

Bio-based food packaging in Sustainable Development

Challenges and opportunities to utilize biomass residues from agriculture and forestry as a feedstock for bio-based food packaging

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February 2016-June 2016



**Food and Agriculture Organization
of the United Nations**

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Executive summary

The Sustainable Development Goals (SDGs) offer a vision of a fairer, more prosperous, peaceful and sustainable world in which no one is left behind. In food- the way it is grown, produced, traded, packed, transported, stored, marketed and consumed- lies the fundamental connection between people and the planet, as well as the path to inclusive and sustainable economic growth. Aligned, food-packaging solutions have an important role to play in sustainable development, and particularly in achieving SDG2¹ in a sustainable manner.

Currently, the majority of food packaging solutions contain fossil-based plastics, which are produced and consumed in an unsustainable manner. First and foremost, the production of fossil-based plastics leads to greenhouse gas emissions. Second and paradoxically, most of the food packaging has a short use-phase; while it can take up to 500 year for the material to decompose and a significant amount of plastic food packaging ends up as litter. Plastic litter results in high waste management costs, pollution of our marine environment, which in turn leads to the death of marine animals and damages the marine ecosystems. Moreover, it has recently been found that plastic debris even enters into our food chain due to the effect of bioaccumulation, which affects our public health.

SDG 12² calls governments, international organizations, the business sector and other non-state actors to contribute to changing unsustainable production and consumption patterns. One way of enhancing production and consumption patterns of food packaging is substituting fossil-based with bio-based packaging materials applied in the packaging solutions.

Substituting fossil-based with bio-based food packaging made out of biomass residues has two main advantages: it decouples food packaging from fossil resources and in a number of cases also includes composting as a possible end-of-life scenario. Furthermore, utilizing biomass residues as a feedstock will contribute to sustainable development of biomass value chains directly and indirectly. Directly, using residues reduces the demand for 'virgin' biomass resources. Indirectly, using residues may result in higher revenues for the biomass generators, such as farmer and forest owners.

Despite the potential benefits from biobased products, certain impediments could hamper a transition to biobased production. First, production cost of bio-based food packaging is higher than fossil-based packaging. Second, due to poor policy support for bio-based packaging, regulations for application of bio-based materials to food products are inappropriate, which in turn constrains new materials to enter the market. Third, inappropriate or absent composting facilities withhold countries to reap the benefits of bio-based and compostable food packaging.

A variety of policy instruments on country and city level are identified to overcome the key barriers to bio-based food packaging:

- Mobilize resources for research and development (R&D) on bio-based food packaging
- Improve and secure access to sustainable biomass resources
- Install demand-side instruments to support the market for bio-based food packaging

¹ SDG 2: End hunger, achieve food security an improved nutrition and promote sustainable agriculture

² SDG 12: Ensure sustainable consumption and production patterns

Next to national and local policy interventions, there is a need for an international coalition that promotes bio-based food packaging as a function of sustainable development. The coalition could focus on four main issues:

- Promote bio-based food packaging as a function of sustainable development
- Establish evidence on how better application of bio-based food packaging can reduce food loss in an environmental friendly manner
- Design guidelines for sustainably utilization of biomass resources
- Provide recommendations on enabling and incentivizing policy frameworks for bio-based food packaging
- Raise awareness about benefits of bio-based packaging among wider public and decision makers

The coalition could be initiated by FAO, and include city- and country governments, research institutes, food companies and brand owners, the packaging sector and NGOs. Such an international and multi-stakeholder coalition will foster an approach that focuses on the whole biomass value chain, from primary producers to end user and waste treatment. With the SDGs in mind, the time has arrived to take action and facilitate a global transition from fossil-based to more sustainable, bio-based and compostable food packaging solutions. This report might serve as a starting point for FAO, as an exploration how food packaging can play a role in sustainable development.

Abbreviations

AP	Acidification Potential
ASTM	American Society for Testing Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BC	Black Carbon
Bio-PE	Biological Polyethylene
BIO-PET	Biological Polyethylene Terephthalate
CEN	European Committee for Standardization
CH ₄	Methane
CO	Carbon monoxide
CO ₂	Carbon Oxide
EC	European Commission
EP	Eutrophication Potential
EPS	Extruded Polystyrene
FAO	Food and Agriculture Organization
FDA	Federal Drug Administration
GHG	Greenhouse Gasses
GWP	Global Warming Potential
HDPE	High Density Polyethylene
ISO	International Organization of Standardization
LCA	Life Cycle Assessment
LDPE	Low density Polyethylene
NMHC	Non-Methane Hydrocarbons
NO _x	Oxides of nitrogen
NREU	Non Renewable Energy Utilization
OC	Organic Carbon
OSHA	Occupational Safety and Health Administration
O ₃	Ozone
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoates
PLA	Poly lactide
PP	Polypropylene
POP	Persistent Organic Pollutant
PS	Polystyrene
SO ₂	Sulphur dioxide
TPS	Thermoplastic Starch
US	United States
USD	United States Dollar
USDA	United States Department of Agriculture
UV	Ultra Violet
VOC	volatile organic compounds
XPS	Extruded Polystyrene

1. Bio-based food packaging as a function of sustainable development

Today, one third of all food produced for human consumption throughout the world is lost between the production and distribution phases, meaning that around 1.3 billion tons of food is annually wasted (Manalili, 2014). Food loss patterns vary in different areas: in developing countries, early stage, post-harvest food loss is significant due to structural and financial limitations, while in developed countries food loss occurs largely in the later stages, for example when products are not consumed in time and expire. While addressing hunger, as stated in SDG 2, thorough further investment in food production is a welcome move, though it must be complemented with strategies for reducing food losses as a way to advance food security as well as to feed the hungry (ibid).

Packaging has a vital role to play in containing and protecting food as it moves through the supply chain to the consumer. The main function of packaging is to protect the product and extend shelf life. It is estimated that 37 per cent of the packaging products are made from rigid and flexible plastics, which makes plastic the most used packaging material as shown in figure 1 (Rexam, 2011). Plastic packaging, in turn, is plastics' largest application, representing 26 per cent of the total volume (Plastic Europe, 2011). Being extremely versatile and durable, with reliable gas and water barriers, plastics has notoriously made itself ubiquitous in the global packaging sector, including for food items (Bradley, 2010).

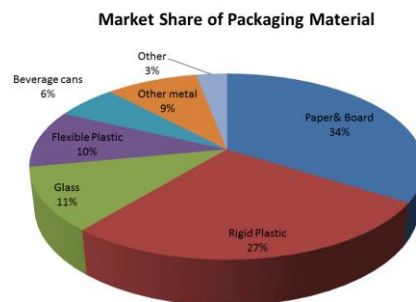


Figure 1: Market share of food packaging materials (Rexam, 2011)

Despite all of its benefits, plastic food packaging is produced and consumed in an unsustainable manner. First, and foremost, the production of fossil-based plastics accounts for 6 per cent of the oil production. Moreover, next to after-use incineration the production of plastics gives rise to greenhouse gas (GHG) emissions, with natural capital cost of 23 billion USD (UNEP, 2013). Second, recent studies estimate that 31 per cent of the plastic debris in marine environments originates from food and beverage packages. Plastic pollution of the global marine environment is a persistent and pervasive problem: annually, 8 million tons of plastics leak into the ocean, which is equivalent to dumping the contents of one garbage truck into the ocean every minute. If no action is taken, this is expected to increase to two per minute by 2030 and four per minute by 2050 (Jambeck et al. 2015). Considering that 31 per cent of a garbage truck is filled with plastics originating from plastic food and beverage packaging, it becomes clear that food and beverage packaging are an important contributor to the pollution of the marine environment.

Marine plastic debris has been proven to lead to the death of wildlife that depends on the oceans for food and habitat, and causes negative impacts on marine ecosystems. Entanglement in- and ingestion of marine debris are also likely to have a range of sub-lethal consequences, such as compromising the ability to capture and digest food, sense hunger, escape from predators and reproduce, as well as

decreasing body condition and impairing locomotion. Of the 120 marine mammal species listed on the IUCN Red List 54 per cent are known to have been entangled in or have ingested plastic debris (Allsopp et al.; Brown, 2011; 2006; Stap, 2011).



Figuur 1: dead sea bird with stomach filled with plastic debris



Figure 2: Waste pickers in Manilla picking plastic in between the fishing boats (My Plastic Free Life, 2009)

On top of the environmental pollution, it became apparent that plastic debris enters food chains and could be affecting human health. Once bulky plastics present in the ocean start breaking down into smaller pieces commonly known as micro plastics, marine species of all kinds – including those commercialized for human consumption – will ingest them together with an array of potentially toxic chemicals (Engler, 2014).

According to the Food and Agriculture Organization (FAO), fishery production from capture resulted in 79.7 million tons of food in 2012, providing for almost 3 billion people together with aquaculture in 2010, and represented 16.7 per cent of global animal protein intake in the same year (FAO, 2014). Needless to say, the ocean provides numerous benefits to those who live close or far from it, and maintains billions of people that are directly dependent on the resources that it has to offer, especially food.

In sum, marine plastic pollution has been causing negative impacts on a fairly large scale, harming ocean dwelling species, posing a threat to coastal economies, building up along the food chain and potentially harming human health. This development runs directly counter to the SDGs, especially against SDG 2,12,13 and 14 (United Nations, 2015):

- SDG 2: End Hunger, achieve food security, improved nutrition and sustainable agriculture
- SDG 12: Ensure Sustainable Consumption and Production (SCP) patterns
- SDG 13: Take urgent action to combat climate change and its impacts; and
- SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable Development.

Hence, there is an urgent need to better align food-packaging solutions with the SDGs. This report investigates the possibility to substitute fossil-based with bio-based food packaging. Bio-based food packaging solutions are expected to have the following comparative advantages to fossil-based food packaging:

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- *Use of **biomass resources**, resulting in lower dependency on fossil resources*
 - *Potential ability to **reduce GHG emissions** throughout their lifecycle, compared with fossil based packaging, and the potential for more **sustainable production** of biobased materials*
 - *Potential to offer more end-of-life scenarios than fossil-based materials, often including **biodegradability and compostability**, which in turn is expected to result in less harmful litter ending up in our marine environment*
-

The emergence of the bio-economy, which means more widespread use of biomass for energy, products and food, results in increased demand for biomass. The use of biomass is, however, limited due to infinite land, water and nutrient availability. It is therefore up to policy makers to ensure that the uptake of bio-based products, such as bio-based food packaging, is sustainable. This report discusses the main sustainability issues associated with bio-based food packaging. It focuses on the potential to utilize unused and locally sourced biomass residues as a feedstock for bio-based food packaging. The key objective of the report is to address the challenges and opportunities to utilize biomass residues of agriculture and forestry as a feedstock for bio-based food packaging. The study is structured along the following research questions:

- What are the main environmental sustainability issues attributed to bio-based food packaging?
- What are the key barriers to substitute bio-based food packaging with fossil-based food packaging?
- What policy interventions enable a transition to sustainable, bio-based food packaging solutions?

