#packaging. Accessed 20 Oct. 2020.

[140] Danone. Circular economy of packaging. URL www.danone.com/impact/planet/packaging-positive-circular-economy.html. Accessed 3 Nov. 2020.

[141] Nestlé. Nestlé and Danimer Scientific to develop biodegradable water bottle, January 2019. URL www.nestle.com/media/pressreleases/allpressreleases/nestle-danimer-scientific-develop-biodegradable-water-bottle. Accessed 25 Oct. 2020.

[142] Mars. Plans To Rethink Our Packaging, Today. URL www.mars.com/sustainability-plan/healthy-planet/sustainable-packaging. Accessed 20 Oct. 2020.

[143] Unilever. Rethinking Plastic Packaging – Towards a Circular Economy. URL www.unilever.com/sustainable-living/reducing-environmental-impact/waste-and-packaging/rethinking-plastic-packaging/. Accessed 20 Oct. 2020.

[144] Notpla. URL www.notpla.com/. Accessed 20 Oct. 2020.

[145] GreenBiz. P&G Brings Sugarcane Packaging to Pantene, Covergirl, August 2010. URL www.greenbiz.com/article/pg-brings-sugarcane-packaging-pantene-covergirl. Accessed 20 Oct. 2020.

[146] Icealnd. #TooCoolForPlastic, Iceland's Plastic 2019 Commitment, 2019. URL sustainability.iceland.co.uk/wp-content/uploads/2020/03/Iceland-Plastics-Annual-Report-2019.pdf.

[147] Fresh Produce Journal. Morrisons asks brands to cut plastic, November 2020. URL www.fruitnet.com/fpj/article/183569/morrisons-asks-brands-to-cut-plastic. Accessed 12 Oct. 2020.

[148] TESCO. Packaging Preferred Materials & Formats Guidelines 2020. URL tescoplc.com/media/755625/preferred-materials-formats-listing-april-2020.pdf. Accessed 20 Oct. 2020.

[149] Greenpeace and the Environmental Investigation Agency. Checking out on plastics A survey of UK supermarkets' plastic habits. Technical report, 2018. URL eia-international.org/wp-content/uploads/Checking-out-on-plastics.pdf.

[150] Packaging Europe. Carrefour: the Retail Giant Acting like a Start-Up on Sustainability, February 2019. URL packagingeurope.com/carrefour-retail-giant-start-up-on-sustainability-loop/. Accessed 20 Oct. 2020.

[151] Packaging Europe. Tesco and Loop: A Reuse Laboratory, November 2020. URL packagingeurope.com/tesco-and-loop-a-reuse-laboratory/. Accessed 25 Oct. 2020.

[152] Waste today. Kroger partners with TerraCycle to recycle flexible plastic packaging, August 2020. URL www.wastetodaymagazine.com/article/kroger-advances-zero-waste-vision/. Accessed 1 Nov. 2020.

[153] Business Review. Carrefour Replaces Plastic Bags With Biodegradable Ones Made in Romania, June 2018. URL business-review.eu/business/retail/carrefour-replaces-plastic-bags-with-biodegradable-ones-made-in-romania-172340. Accessed 1 Nov. 2020.

[154] Bakery and Snacks. Carrefour Introduces Biodegradable Bags, June 2002. URL www.bakeryandsnacks.com/Article/2002/06/10/Carrefour-introduces-biodegradable-bags. Accessed 1 Nov. 2020.

[155] Costco Wholesale. Packaging. URL www.costco.com/sustainability-packaging.html. Accessed 20 Oct. 2020.

[156] Bloomberg. 7-Eleven to Wrap 2 Billion Rice Balls in Plant-Based Plastic, June 2019. URL www.bloomberg.com/news/articles/2019-06-26/7-eleven-to-wrap-2-billion-rice-balls-in-plant-based-plastic. Accessed 22 Nov. 2020.

[157] 7-11 Japan. Initiatives at stores. URL www.sej.co.jp/csr/environment/resources.html. Accessed 13 Nov. 2020.

[158] FamilyMart. Climate Change Mitigation and Adaptation. URL www.family.co.jp/english/sustainability/material_issues/environment/carbon.html. Accessed 20 Oct. 2020.

[159] New York Times. Food Delivery Apps Are Drowning China in Plastic, May 2019. URL www.nytimes.com/2019/05/28/technology/china-food-delivery-trash.html. Accessed 22 Nov. 2020.

[160] Greenpeace and Break Free From Plastic. Research Report on the Characteristics and Management Status of China's Express Package Discard. Technical report, 2019.

[161] 4PX. Global Smart Logistics Summit: Cainiao Network launches "Green Action Plan", June 2016. URL express.4px.com/article/detail/id/500901/cid/2. Accessed 22 Nov. 2020.

[162] DoNews. Qingliu plan's new efforts: JD.com Logistics launches green packaging alliance, August 2018. URL www.donews.com/news/detail/4/3016603.html. Accessed 22 Nov. 2020.