This report aims to show that sustainable biobased alternatives for fossil-based food packaging exist. It elaborates on methodologies and studies to calculate and articulate the costs and benefits of food packaging solutions. It is found that more than 100 cities banned fossil-based extruded polystyrene (EPS) packaging, which can be considered as a great opportunity for biobased food packaging suppliers. The report elaborates on both challenges and opportunities to substitute fossil-based with sustainable biobased food packaging. By putting forward policy instruments that enable and incentivize bio-based and compostable food packaging solutions it is shown that innovative food packaging solutions can foster sustainable development. Indications are that FAO has the unique potential to deploy its interdisciplinary knowledge on forestry, agriculture and food industries into a concerted effort to capture the many opportunities in bio-based food packaging.

2. Food packaging materials and environmental concerns

This chapter informs the reader about the main environmental costs and benefits associated with both fossil-based and bio-based (food) packaging materials. It provides an introduction to the life cycle assessment (LCA), a methodology to assess the environmental performances of a packaging product. It furthermore discusses how environmental advantages of bio-based materials are articulated via standards and labels to inform the consumer.

2.1 Methodology to assess environmental performances of a packaging material

Life cycle thinking

Assessing the environmental impact of a packaging material, either fossil- or bio-based is rather complex. A packaging material can have an impact during different stages in its life cycle, starting with the extraction of natural resources to final disposal of the product. The Life Cycle Thinking (LCT) concept is used to evaluate whether substitutes translate into actual improved performance without inadvertently increasing or transferring the burdens elsewhere. A key aim of LCT is to avoid burden shifting. This typically means minimising impacts at one stage of a product life cycle, or in a geographic region, or in a particular impact category, while avoiding increases elsewhere (UNEP and SETAC, 2013). For example, in case of food packaging materials, a LCT approach ensures saving CO₂ emissions in the feedstock production phase without the cost of increasing the amount of material needed to provide the similar function of the packaging material.

Life Cycle Assessment

Life cycle assessment (LCA) is a quantitative application of LCT for evaluating the life cycle environmental performance of a product. The LCA is a method to quantify the environmental impact and therefore turned into a powerful tool to inform decision makers. There are three different types of LCAs, varying in the life cycle stages a product included in the assessment, often referred to as system boundaries.

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- A *'cradle-to-gate'* LCA starts with the extraction of raw materials and ends when the finished product leaves the factory gate
 - A *'cradle-to-grave'* LCA ranges from the extraction of the raw materials used for manufacturing of products through the disposal of the product in landfill, incineration or recycling
 - A *'cradle-to-cradle'* LCA starts with the extraction of natural resources to final disposal of the product, including any material recycling, energy recovery, or reuse that may occur prior to ultimate disposition
-

The outcomes of LCAs articulate the impact of a product during its life cycle on a selection of environmental impact category indicators. Impact category indicators include, but are not limited to,

global warming potential, non-renewable energy utilization (NREU), eutrophication and acidification potential (ibid).

Limitations of Life Cycle Assessments

Like any tool LCAs have their limitations. LCA methodology has been standardized under the ISO-14040 series distinguishing four key phases (goal and scope definition, inventory analysis, impact assessment, and interpretation). Despite the existence of these standards, the number of degrees in freedom for conducting LCAs remains significant (OECD, 2013). As a result, LCA outcomes cannot be compared. For example, LCAs outcomes are very context depended, the impact during the end-of-life phase will be heavily affected by transport distances, the available waste management facilities at point of disposal and the contamination of the packaging material (World Economic Forum, 2016). Another critical factor is that each LCA can include a different set of impact categories, and the choice of impact categories has a high influence on LCA outcomes. It is therefore that LCAs are well suited to evaluate individual material choices, but are less suitable for determining the target state towards which the food-packaging sector as a whole could innovate. The LCA methodology is solely applicable to an individual comparison between petrochemical packaging materials with bio-based packaging materials under certain conditions.

Another important issue is the extent to which the environmental impact of the production of biomass residues is included in the assessment. Some LCA studies that include biomass residues do not allocate any environmental costs for the production of biomass residues, justified by the fact that waste materials would otherwise been unused (Murphy et al., 2004). Whereas, other LCAs base allocation factors on the economic value of the biomass residues, compared to the main product. In any case, different allocation approaches can lead to very different LCA outcomes.

Furthermore, most LCAs do not include the chance for materials to end up as litter, and its attributed environmental impact (World Economic Forum, 2016). Recent studies revealed that 31 per cent of all plastic packaging ends up in the marine environment, implying that there is a significant chance for packaging material to end up as litter (Jambeck et al. 2015). Hence, it might be concluded that most LCA outcomes do not fully capture a material's environmental impact during its end-of-life scenario. Most important, most LCA outcomes do not articulate the environmental advantages of a compostable material compared with a non-compostable material, when littered.

Life Cycle Assessments applied

Despite its shortcomings, LCA outcomes are a good starting point for understanding the environmental hotspots of bio-based food packaging products. A comparison of the cradle-to-grave GHG emissions associated with conventional and bio-based chemicals, based on a total of 44 LCA studies covering approximately 60 individual bio-based materials and 350 different life cycle scenarios, suggests that bio-based materials emit less GHG compared to fossil-based materials (OECD, 2013). A more specific comparison of bio-based food packaging with fossil-based food packaging is hardly possible, due to the limited amount of LCA studies available on bio-based materials derived from biomass residues, and especially applied to food packaging. It becomes apparent that more LCA studies on bio-based materials derived from biomass are needed to get a better understanding of their environmental advantage compared to fossil-based materials, and bio-based materials derived from primary biomass resources.

The main stages in the life cycle of a packaging product are: feedstock production, processing and manufacturing, product distribution and use, and end-of-life scenario (SCB, 2009). This report concentrates on the first and the last stage in the life cycle. This, because those two stages are causing the most environmental pollution in case of plastic packaging.

2.2 Bio-based feedstock

Defining bio-based products

One of the main differences between fossil-based and bio-based materials is their feedstock resource. According to the European Committee for Standardization's biobased products can be defined as products that are wholly or partly derived from biomass, such as plants or trees. Bio-based carbon content is the variable describing the amount of bio-based content (in relation) (CEN, 2014). Bio-based materials are subdivided into three categories (Molenveld et al., 2015):

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1. *Materials originating directly from biomass, such as wood, paper, pulp, cellulose, starch and proteins*
 2. *Materials that can be made from building blocks originating (e.g. fermentation) from biomass, such as polylactic acid*
 3. *Materials that are produced by micro organisms, such as PLA*
-

Primary versus secondary biomass resources

An additional distinction is made between primary and secondary biomass. Secondary biomass feedstocks differ from primary biomass feedstock, as they are a by-product of the primary feedstock. Residues and by-product streams from food, feed, fibre, wood, and materials processing plants are the main source of secondary biomass. By "processing" it is meant that there is substantial physical or chemical breakdown of the primary biomass and production of by-products (U.S. Department of Energy, 2016).

Bio-based products can be carbon neutral products

Bio-based products are often presented as carbon neutral products. This, because these trees or plants grow absorb carbon dioxide, and when they biodegrade they transform their carbon content back into the carbon dioxide sequestered previously during their development. Due to this naturally occurring process, there is no loss or gain of carbon dioxide in the environment over the short period of time in which the material will be used (Kenneth and Bugusu, 2007). This is in contrary to fossil-based materials, the carbon sequestered is known as fossil carbon, previously dormant and stored in underground geological formations for many years. The biodegradation of these materials therefore releases carbon dioxide into the environment that would not have been released in a natural situation. While the short-term, new carbon released by bio-based materials harmonizes with the natural balance of CO₂, in the atmosphere, the long term, old carbon, released by fossil-based materials contributes to the release of hazardous greenhouse gasses (ibid).

Environmental considerations for bio-based products

Nevertheless, there has been much discussion about the actual environmental benefit of utilizing biomass for bio-based products, such as for bio-based (food) packaging. One of the main issues is the impact of the use of land for biomass feedstocks for industrial purposes on recent food price increases. The discussion about land-use competition, however, is most connected with the land use patterns used for the production of bio-energy. The fact that 92 per cent of all global arable land is used for food and animal feed production, and only six per cent for industrial materials and two per cent for biofuels suggests that the impact of using biomass for biobased food packaging can be limited (OECD, 2013). Furthermore, estimates have shown that the impact of bio plastics, one of the bio-based alternative materials for fossil-

based materials, on food markets, agricultural prices and land competition in 2008 was about 250 times less than that estimated for biofuels (Carus and Piotrowski, 2009; OECD, 2013). It becomes clear that research on the increased competition for biomass resources is needed to ensure sustainable utilization of biomass resources, but it might be suggested that the impact on the food price will be small.

Crop and forestry residues are often burned because it is the cheapest and easiest method to dispose the leftover crop residues after harvesting, for land clearing and pest control. Burning of these residues emit gases like sulphur dioxide (SO₂), oxides of nitrogen (NO_x), carbon dioxide (CO₂), carbon monoxide (CO), black carbon (BC), organic carbon (OC), methane (CH₄), volatile organic compounds (VOC), non-methane hydrocarbons (NMHCs), ozone (O₃), and aerosols, which affect the global atmospheric chemistry and climate. Biomass burning not only influence the atmospheric air quality including climate, it also affects the human health (Satyendra, 2013). Utilizing biomass residues for packaging might reduce the amount of residues disposed through burning and its associated environmental impact.





There are, however, also environmental concerns attributed to utilization of biomass residue. For instance, transport distances of fragmented biomass residue streams might result in increased GHG emissions. This example again underlines the demand for LCAs and further research on the actual environmental improvement of using biomass residues for a specific packaging product in a certain context and applied in a certain product. Nevertheless, based on the fact that residues would otherwise contribute to waste that need to be disposed, it would be beneficial if this waste streams would be considered as a feedstock, rather than an externality.

Regulations and standards for bio-based materials

Regulations and standards can help to ensure that claims made for the properties of bio-based products are genuine and verifiable. Bio-based materials are dealt with in the EU Directive under the manufacturing and composition heading and, more specifically, under EN13428 (prevention, reduction). One commonly used term is 'bio-based content', which is the percentage of a product's weight that is based on renewable raw materials. In the 'Bio Preferred Program', the US applies ASTM D6866, which is based on the amount of recently stored carbon in a product. A minimal amount of 25 per cent of bio-based content is established for many material categories. The bio-based percentage of the product, the packaging or both must always be stated on the label (USDA, N.D.).



Within the EU, CEN is currently developing a European standard. This includes assessing whether the ASTM standard can be followed or whether improvements are necessary, for instance by also taking on board other components such as oxygen, nitrogen and minerals. This research is being carried out in two EU KP7 projects – KBBPPS and Open-Bio – with the participation of the Dutch research institutes ECN and Wageningen UR Food & Bio-based Research. Ahead of European regulations, Vinçotte is issuing certificates in Europe for the bio-based content of materials: one star denotes a bio-based content of more than 20 per cent, two stars more than 40 per cent, three stars more than 60 per cent and four stars more than 80 per cent.

			
between 20% and 40% Biobased	between 40% und 50% Biobased	between 60% und 80% Biobased	more than 80% Biobased

The German certification company DIN CERTO mentions the bio-based content in the logo. Both companies base their tests on ASTM D6866.



Both private and public certification schemes have emerged to respond to the demand of consumers and brand owners to articulate the biomass content in a product or packaging. These labels serve as a tool to inform consumers, to set standards and incentivize companies to substitute fossil-based products for bio-based products in order to enhance their environmental image.

2.2 End-of-life scenarios: compostable and biodegradable

The end-of-life scenario is a very important stage in the life cycle of products. It refers to the after-use stage and articulates the possible scenarios for a product to get disposed. The main advantage of bio-based materials compared is their potential to offer more end-of-life options than fossil-based materials. This paragraph elaborates on the end-of-life properties of bio-based materials, and different end-of-life

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1. *Recycling*
 2. *Organic recycling*
 3. *Incineration with or without energy*
 4. *Littering*
-

scenarios for bio-based food packaging materials and their relative environmental impact. There are, in theory, the following disposal options for bio-based packaging materials:

Recycling

Most of the common materials used in packaging (i.e. steel, aluminium, glass, paper, paperboard, plastics and wood) can be efficiently recovered by recycling; however, if packaging materials are soiled with foods or other organic substances, physical recycling of these materials may be impractical and economically not feasible. Consumers are less likely to redirect materials contaminated with food residues to a recycling infrastructure. Furthermore, it is time intensive to separate the food residues from the packaging materials, which makes material recycling of food packaging materials most often too costly (Kale et al., 2007).

Organic recycling

Organic recycling is defined by the EU Packaging and Packaging Waste Directive 94/62/EC (amended in 2005/20/EC) as the - aerobic treatment (composting) or - anaerobic treatment (bio gasification) of packaging waste. Organic recycling basically refers to the process in which materials are transferred into valuable compost, water and CO₂. This CO₂ does not contribute to Greenhouse Gas emissions because it is considered new carbon.

There are two properties that describe whether a material can be organically recycled: biodegradation, and composting (industrial or home compostable). Both definitions are very much alike, but have important differences.

The term biodegradable, by itself, is not very useful. There are, in the European Union no standards for biodegradation of materials, in contrast to composting. It is a general recognition that, in the biosphere, there is at least one enzyme which can speed up the breaking rate of the chemical bonds of a given polymer chain. Biodegradable materials are materials that can be broken down by microorganisms (bacteria or fungi) into water and naturally occurring gases such as carbon dioxide (CO₂) and methane (CH₄) (Molenveld et al., 2015). However, degradation will not occur in an unfavourable environment or the biodegradable material will not degrade within a short time. Notably, the term "biodegradable" does not imply a fast process. It is, therefore, important to couple the term biodegradable with the specification of the particular environment where the biodegradation is expected to happen, and of the time scale of the process (CEN, 2014).

Within the EU Directive, composting is regarded as a specific method for organic recycling. Compostable packaging materials are materials that comply with EN13432. This standard defines how quickly and to what extent a biodegradable plastic must degrade under industrial composting conditions. According to the EN13432 standard, plastic packaging can only be called compostable if it is demonstrated that:

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- *The packaging material and its relevant organic components are naturally biodegradable*
 - *Disintegration of the packaging material takes place in a composting process for organic waste*
 - *The packaging material has no negative effect on the composting process*
 - *The packaging material does not negatively influence the quality of the compost*
-

There are still no European standards for 'home compostable' and 'soil degradable' packaging. Within the EU, the European Commission for Standardization (CEN) is working on European standards for these end-of-life routes. Research for this purpose is being carried out in the EU Open-Bio KP7 Project (Molenveld et al., 2015). Ahead of European regulations, there are several certification companies setting up standards for biodegradation, industrial composting and home composting. In most of the certification cases, industrial composting means that materials will compost in an industrial compost plant, most often under temperatures of 50-60 °C, while home composting means that materials will compost under lower temperatures, in a compost facility at home. Considering that in most countries over 50 per cent of municipal solid waste is organic (garden and food waste and non-recyclable paper products), having composting facilities with appropriate infrastructure reduces the quantity of biomass disposed in landfill, leading to methane emissions (World Bank, 2012).

The most common private institutes providing certificates for composting and biodegradation of materials are the European company Vincotte and the U.S. Company BPI. In both the EU and the U.S, 'compostable' labels have to comply with strict standards, such as those established by ASTM D6400-12 or ISO 17088, in opposite to biodegradation.

Both ISO and ASTM accept that industrial composters are expected to reach temperatures of up to 70 degrees Celsius for successful composting to occur. Other standards may vary, as for example in the EN, where it is required that at least 90per cent of the organic matter is converted into CO₂ within the period of 6 months. BPI and Vincotte provide the following labels:

The logo was created by the Biodegradable Products Institute (BPI) in 1999 and provides certification for companies that meet the ASTM D6400 and/or ASTM D6868 regulations (BPI, 2016).



Certifiers Vincotte offer the Seedling-label and DIN CERTCO and the products are certified according to EN 13432/14995 standards. The logo is being applied throughout the European Union, as has already been accepted in Belgium, Switzerland, Germany, The Netherlands, Poland and the UK.



Products labelled with Vincotte's Ok Compost logo are guaranteed biodegradation in an industrial composting plant. The reference point for this certification is the EN 13434:2000 standard.



Existing claims of compostability refer only to organic recycling in industrial composting plants, unless they have been certified by Vincotte as OK Compost Home, for which the product or package material is tested in conditions of reduced temperature and prolonged duration for complete and harmless breakdown to occur. As shown below in table 3, while temperature variations for the Seedling-label in approximately 58°C and biodegradation/disintegration varies between 2-6 months, Home Composting occurs in the ambient temperature of 20°C-30°C and biodegradation/disintegration can take up to a year to be fulfilled (European Factsheet, 2015).



In an attempt to articulate the conditions under which a product will biodegrade, Vincotte offers certifications for the different kinds of environments where products are likely to end up: water and soil.

Thus, these products are labelled as OK biodegradable SOIL, especially beneficial in agricultural uses, and OK biodegradable WATER, reducing waste streams in natural fresh water. More recently, in 2015, Vinçotte developed an OK biodegradable MARINE label.

Products certified for OK Biodegradable Soil guarantee biodegradation in a natural soil environment, however again it is not set in what time frame the degradation will occur.



Before products are certified for biodegradability in the marine environment, they are tested in four ways. First, 90per cent of the material needs to be sufficiently fragmented after a period of 2.5 months (84 days) to pass through a sieve of 2 to 2 mm. Second, 90per cent of the material needs to break down to the level of CO₂ H₂O molecules. The eco-toxicity test verifies whether the degraded test material exerts no negative influence on marine aquatic organisms. It is important to take note that this logo is only allowed on products that are used in the marine environment, such as fishing line, baits, cull panels etc. This is because it is assumed that the logo saying it is marine degradable encourages people to discard the product or material inappropriately.



Products certified for OK Biodegradable water guarantee biodegradation in a natural fresh water environment, and thus substantially contribute to the reduction of waste in rivers, lakes, or any natural water. Note that this not guarantees biodegradation in marine waters.



Incineration with or without energy recovery

Incineration is a waste treatment process that converts waste into ash, flue gas and heat. It can also be combined with energy recovery. According to a study of Yates and Barlow (2013), who compared multiple LCA studies on biodegradable and commercial biopolymers, incineration is less environmental advantageous for bio-based and degradable materials, since energy recovery is poor in most facilities. Furthermore, according to the packaging recovery organisation of Europe, there is a poor infrastructure of incineration available for packaging in Europe, which lowers the chance for bio-based packaging ending up in an incineration facility in Europe (Pro Europe, 2009). Incineration without energy recovery, also referred to as landfilling is considered the least environmental advantageous option for bio-based and degradable materials, mainly because materials that contain biomass will emit methane, which is a more potent GHG than CO₂ (Garraín et al., 2006; Yates and Barlow, 2016).

Littering

At least 8 million tonnes of plastics leak into our oceans each year, which is equivalent to dumping the contents of one garbage truck of plastics into the ocean (Jambeck et al., 2015). Most LCA studies applied to plastic packaging, however, excluded the consideration of litter within the boundaries of the study. Especially for food and beverage packaging litter should be included in the assessment as recent studies pointed out that 31 per cent of the plastic debris in our marine environment originates from food and beverage packaging.

2.3 Concluding remarks

This chapter indicates that the methodology to assess the environmental performances of food packaging could be enhanced. It became apparent that an unambiguous and international standard that describes how LCA studies could be applied to food packaging is needed. Such a standard could determine the

system boundaries, impact categories and ensure that litter is included as an end-of-life option for food packaging.

The production of feedstock and the end-of-life scenario in the life cycle of a packaging material are especially relevant when moving from fossil-based to biobased foodpackaging, as those two phases are causing the most environmental harm in case of fossil-based food packaging. The meaning of and difference between the terms "biobased", "biodegradable materials" and "compostability" in the context of bio-based packaging are highly important. With the help of voluntary certification schemes and directives of the EU and the US consumers can find information on the bio-based content, compostability and biodegradability of packaging materials, and verify the meaning of those terms. There is, however, no harmonious standard for biodegradability, meaning that the term can be incorrectly interpreted or falsely claimed. This chapter does not include an assessment on the actual production processes, such as bioconversion technologies. Mainly because these technologies are patented or protected and there are just a few studies on environmental issues attributed to bio-based conversion technologies available. The chapter shows that using biomass residues as a feedstock for food packaging rather than fossil resources is an improvement based on the fact that residues would otherwise contribute to waste that need to be disposed, it would be beneficial if this waste streams would be considered as a feedstock, rather than an externality. It also became apparent that compostability of a product is most beneficial in case of food packaging, which also requires a biobased content.

3. Bio-based substitutes for fossil-based materials applied in food packaging

This chapter provides an introduction to bio-based materials that can be applied to food packaging solutions. It focuses on bio-based materials that contain bio-based residues. A distinction of two main categories in bio-based substitutes for fossil-based materials suitable for food packaging can be made: fibre-based and bio-plastic materials. This chapter introduces the main materials in each category and which material can be produced from biomass residues. It furthermore, introduces two bio-based food-packaging solutions that use biomass residues as a feedstock. The main objective of this chapter is to show that bio-based and compostable food packaging exist and can replace fossil-based food packaging.