[163] Amazon. Environmental Marketing Guidelines. URL sellercentral.amazon.com/gp/help/external/G201893650?language=en_US. Accessed 29 Nov. 2020.

[164] Delivery Hero. Delivery Hero Strengthens Its Global Commitment to a Sustainable Future With Strategic Investment in Biodegradable Packaging Manufacturer BIO-LUTIONS, May 2019. URL www.deliveryhero.com/delivery-hero-strengthens-its-global-commitment-to-a-sustainable-future-with-strategic-investment-in-biodegradable-packaging-manufacturer-bio-lutions/. Accessed 14 Nov. 2020.

[165] Bio-Lutions. Natural Disposables Product Catalogue, September 2019. URL www.bio-lutions.com/wp-content/uploads/2019/09/BL_ProductCatalogue_201909_web.pdf.

[166] New Food Magazine. Just Eat Develops "World's First" Biodegradable Seaweed Takeaway Box, February 2020. URL www.newfoodmagazine.com/news/106226/just-eat-develops-worlds-first-biodegradable-seaweed-takeaway-box/. Accessed 22 Nov. 2020.

[167] Hua Shang Wang. Meituan Takeaway Qingshan plans to announce new targets: Make 100 million users to practice sustainable consumption, August 2020. URL finance.hsw.cn/system/2020/0831/310870.shtml. Accessed 22 Nov. 2020.

[168] Ellen MacArthur Foundation. The New Plastics Economy Global Commitment 2019 Progress Report. Technical report, 2020. URL www.newplasticseconomy.org/assets/doc/Global-Commitment-2019-Progress-Report-Summary.pdf.

[169] G. Chen and Y. Wang. Research and industrialization progress of "bio-based materials" in china. 31(6):955–967, 2015.

[170] Diao Xiaoqian, Weng Yunxuan, and Huang Zhigang. Development status of domestic bio-based materials industry. 6:715–725, 2016.

[171] Lu Haixu. The development status and trend of biodegradable plastics. 34(3):7–14, 2016.

[172] Jing Ming. Production progress and market analysis of polyvinyl alcohol in china. 10: 65–69, 2013.

[173] Xiao Ming. The supply and demand status and future development trend of polyvinyl alcohol in china and abroad. 211(3):8–11, 2018.

[174] N. A. Azahari, N. Othman, and H. Ismail. Biodegradation studies of polyvinyl alcohol/corn starch blend films in solid and solution media. 22(2):15–31, 2011.

I APPENDIX

Table 8.1: Major biodegradable polymers

Material	**Major applications**[24,169,170]	**Feedstock**	**Biodegradation conditions and time needed in different experiment**[66]
PLA (polylactic acid)	The applications of PLA include clear and opaque rigid plastics for packaging, disposable goods, durable goods, and bottles, as well as films and fibers for a variety of purposes.	Starch mainly from corn and cassava.	Industrial composting condition (58°C): 84% biodegradation after 58 days.
		Sugar mainly from sugarcane.	Industrial composting condition (58°C, 60% moisture): 60% biodegraded after 30 days.
PHAs (include PHA - polyhydroxyalkanoate, PHB - polyhydroxybutyrate, PHBV - poly(3-hydroxybutyrate-co-3-hydroxyvalerate))	With high price, PHA is mainly used in the medical sector, with a small portion used in packaging.	Microbial fermentation mainly using sugar or oil	PHB in industrial composting condition (58°C): 79.9% biodegradation after 110 days. PHA in soil condition (35°C): 35% biodegradation after 60 days. PHB in real soil (temperature and humidity changes): 98% biodegradation after 300 days.
Polybutylene-based polymers (include PBS - polybutylene succinate, PBAT - polybutyrate adipate terephthalate, and PBSA - poly(butylene succinate-co-butylene adipate))	Agricultural mulching film, packaging, disposable cutleries, plastic carrier bags.	Petrochemical-based, with some production uses bio-based feedstock (mainly sugarcane)[171].	PBS in anaerobic composting condition (58 - 65°C, 50-55% moisture): 90% biodegradation after 160 days.

			PBS/starch blends in soil condition (25°C, 60% moisture): 7% biodegradation after 28 days.
Starch blends	Food packaging, single-use cutlery, plastic carrier bags, agricultural mulching film.	Starch mainly from corn, cassava and potatoes.	Anaerobic composting condition (58°C): 85% biodegradation after 90 days. Anaerobic composting condition (23°C, 55% moisture): 26.9% biodegradation after 72 days. Soil condition (20°C, 60% moisture): 14.2% biodegradation after 110 days.
PVA or **PVOH** (polyvinyl alcohol)	Mainly used to make biodegradable fibre and solvents[172].	Petrochemical-based, or calcium carbide, and some production uses bio-based feedstock[173].	PVA/starch blends in composting condition: 85% biodegradation after 56 days (8 weeks)[174].
PPC (propylene carbonate)	Still in the lab phase.	Carbon dioxide.	
PCL (polycaprolactone)	Mainly used in the medical sector.	Petrochemical-based.	

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