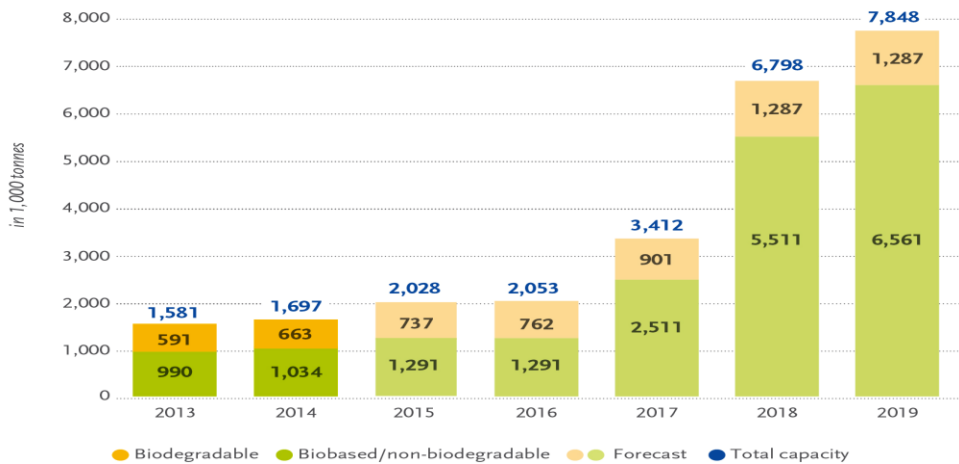
3.1 Bio-based plastics

According to the Food Packaging Forum (2014), bio plastics emit less emissions coming from raw material extraction, and in most cases during the production process. However, case-by-case LCA studies are required to determine the actual benefit of bio-based plastics compared to fossil-based plastics packaging. European Bio plastics is a European association for bioplastic suppliers. They define bio-based plastics, also referred to as bio-plastics, as plastics that are bio based, biodegradable or both. Three types of bio-plastics are distinguished (European Bio plastics, N.D.):

-
- *Biobased or partially biobased on non-biodegradable plastics such as biobased PE, PP or PET*
 - *Plastics that are both biobased and biodegradable, such as PLA and PHA or PBS*
 - *Plastics that are based on fossil resources and are biodegradable, such as PBAT*
-

Currently, bio plastics represent about one per cent of the about 300 million tonnes of plastics produced annually. But as demand is rising, the worldwide production capacity for bio-based plastics is expected to increase from 1.7 million tons (2014) to 7.85 million tonnes in 2019 (European bioplastics, 2015). According to European Bioplastics, Nova Institute and the University of Applied Sciences and Arts in Hanover, packaging remains the single largest field of application for bioplastics with almost 70 percent (1.2 million tonnes) of the total bioplastics market. Due to the excellent fit of bioplastics in the packaging market, this number is expected to increase to more than 80 percent (6.5 million tonnes) in 2019. The fact that the market is increasing creates promising opportunities for biomass residue producers, as well for bio-based food packaging application.

Global production capacities of bioplastics



Source: European Bioplastics, Institute for Bioplastics and Biocomposites, nova-Institute (2015).
More information: www.bio-based.eu/markets and www.downloads.ifbb-hannover.de

Figure 3 Global production capacities bioplastics (European Bioplastics, 2015)

Bio-based plastics are partly or completely derived from biomass. Biomass can undergo any kind of physical, chemical or biological treatment in order to be transformed into bio-based plastics (figure 3). The biopolymers for the bio-plastics are either directly extracted from the biomass (e.g. starch, cellulose) or produced by microorganisms in fermentative processes (PHA) utilizing suitable carbon source. Plant biomass can either be chemically or bio-catalytically converted into building blocks for other polymers (e.g. PLA) (Food packaging Forum, 2014).

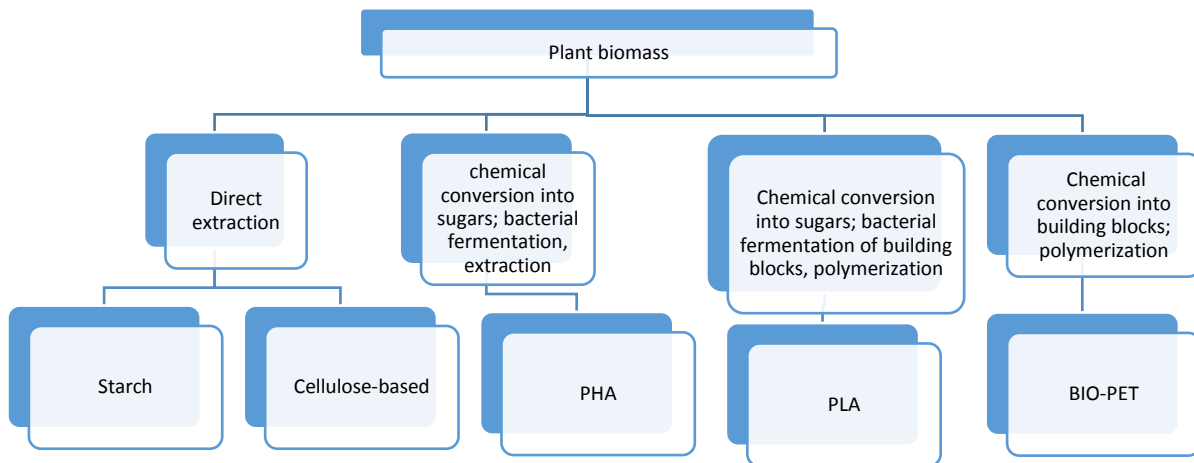


Figure 4: production route of bio- plastics that are bio-based (Food Packaging Forum, 2014)

Figure 4 provides an overview of the most important bio-based plastics applied to food packaging. There is, however, a larger variety of bio plastics applied to food packaging, which are provided in appendix A. As mentioned before, besides the feedstock chosen for a biobased foodpackaging, it is found most beneficial if food packaging can be composted. Table1 provides an overview of the main bioplastics applied to food packaging, and specifies which materials can be derived from biomass residues and which materials are compostable. Materials that are biobased, derived from biomass residues and compostable are preferred from an sustainability point of view.

Table 1: Biobased materials for food packaging: substitute, feedstock, end-of-life scenario, application and market information

Polymers	Substitute for	Main feedstock	End-of-life scenario	Main application	Market information
Starch-based polymers	PS	Starch-crops, such as potatoes and corn. Starch-based polymers can be made of biomass residues, such as tapioca and potato starch residues (Wageningen UR 2014).	Biodegradable and compostable (depending on exact properties of material) (Wagner, 2014).	Disposable tableware and cutlery, coffee machine capsules, bottles (ibid).	In 2014, starch-polymers represented 10 per cent of the global production capacities of bio-plastics, which was then estimated at 1.7 million tons (European Bio plastics. N.D.). Starch has gained high demand in the biodegradable films market, owing to its wide availability, and low cost (PRNewswire, 2016).
Cellulose-based polymers	LDPE, HDPE, PS, PP	Fibre crops, wood and herbaceous crops (Wageningen UR, 2014). Not yet made on commercial scale.	Biodegradable and compostable, depending on coating and exact properties of material	Bread, fruits, meat, dried products.	Limited market share due to: Low water vapour barrier, poor mechanical properties, bad processing, brittleness (pure cellulosic polymer), high production costs Wagner, 2014).
Polyhydroxyalkanoates (PHA) Polymers	PP, PE	Sugar crops, such as sugar cane and oils and fats from oil crops (soy, sunflower, rape and olive). PHA	Biodegradable. Compostable and marine degradable in case of MGH (Bilbow, N.D.)	Containers used as bio-based additive.	In 2014, PHA 2 per cent of the global production capacities of bio-based plastics, which was then

		polymers can also contain biomass residues (such as palm oil residues), but not on a commercial scale produced yet (wageningen UR, 2014).			estimated at 1.7 million tons. The cost of production of PHA is 20per cent-80per cent higher than conventional plastics. This primarily due to the high polymerization cost, as most of the processes are still in lab stage (European Bio plastics, N.D.)
Poly lactide (PLA) polymers	LDPE, HDPE, PS, PET	Sugar crops: corn, sugarcane, and cassava. Current research project of Corbion- Purace, the largest PLA producer in Europe, on utilization of corn Stover, bagasse, wheat straw and wood chips as feedstock for PLA polymers (Corbion-Purac, 2015).	Non-biodegradable. Only industrial composting or incineration possible. Requires separate recycling infrastructure from fossil-based plastics.	Disposable, Transparent, rigid containers, bags, jars, films	In 2014, PLA polymers represented 12per cent of the global production capacities of bio-based plastics, which was then estimated at 1.7 million tonnes (European Bio plastics, N.D.).
Bio-PET polymers	PET	Sugar crops: sugarcane, sugar beet	Non-biodegradable, similar properties as fossil-based plastics and therefore allowed in conventional recycling facilities.	Water bottles, containers, films	In 2014, Bio-PET represented 35.4per cent of the global production capacities of bio-based plastics, estimated at 1.7 million tonnes (European Bio-plastics, N.D.).

3.2 Fibre-based materials

Fibre-based materials belong to the second category of materials suitable for bio-based packaging. Packaging material made from fibres are one of the oldest packaging materials known in mankind. Paper and board are the most commonly used fibre-based packaging materials. More than 95 per cent of paper and board is made from wood, and the remaining sources are mainly agricultural residues, such as straw (of wheat, rye, barley, and rice), sugar cane bagasse, cotton, flax, bamboo, corn husks, and so on. Making pulp is the initial stage in paper and board production. Pulping can be done in a variety of ways: using mechanical, chemical, or a combination process (Shin and Seelke, 2014). Pulp, in other words, is the building block of all fibre-based packaging materials (figure 2).

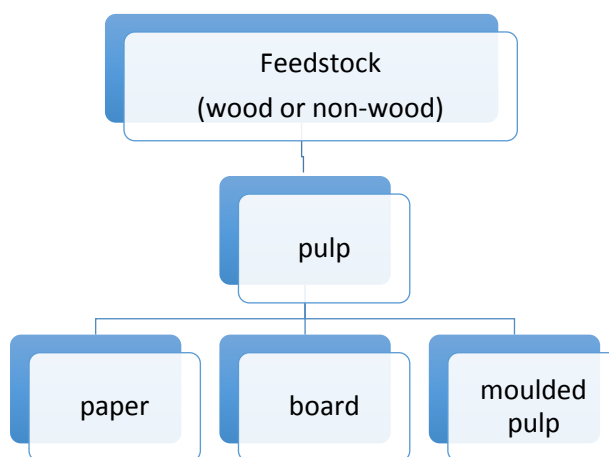


Figure 5: overview of products based on pulp (composed by author)

In 2013, paper and board accounted for 35 per cent of worldwide packaging, with sales around \$280 billion (Smithers Pira, 2015). Different varieties of papers and boards are used in food packaging applications, including Kraft paper, grease proof and glassine paper, waxed paper, vegetable parchment paper, whiteboard, linerboard, food board, carton board, folded carton board, moulded pulp. In terms of production, a distinction can be made between paper products, board products and moulded pulp products. Paper and board currently accounts for 34 per cent of the materials used in the packaging sector (Rexam, 2011).

One of the main environmental burdens associated with paper-and board packaging is that it contributes to deforestation by utilizing virgin wood as a feedstock. Another critical issue is the fact that the production of paper and board products requires a relatively large amount of energy. Moulded pulp production, however, requires less energy, but has a lower quality (Molenveld, 2015). It is, however, beyond the scope of this report to elaborate extensively on the environmental performances of conventional paper- and board packaging and ways to enhance it. Utilization of residue streams that would have otherwise been burned or improperly disposed, leading to environmental pollution, makes sense from a sustainability point of view. Furthermore, using biomass residues rather than wood has the added benefit of reducing deforestation. It is therefore that paper, board and moulded pulp products that contain biomass residues are considered an environmental friendly alternative for fossil-based plastics.

There are two alternative sources of biomass used for pulp production: straw and bagasse (FAO, 2013). Utilizing straw for pulp production allows for avoiding the illegal burning of straw and other agricultural residues. Bagasse is the fibrous residue remaining after sugarcane is crashed to extract its juice and is currently used as a renewable resource in the manufacture of pulp and paper products and building materials. The fibres are about 1.7mm long and are well suited for paper and card packaging (Abdullah and Sulaiman, 2013; Poopak and Reza, 2012). Straw is a residue of agricultural production, such as wheat straw, rice straw or corn stover. It means that straw would be produced regardless of whether it is used for pulp or other products. However, due to a surplus of straw production, a significant amount of straw is burned directly in the fields, leading to soil degradation, air pollution and GHG emissions.

Environmental burden of burning straw in China

Burning of crop straw is a major concern with respect to increasing greenhouse gas emissions in China. Globally, greenhouse gas emissions from the agricultural sector contribute 14per cent, whereas emissions from agricultural sources account for 17per cent of China's total emission as reported in the first national Communication on Climate Change of the Peoples Republic of China in 2004. The total cultivated croplands under rice, wheat, maize and cotton amounts to 155 Mha and a total biomass production amounts to 1300 Mt. In turn, the resulting straw wastes from these crops have been estimated to be 0.7 Pg dry mass in 2006. In Henan Province, the central plain of north China, approximately 25per cent of the straw material is burned to prepare the fields for the next crop¹⁰. In other areas the problem is worse, such as in Jiangsu Province, where straw burning has increased from 21per cent in mid-1990's to 48per cent in mid-2000s¹¹. An overall annual CO₂ emission from straw burning in the field could amount to as much as 0.2 Pg, corresponding to 15per cent of the total CO₂ emissions generated from energy production in China. Therefore, proper disposal of straw is an urgent concern not only for control of air pollution and improvement of environment quality of human being, but also for reducing GHG emissions from China's fast developing economy (Pan et al., N.D.)

Both bagasse and straw are biomass resources, which can be converted into bio-based materials that can be compostable, depending on the blend of the end-material, under various conditions. For every 10 tonnes of crushed sugarcane, nearly three tonnes of bagasse is produced by a sugar industry. Since bagasse is a by-product of the sugar cane industry, the quantity of bagasse produced by each country depends on the amount of sugarcane it produces. Taken this into consideration, countries like Brazil, India and China can benefit by using the waste products of their sugar industry as an alternative as these are the world's largest producers of sugar. Furthermore, according to FAO (2013), in 2010 sugarcane was cultivated on about 23.8 million hectares, in more than 90 countries, with a worldwide harvest of 1.69 billion tons. The crop's abundance makes the use of its by-product for packaging production feasible on a worldwide scale. China is the largest producer of straw pulp, while India and Pakistan also have major straw processing mills, but they are not directly linked with paper and board production (IFC, 2013).

In sum, it became apparent that biobased, derived from biomass residues, and compostable food packaging materials exist and could replace fossil-based materials applied in food packaging. These materials, however, are relatively new concepts that are in most cases produced on a small scale.

3.3 Bio-based food packaging made from biomass residues

This section introduces two randomly selected bio-based packaging solutions containing biomass Residues to provide an insight in their challenges to compete with fossil-based packaging solutions.

Carton boxes made from tomato plant residues

One of the best examples of such biobased packaging solutions is a carton box that contains the residues of tomato plants. This carton packaging solution is produced by The Greenery and contains 15 per cent tomato plant residues and 85 per cent recycled paper and board. The plant residues are usually disposed, but due to this packaging concept, the stalks of tomato plants can be used for food packaging boxes and the leaves for smaller food packaging.



A LCA study of Blonck Consultants shows that packaging in which 110 per cent of recycled paper is substituted with tomato-plant residues already reduces fossil depletion from 0.6 to -17.6 kg oil equivalent and agricultural land occupation from 0.03 to -130.7 m². Furthermore, it shows that packaging offers more end-of-life scenarios, because it is recyclable via the conventional paper- and cardboard infrastructure and both home and industrial compostable (Broekema, 2015). The boxes can be produced via the traditional paper-and board production process, which is beneficial for regions where such facilities are in place yet. The smaller, and simpler boxes are less advanced and can be produced via a simpler pulp production process.

According Aad van Dijk, senior manager at The Greenery, funding for research and development is essential for increasing the efficiency of the conversion technology. For instance, the percentage of tomato plant residues, currently 15 per cent, can be invreased, but requires R&D (Van Dijk, 2016). In otherwords, innovation is hampered due to technical limitations and limited resources for R&D.

Solanyl

Another example of biobased packaging is Solanyl®, which is produced by Rodenburg Polymers. Solanyl® is a biobased resin that is suitable for direct bioconversion technologies. Solanyl® is 50 per cent based on reclaimed biomass residues from potato processing industry grain, root or seed and or flour based resources. According to Tom Rodenburg, Solanyl® demands 65 per cent less energy for production compared to fossil-based materials, and emits less GHG, due to the fact that it contains biomass residues instead of fossil resources. Solanyl® is certified as industrial compostable, meaning that it will compost in an industrial composting plant most often under temperatures of 50 to 60°C (Rodenburg, 2016). Solanyl® can replace fossil-based resins such as PP, HDPE and LDPE applied in (food) packaging.

In 2015, Rodenburg entered into a partnership with Mars to apply Solanyl® to produce bio-based wrappings for the Mars candy bars. The project received funding under the EU Eco-Innovation program, and was set up as a joint effort of the Italian company, Taghleef, producing the film, Rodenburg developing the material, and Mondi Group, an international packaging group, who would manufacture the actual packaging. The wrapping material is industrial compostable (Laird, N.D.). Due to high cost associated with biomass mobilization and small scale production biopolymers cannot enjoy the benefits of economies-of-scale. According to Rodenburg, the project with Mars was only possible due to public funding, which underlines the need for financial support for innovative bio-based packaging (Rodenburg, 2016).

5. A case-in-point: bans on polystyrene foam (EPS) food packaging

To demonstrate the opportunities to substitute fossil-based with biobased and compostable food packaging solutions in this chapter a case-in-point is presented. Polystyrene foam, also referred to as extruded polystyrene (EPS) or Styrofoam, is a fossil-based foam, which is widely applied to food containers, disposables and other food packaging items. The fact that EPS is one of the most widely used petrochemical-based plastics, while also the second major contributor to plastic debris in the ocean, where it becomes toxic to marine life. This fact makes it well suited as an illustrative case for other conventional plastics (Gold et al., 2013). Second, there are more than 100 cities that banned the application of EPS in food packaging, which underlines the public concern about EPS and suggests that there is a need for sustainable packaging alternatives.

In this chapter an introduction to EPS, its main characteristics and applications, followed by an elaboration of its environmental impact and bans on EPS installed is given. Furthermore, an number of bio-based packaging materials that can substitute EPS food packaging will be presented.

5.1 Extruded Polystyrene (EPS)

Polystyrene is either produced solid or foamed. This chapter concentrates on foamed Polystyrene, which will be referred to as EPS. EPS has a high tensile strength, good water resistance, low moisture transmission, ease of fabrication and low costs (Robertson, 2013). The properties of EPS make it useful for many applications, including food packaging. Eggs and dairy products, meat, fish and poultry, cold drinks or carryout meals are commonly packed in EPS (Murphy et al., 1992). EPS can consist of 95 per cent air, which makes it relatively cheap for production. And, with the addition of steam, EPS resins expand up to 40 per cent of its original size (Lickly et al., 1995; Plastics Europe, N.D.).



Polystyrene is one of the six most used fossil-based plastics. 7.1 per cent of the European plastics demand is for PS and foamed PS (2013) (Plastics Europe, 2012). It means that there is a huge potential to substitute this material with a more sustainable biobased material. In 2013, the global demand for EPS was estimated at 10 million tons (GPCA, 2013). In 2015, the market size of EPS, in terms of value, was estimated at USD 13.23 Billion and was projected to reach USD 17.74 million by 2020. Around 25 per cent of the EPS production is applied to the overall packaging sector. Insulation and construction are

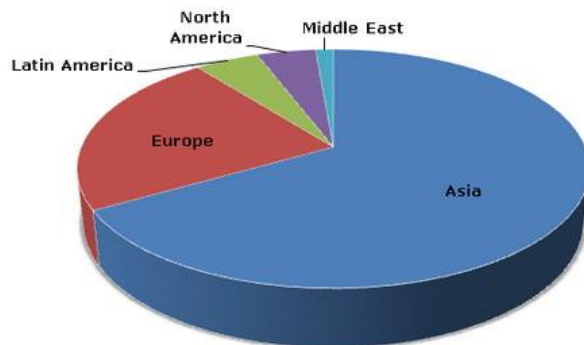


Figure 6: Global EPS capacity (Merchant Research & Consulting, 2012)

The major expanded polystyrene manufacturers are BASF SE (Germany), Total S.A. (France), Synthos S.A. (Poland), Kaneka Corporation (Japan), Saudi Basic Industries Corporation (SABIC) (Saudi Arabia), PJSC SIBUR HOLDING (Russia), Alpek SAB de CV (Mexico), ACH Foam Technologies, LLC (U.S.), Ineos Styrenics International SA (Switzerland), SUNPOR KUNSTSTOFF GmbH (Austria), and Synbra Holding bv BV (The Netherlands), among others (Research and Markets, 2015).

Environmental concerns with EPS

Although EPS has unique properties, it is a pervasive and persistent material when leaked in the environment. It is extremely damaging throughout its life cycle and it's rarely recycled. A study of Integrated Waste Management Board in 2004 examined the environmental impacts of various packaging materials (in the categories of energy consumption, greenhouse gas effect, and total environmental effect) and determined that polystyrene, both in foam and rigid, has the second highest impact, behind aluminium (Integrated waste Management Board, 2004). Because EPS is lightweight and floats, it readily travels from land to waterways and eventually out to the ocean. It takes several decades to hundreds of years for polystyrene foams to deteriorate in the environment or a landfill. A study of the Emmet Center on Climate Change and The Environment (2013) found out that EPS food packaging is one of the most common and damaging types of plastic marine litter (Gold et al., 2013). In addition to being unsightly, toxic chemicals stick to the surface of foam particles. Birds, fish and other wildlife may ingest the foam particles, causing the polystyrene and other toxins to enter the food chain. It is estimated that over 267 species of wildlife have been affected by EPS litter, including birds, whales, fish and many other wildlife (Algalita Marine Research Foundation, 2005; Food Service Waste Reduction Ordinance 2006).



Figure 7: EPS litter in streets and drainage channels of Haiti (Hickman, 2012)

Moreover, polystyrene foams are found the second most common type of beach litter in the U.S. (Gold et al., 2013; Moore et al., 2001). Also in Japan, 85 per cent of beach debris measured comprises styrene (Saïdo et al., 2009). EPS comprises 15 per cent of storm drain litter and comprises 71 per cent of the plastic debris flowing throughout Californian rivers (California Business, Transportation and Housing Agency; USDC, 1999), indicating that polystyrene is an important contributor to the costs associated with marine litter.

EPS and high waste management costs

EPS also results in high waste management costs. A recent study of EPA (2012) found that on average small and medium-sized West-coast cities in the U.S. spend at least \$14 U.S. dollars per year per resident in litter management and marine debris reduction efforts (Stickel et al., 2012). The largest cities are spending conservatively, \$13 U.S. dollars per year per resident for these same trash management and marine debris reduction efforts. A study by California Integrated Waste Management Board (2004) estimated that 300,000 tons of Polystyrene, both in foam and rigid condition, was landfilled, with a total disposal cost of \$30 million and only 0.2 per cent actually recycled. Since up to 95 per cent of EPS consists of air, it takes a lot of space in disposal sites. Landfilling is, however, the most economically viable option for EPS waste, with a significant amount leaking into our marine environment (Stickel et al., 2012).

Littering of EPS has been partly attributed to its poor end-of-life scenarios. The first explanation is that, whilst EPS can technically be recycled, the economics of doing so remain tenuous. The two main reasons

are that consumers are less likely to separate materials contaminated with organic residues at source. Second, it appears to be a difficult and costly activity to separate food residues from EPS, and make it viable for recycling. According to Zero Waste Scotland polystyrene waste compacting and collection was the only one in five options considered that did not represent a viable business opportunity in Scotland (Zero Waste Scotland, 2015). According to the Los Angeles County, the overall recycling rate of EPS is approximately 1 per cent of all EPS sold on the marketplace.

EPS and public health concerns

Additionally, there is a concern for the impact of polystyrene on public health. The main building block of polystyrene is styrene, which is “reasonably anticipated to be a human carcinogen” according to a study of the Agency for Toxic Substances and Disease Registry (ATSDR) of the United States (2010). Styrene can migrate from the styrene based packaging material to the food. As a result, the EPA, the Occupational Safety and Health Administration (OSHA), and the Food and Drug Administration (FDA) developed “not-to-exceed” levels for styrene, with which most food packaging concepts comply (IWMB, 2004). There are additional concerns on the effect when polystyrene containers are heated. The Canadian Food Inspection Agency states: “Remove food from plastic wrap, freezer cartons and/or EPS trays before defrosting or cooking. They are not heat stable and could leak hazardous compounds from the container or plastic wrap to the food” (Future Centre Trust, 2010).

There have been concerns about the exposure of polystyrene to people working in the production of polystyrene products. A study of Toxnet, the U.S. Toxicology databank, has proven that workers in polystyrene products manufacturing are exposed to many harmful chemicals, including styrene, toluene, Xylene, Acetone and more, which increases the risk of leukaemia and lymphoma (TOXNET, 1994). Levels in packages can be limited and determined, but the level of styrene in the marine environment, and eventually entering into our food chain cannot be managed, leading to concerns for public health and the environment.

5.2 Bans on polystyrene foam food packaging

The major concerns of the effect of polystyrene foam on public health and the environment have eventually led to worldwide policy bans on EPS food packaging. At present, more than 100 cities in Asia, Europe, the U.S. and Canada, including two major cities Paris and Toronto, have instituted a ban on polystyrene foam food packaging (USDHH, 2010). Most bans have been installed in the last five years, but in Antarctica, polystyrene has been banned since 1978 (please see appendix B for bans installed). The list is complemented with recent bans and provided in appendix B. The fact that there are an increasing amount of bans on EPS food packaging worldwide in the last 10 years shows that there is political support for a transition to more sustainable food packaging.



Figure 8 A 25ft high today wave of rubbish: The Philippines financial capital banned disposable plastic shopping bags and EPS food containers as part of escalating efforts across the nation's capital to curb rubbish that exacerbates deadly flooding (Reilly, 2013)

In addition to the policy bans, there has been a number of key companies in the fast food sector that have pledged publically to phase out EPS applied in cups for hot beverage. McDonald's is one of the fast food companies that started to replace foam with paper cups: 5per cent of MC Donald's packaging materials used to be EPS (Stringer, 2014). This change will have a significant effect on their EPS suppliers, taken into consideration that McDonald's had the largest share in the fast food restaurant industry with 17 per cent in the U.S. 2014 (Ibis World, 2016). It daily serves 70 million customers, which is more than the whole population of France. Both Jamba Juice and Dunkin's Brand, two other important players in the fast food sector, have also recently publically banned of polystyrene in their beverage cups (Mackeron, 2015; Stringer, 2014). The fact that such big market players are publically banning EPS food packaging shows that the private sector also responds to the public concern about EPS. It is an indication that an increasing demand for EPS substitutes is evolving, which can be an opportunity to promote bio-based and compostable alternatives. The next section will elaborate on potential, bio-based alternatives for EPS food packaging.

5.3 Bio-based materials for food packaging

There are a variety of bio-based materials available to substitute fossil-based materials applied in food packaging. This report concentrates on bio-based food packaging products that contain biomass residues. The first part presents alternatives for EPS food packaging in particular, while the second part elaborates on substitutes for fossil-based materials in general. The main objective of this chapter is to give examples of bio-based packaging solutions made from biomass residues, and provide an understanding of their main challenges in competing with fossil-based packaging materials applied in food packaging.

Examples of existing sustainable biobased alternative for EPS food packaging

PaperFoam® as substitute for EPS food packaging

One of the examples is a packaging produced by PaperFoam a Dutch company that produces The Netherlands, United States and Malaysia. Their alternative to EPS is, also, called: Paper Foam®, and produced from potato or tapioca residues (70per cent), wood-fibres (15per cent) and a premix that is patented (15per cent) (PaperFoam, 2016a).



PaperFoam® is applied to egg trays, and other non-food packaging.

In 2015, 5 million Paper Foam® egg trays were sold and it is expected to increase to 7.5 million egg trays in 2016. For each production facility, the biomass residues are purchased from local biomass generators. A LCA study of Shen and Patel (2007) clearly shows that PaperFoam® demands 40per cent less material, and produces 65per cent less CO₂ along its whole life cycle compared to products that contain polystyrene (PS). Another important advantage of PaperFoam® is that it is suitable for multiple end-of-life scenarios, which suitable for different waste management infrastructures. The material itself is either recyclable via the conventional paper recycling infrastructure, but also degrades 100per cent in a home composting facility. In sum, PaperFoam® egg trays have both environmental advantages in the feedstock production and the end-of-life phase (PaperFoam, 2016b).

PaperFoam® however faces a number of challenges in competing with EPS and other types of fossil-based packaging materials. First, there is a significant price difference between EPS and PaperFoam® packaging. For instance, PaperFoam® egg trays are 30-50per cent more expensive than trays made from EPS. According to Willem Derkman, sales manager of PaperFoam®, the main drivers of the costs are the costs for setting up a new production facility and establishing a biomass value chain, the costs for research and development to further enhance the conversion processes and the disadvantage of producing on a small scale (Derkman, 2016). Second, no regulations or standards are in place for food contact of bio-based materials. Consequently, the bio-based packaging materials of Paper Foam have become subject to the regulations and standards applying to paper materials, according to Mark Geerts, director of PaperFoam®, One of Paper Foam's new, bio-based materials, containing caramel, was not approved for food contact because caramel was not included on the list of food approved components for paper products. This example illustrate that not updated standards hinder the uptake of bio-based materials in the food-packaging sector (Geerts, 2016).

NPulp® as substitute for EPS food packaging

NPulp® is an alternative to EPS, produced by YFY Jupiter. YFY Jupiter is a company based in China and the United States, but NPulp is only produced in China. NPulp® packaging consists of 85 per cent recycled paper and 15 per cent wheat- and rice straw. N'Pulp is produced as moulded pulp, liner or corrugated cardboard. Their moulded pulp packaging variant can replace EPS food packaging (Freeman, 2016).

There is a huge environmental benefit in utilizing straw residues. Straw is the world's largest by-crop and is an ultra-rapidly renewable resource, which can be widely used for the production of biobased products. In China, farm crops produce over 900 million tons of straw per year. Farmers traditionally burn ninety per cent of the straw in China to clear their fields. This is creating causing both soil degradation and air pollution. Utilizing straw for packaging, costs associated with burning and pollution can be eliminated.

Putting this annual produced straw into production of packaging, rather than burying it, NPulp® states to reduce 200,000 tons of CO₂ emissions annually at its current production capacity. As an additional benefit, moulded pulp packaging, consisting of 70 per cent NPulp® and 30 per cent recycled pulp, requires 20 per cent less material. This reduction in mass results in a lower energy demand during the moulding process (N'Pulp, 2016). Similar to PaperFoam®, the products can be recycled, composted at home or in an industrial composting facility.

YFY designed a tailored logistic system for the collection of straw. In order to keep NPulp® production commercial viable, biomass producers have to be located in a radius of 100 km (Freeman, 2016). NPulp® utilizes segmentation and screening technologies to separate fibre from fines, and the fibre is used to produce pulp through thermal energy, mechanical force and enzyme, without the use of harsh chemicals. The remaining natural fertilizers in the straw that are rich in organic substances can fertilize the fields in return, and can be bought back by the farmers. Through the integration between NPulp® technology and agriculture, farmers can harvest both grains and fibre, and enjoy doubled profits from land (YFY, N.D.).

According to Jan Freeman, director YFY Packaging, mobilization of biomass residues is a limiting factor to the production capacity of NPulp. Freeman explains that production of NPulp® is only commercial viable if collection of 1 ton of wheat and rice straw is possible within a scale of 100 km per month, due to otherwise exceeding costs for transportation. No production facility in the U.S. has been set up, because mobilization of sufficient straws in a cost effective manner is not possible in the U.S. An additional constraint is the fact that most biomass crop production takes place during a period of the year. This means that there is no continuous supply of biomass residues, which is a necessity for large-scale industrial production (Freeman, 2016).

Earth Cycle® as substitute for EPS

Earthcycle® also provides an alternative to EPS food packaging. Earthcycle® packaging products are produced in Malaysia by CFK packaging, a Canadian company. Earthcycle pulp is made from palm fibre, a waste product of palm fruit oil production. The fibre is mixed with food-grade additives that increase its water and oil repellence. Earthcycle® states that the packaging is home compostable in 90 days or industrial compost. Earthcycle® packaging is certified by the Biodegradable Products Institute (Sustainable Packaging, N.D.).



5.4 concluding remarks

First of all, the fact that EPS is banned in an increasing number of cities shows that cities can spearhead the initiative to substitute EPS, or other fossil-based food packaging with more sustainable alternatives. Second, the bans on EPS indicate that there is a growing demand for more sustainable food packaging solutions that can replace packaging like EPS. Bio-based food packaging suppliers should grab this opportunity and promote their bio-based food packaging solutions. There are, however, a number of key barriers to substituting fossil-based food packaging with bio-based food packaging identified, on which the next chapter will further elaborate.

6. Key barriers for substituting fossil-based food packaging products with bio-based food packaging products

Bio-based food packaging has potential to foster sustainable development, providing environmental benefits and improving socio-economic development. In theory, bio-based materials can substitute fossil-based materials applied in food packaging. Despite the potential benefits from biobased products, certain impediments could hamper a transition to biobased production, including but not limited to:

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- *Production cost of bio-based materials for food packaging*
 - *Poor policy support for bio-based food packaging*
 - *Lack of appropriate waste management facilities for bio-based packaging materials*
-

6.1 Production cost of bio-based materials for food packaging

The vast majority of bio-based food packaging products are relatively expensive compared to fossil-based alternatives (Molenveld et al., 2015). Unfortunately, no precise statistics on the cost comparison between fossil-based compared with bio-based materials for food packaging is available, a few studies give an indication that bio-based materials made from residues is between 3 to 5 times more expensive compared with fossil-based materials for packaging (Economic Planning Systems Inc, 2012; Rodenburg, 2016; Van Dijk, 2016). The main drivers of the cost for producing bio-based materials include:

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- *Cost of mobilizing biomass residues*
 - *Cost for technological innovations required*
 - *Lack of economies-of-scale*
-

Cost of mobilization biomass residues

Biomass is produced dispersed and only in some periods of the year. It includes storage and transport issues unique to biomass residues (Wageningen UR, 2014). Setting up a sustainable bio-based production chain, from biomass residues to final bio based product is therefore a complicated and costly process. The main challenge is sustainable mobilization of biomass that meets the industrial demands in an economical manner.

In 2011, Malaysia launched a National Biomass Strategy for 2020 for optimal utilization of biomass for high-value activities (including biochemical used applied in bioplastics). The palm oil sector is key in the strategy because it generates the largest amount of biomass. It is noteworthy that 90 per cent of a palm tree is not used for the oil production in Malaysia. In 2012, by-products of the palm oil sector were estimated at 83 million dry tonnes and expected to increase to about 100 million dry tonnes in 2020, just in Malaysia. The waste streams of palm trees consist of empty fruit bunches (EFB), mesocarp fruit fibres (MF) and palm kernel shells (PKS). The vast majority of EFB's and MFs are traditionally burned for disposal, causing air pollution¹. Furthermore, disposal of EFB into oil palm plantation without recovering remnant oil in the EFB contributes to oil spills and to methane emissions, a more potent GHG compared to CO₂. It is only recently discovered that EFB can be converted into ethanol, which in turn can be converted into bio-fuel or bio-chemicals, such as bio-plastics. The same counts for the invention that pulp could be made from palm fibres, as applied in Earthcycle.

The bio-plastics, however, are not produced on an industrial scale yet. One of the main constraints is the costs for mobilization the palm tree residues. The main problem is that no single owner has sufficient scale to mobilize a sufficient volume of biomass for industrial use. The mobilisation of biomass waste streams, referring to collection, aggregation and semi-processing, therefore often becomes too costly compared to the mobilisation of petrochemical feedstock resources (Agensi Innovasia Malaysia, 2013).

Cost for technological innovations requires

Advances in technology, such as in efficient biotechnologies and biomass conversion technologies can lead to cost savings in bio-based packaging. However, there is low investment in R&D for innovation in technologies relevant to bio-based materials derived from biomass residues applied in food packaging (OECD, 2013). More specifically, biomass residues are most often more heterogeneous than virgin feedstock. Hence, innovations are needed to adapt existing bioconversion technologies to new types of feedstock, or develop new technologies. Investment in production and R&D in the bio-based packaging sector requires a policy framework, which supports sustainable use, re-use and recycling of these materials (Europa Bio, 2015).

Lack of economies-of-scale

The carbon-based industries of today are well established and profitable and largely rely on low-priced fossil feedstocks. Introduction of innovative processing technologies has contributed to large scale production systems in petrochemical industries. These energy and chemical companies are vertically integrated to coal, oil, and natural gas and have economic ties to the extraction of these fossil resources. In contrary to fossil-based materials, most bio-based lack the benefits of economies-of-scale. Economies-of-scale are the cost advantages that enterprises obtain due to size, output, or scale in operation, with cost per unit of output generally decreasing with increasing scale as fixed costs are spread out over more units of output (Wageningen UR, 2014).

6.2 Poor policy support for bio-based food packaging

There is an increasing interest in transiting from a fossil-based to a bio-based economy. However, the vast majority of countries that have a policy in place that targets the bio-economy tend to focus on bioenergy, rather than bio-based products. An OECD report on bio plastics (2013) found out that lack of policy support places bio plastics at a disadvantage in the competition for biomass (OECD, 2013), in addition to other constraints for bio-based products. Poor policy support for bio-based food packaging is shown by:

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- *Poorly developed standards on bio-based packaging and food contact approval*
 - *Confusing labels on bio-based and compostable food packaging*
 - *Limited information on sustainable biomass utilization*
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Inappropriate standards on bio-based materials and food contact

Bio-based packaging products need to compete with the more economic fossil-based food packaging products. Fossil-based packaging is relatively cheaper because the environmental costs of fossil-based materials are not included in the price or articulated to consumers. There are no standards on bio-based materials and food contact are in place yet. This has led to incidents in which safe and bio-based materials were not allowed in food packaging, which clearly hinders the uptake of bio-based food packaging solutions.

Confusing labels on bio-based food packaging

To facilitate a smooth implementation of bio-based materials in the food-packaging sector, a policy strategy to improve the awareness of the benefits of bio-based materials compared to fossil-based materials is a necessity. Today there are many different ‘eco-labels’ used globally, and definitions and procedures to identify goods as ‘bio-based’, ‘renewable’, reduced GHG impact’ or ‘compostable’, which is confusing for both producers and consumers (Eco labelling Index, N.D.). Harmonised standards could enhance consumer choice to identify sustainable and biobased products.

Limited information on sustainable biomass utilization

Policymakers, consumers and even investor’s unambiguous and technical information on optimal utilization of biomass residues and their function in sustainable development. A report of UNEP (2009) revealed that decision-makers and end-users of biomass waste streams most often lack sufficient information for selecting appropriate biomass waste conversion technologies (UNEP, 2009). Additionally, a report of the International Renewable Energy Agency (IRENA) found out that poor data on the biomass availability and accessibility in Africa hinders businesses to set-up bio-based industries (Geerts, 2016). Both reports illustrate that the knowledge base on sustainable consumption and production of bio-based materials is very limited. For this research, it became apparent that there are boundaries to access information on bio-based food packaging technologies and production patterns. Due to confidentiality on the production systems various companies were not willing to disclose feedstock. In sum, it shows that the bio-based packaging sector is very protected, and most of the conversion technologies are patented. It hinders optimal utilization of technological innovations to overcome technical barriers and transfer of technology to developing countries (Agensi Inovasia Malaysiam, 2013; Reddy and Yang, 2005; SBC, 2009). There is a strong need for appropriate information and knowledge exchange on optimal utilization of the global biomass potential.

6.3 Lack of appropriate waste management facilities for bio-based packaging materials

To reap the benefits of the flexible end-of-life scenarios of bio-based and compostable food packaging, appropriate waste collection and composting facilities have to be in place. Better use of compostable materials will help to divert organic waste from landfills and incineration to organic recycling. In most countries, no separate collection system for bio waste is in place. Most developing countries lack an industrial compost facility, or a landfill with energy recovering mechanisms. If in place, the available capacity of composting facilities for bio-based products is also very limited. In 2006, around 1,900 industrial composting plants in the EU represented an annual capacity of more than 19 million tonnes of waste (around 0.79 per cent of the total treated waste in the EU) (Gilbert, 2007). However, 40per cent of those facilities only address garden waste (Meekers and Janssens, 2009). Many of the existing composting facilities are not adapted to processing compostable packaging, due to limited capacity at the level of pre-processing (ibid). Also, in the U.S, a study of Institute for Local Self-Reliance (ILSR) shows that composting facilities in the U.S. only allow for composting of garden waste. The study shows that 71per cent of the 4,914 composting operations only compost yard trimmings, which is based on 44 states reporting (Platt et al.2014). The unused potential is estimated at about 100.000 million tonnes of bio waste annually, as a valuable bio-based resource and secondary raw material, in the EU only (Europa Bio, 2015).

6.4 concluding remarks

Further development of the bio-based materials applicable in food packaging will provide the opportunity to start a new bio-based packaging sector and transform existing ones. It will contribute to food security in an environmental friendly manner. However, for this to be achieved on a global scale, a enabling environment is needed that tackles the key barriers for the uptake of bio-based materials derived from biomass residues in the food-packaging sector.

7. Enabling policy frameworks for biobased food packaging products

To address the above mentioned barriers there is a need for enabling policy frameworks for biobased food packaging. Bio-based food packaging fits in with the Sustainable Development Goals agenda. Bio-based food packaging contributes to achieving SDG2: “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”. And SDG 12: “Ensure sustainable production and consumption patterns”. There are an increasing number of countries that instituted supportive policies for the bio-economy.

The term ‘bio economy’ in itself is not precisely defined in a consistent manner across countries in their bio economy strategies. One of the definitions for bio economy most often used and cited in strategies is the definition established by the European Union:

“The bio economy encompasses the sustainable production of renewable biological resources and their conversion and that of waste streams into food, feed, bio-based products, such as bio plastics, biofuels, and bioenergy. It includes agriculture, forestry, fisheries, food, pulp and paper production, as well as parts of chemical biotechnological and energy industries”

(European Commission, 2012)

Given the background of climate change, dwindling fossil resources, the global food situation and great advances in biotechnology, the U.S., E.U., several Asian countries, Canada have adopted policies to support a transition from a fossil-based economy towards a bio economy. With this definition in mind, bio-based food packaging, fit in this new economic concept as it utilizes biomass waste streams as a feedstock, instead of fossil-based feedstock, for food packaging. Although policy that supports the bio economy often indirectly encourages the uptake of bio-based food packaging, there are very few policies in the bio-economy or sustainable development framework targeted that specifically stimulate the market for bio-based materials derived from biomass residues, or have the objective to overcome the barriers to bio-based food packaging.

Within the context of holistic bio economy strategies and the SDGs, there is scope for the use of more intelligent policy mixtures targeted at the development of bio-based and compostable food packaging. The first section provides examples and recommendations on policy instruments that directly target and support the development of bio-based food packaging products. Next to policy recommendations on national and local level, it is found that an international coalition to promote bio-based food packaging as a function of sustainable development is required. Hence, the second section elaborates on the establishment of a coalition.

7.1 Policies to stimulate market demand

Compared to fossil-based food packaging, bio-based food packaging products have numerous cost disadvantages: it lacks economies of scale, demands higher investment in technological innovations, and there are some costly storage and transport issues unique to biomass mobilization. Hence, early market support is needed to make bio-based food packaging competitive with fossil-based food packaging. The following demand-side instruments are expected to stimulate the market demand for bio-based food packaging products:

Demand-side instruments

- BAN FOSSIL-BASED PACKAGING MATERIALS
- TAX FOSSIL-BASED PACKAGING MATERIALS
- PREFERRED PUBLIC PROCUREMENT POLICIES

Ban fossil-based packaging materials

A ban on fossil-based materials, plastics or fossil-based food packaging is a very effective tool to ban fossil-based materials, and support the uptake of bio-based food packaging. The number of countries installing bans on the consumption of fossil-based plastics has been increasing in the last decade. There are more than 100 cities worldwide that have banned the use of EPS food packaging, including large cities like Paris, Toronto and San Francisco. Also, there has been an increase in bans on fossil-based plastic bags. The fact that bans on fossil-based plastic bags have been most often installed on national level, while bans on fossil-based food packaging, have been put in place on city level, indicates that both the national and the city level can take action in banning fossil-based food packaging. Moreover, the fact that more than 100 cities specifically banned fossil-based food packaging shows the need and interest for sustainable alternatives for fossil-based food packaging. There is a high potential for bio-based packaging to substitute fossil-based food packaging. For instance, the ban instituted in San Francisco on EPS in 2006, which was accompanied by a compensation mechanism, appeared to be highly effective in banning EPS and stimulating the market for bio-based alternatives.

San Francisco installed a ban on Extruded Polystyrene (EPS) applied to food packaging. The ban includes suggestions for alternative, environmental friendly alternative materials that are bio-based, biodegradable/compostable or recyclable. An economic hardship waiver that establishments can apply for as recourse if they are having difficulty complying with the ordinance, which can be waived for up to a year, accompanies the ban. Businesses have to demonstrate that biodegradable/compostable and recyclable items are at least 15per cent higher than the EPS product. The City conducted litter audits of city streets and sidewalks in 2007, 2008 and 2009. The studies show a decrease of 41per cent in polystyrene litter over the three-year period after passage of the ordinance, which proves the effectiveness of the ban on reducing litter (Nguyen, 2012). A study of Cascadia Consulting Group in 2011 on bans on EPS installed in cities in the U.S. concluded that the effectiveness of a ban increases when it is accompanied by a compensation tool, and affordable and adequate alternative packaging materials are available (Cascadia Consulting Group, 2011).

Tax fossil-based packaging materials

Taxing mechanisms can be used to increase costs on fossil-based food packaging, which in turn makes bio-based packaging more competitive. Taxing mechanisms can take several forms. This section will discuss three taxing instruments, both direct and indirect.

Tax reductions can be offered to companies that want to research and invest in bio-based industries and more specifically bio-based food packaging. Such tax mechanisms have been most often applied in Asian countries (OECD, 2013).

Furthermore, carbon tax or carbon pricing mechanism can be installed to internalize the environmental externalities of fossil-based packaging materials. A carbon tax can take several forms, but in general it refers to a tax directly linked to the level of CO₂ emissions, often expressed as a value per tonne CO₂ equivalent (per tCO₂e). Since a carbon tax puts a price on each tonne of GHG emitted, it sends a price signal that gradually cause a market response across an entire economy, creating incentives to shift to consumption of less carbon intensive goods. For instance, Costa Rica enacted a tax on carbon pollution in 1995, which set at 3.5 per cent of the market value of fossil fuels. The revenue generated by the tax goes toward the Payment for Environmental Services (PSA) program, which offers incentives to property owners to practice sustainable development and forest conservation (World Bank, N.D.). The case of Costa Rica illustrates how a tax mechanism can increase the price on fossil-based products on the one hand, and utilize the tax income to support sustainable development, which can also be used to support bio-based food packaging.

Also, taxes can target fossil-based packaging directly. For instance, since 2016, EU countries are permitted to reduce the consumption of plastic bags by 50per cent in 2019. The EU lawmakers recommended to introduce extra taxes or levies on plastic bags or even ban single-use plastic bags on national level (Euractiv, 2014). This serves as an international example and shows that also the international or regional level can take the lead in banning fossil-based (food) packaging. Another great example is the impact of the ban on fossil-based packaging in The Netherlands. The Netherlands instituted a tax on carbon content of packaging materials in 2007. Tax ranges from €21 (\$25) per tonne on wood packaging to €470 (\$573) per tonne on plastic. The goal of recycling 65 per cent of plastic by 2012 was already achieved in 2010 (EESI, 2014).

It is beyond the scope of this paper to elaborate on all possible taxing mechanisms that are expected to have a positive impact on the market for bio-based food packaging. The three examples, however, indicate that both direct and indirect taxes are mechanisms to enhance the competitiveness of bio-based food packaging compared with fossil-based food packaging.

Public procurement policies and certification

Public Procurement policies are also an instrument to support the market for bio-based packaging materials, while publically promoting bio-based food packaging materials. A strong recommendation therefore is to include bio-based packaging in the public procurement policies.

The U.S. developed and implemented an advanced public procurement program for bio-based products. 'The Bio Preferred program' is managed by the USDA and requires federal agencies and sub-contractors to favour purchase of bio-based products throughout the United States. In addition the program provides loan guarantees for bio-refinery projects and funds for biomass research and development. The Bio Preferred program is now featured on more than 1,940 products sold in stores across the country with

companies in over 40 countries on six continents participating in the program. The program also resulted in the uptake of bio-based and/or compostable disposable food ware at universities and other semi-public institutions (USDA, 2012).

The potential of public procurement has also been realised in the EU, where public authorities spend 16per cent of GDP on publically procured goods and services annually. Launched in 2008, the Green Public Procurement program is a voluntary policy instrument that provides guidelines that aim to inform

Interventions to sustainably commercialize biomass residues

- FACILITATE APPROPRIATE DATA COLLECTION ON BIOMASS RESIDUES
- REGULATED LABELS AND CERTIFICATION
- INVEST IN LOCAL INFRASTRUCTURES TO ALLOW OPTIMAL AND SUSTAINABLE UTILIZATION OF BIOMASS RESOURCES
- ESTABLISH ADEQUATE WASTE MANAGEMENT INFRASTRUCTURES FOR BIO-BASED FOOD PACKAGING

National Action Plans. Member States determine their own implementation targets for the purchase of sustainable products. This has resulted in varying responses, including the Netherlands, who set its target on 100per cent green procurement in 2010 (OECD, 2013). The EU program, could improve its support for bio-based food packaging, by setting up a list with preferred products and materials, in which bio-based food packaging derived from biomass residues is included.

7.2 Improve and secure access to sustainable biomass resources

To ensure a reliable and affordable biomass feedstock that is competitive with fossil feedstock, supportive programs on a global scale are needed. If the market for bio-based food packaging products is to develop, the establishment of efficient, cost-effective supply chains, providing raw materials of known and consistent quality will be essential. The following policy instruments are recommended for improving and securing access to sustainable biomass resources:

Facilitate appropriate data collection on biomass residues

Reliable and adequate data on the generation of biomass in both developing and developed economies is required to make optimal use of resources available. At first, the quality of data collection on developing countries needs to be enhanced. Second, data collection should be accompanied by an assessment of the availability of the biomass residues for industrial purposes, such as food packaging.

For instance, the Biomass collection program of the U.S. National Renewable Energy Laboratory (NREL) collects data on biomass and biomass residues generation in the U.S., which is accessible for both private and public actors. It therefore indirectly contributes to accessibility of sustainable biomass resources. The program makes use of proxies to determine the availability of biomass residues for industrial purposes. It allocates 35per cent of crop residues for industrial purposes. Olivier Dubois, bio-economy expert of FAO, however, stresses that proxies should be used with great care, as utilization of biomass residues for maintaining soil fertility; feeding cattle and energy differ largely per local context (Dubois, 2016). Also in a report on bio plastics by OECD (2013) it is underlined that policy guidelines are required to safeguard sustainable use of biomass residues. The OECD report suggests that sustainability assessments of biomass resources should be based on all three pillars of sustainability: environment, economic and social (OECD, 2013). In a preferred program data collection is combined with a sustainability assessment.

Regulated labels and certification

Stringent labels can help to ensure that claims made for the properties of bio-based packaging materials (such as bio-baseness and compostability) are genuine and verifiable by consumers, waste management authorities and legislators. Certification schemes and standards are strong tools to inform consumers on the added value of a bio-based packaging material compared to a fossil-based material (OECD, 2013).

For instance, the U.S. established a certification system for bio-based products, referred to as ASTM D6866. The USDA certifies the bio-based content of products and awards labels (both domestic and non-domestic products) in order to include product categories in the program and increase consumer recognition. Within the EU, CEN is currently developing a European standard for bio-based products, including packaging. This includes assessing whether the ASTM standard, derived from the U.S. can be followed or whether improvements are necessary, for instance by also taking on board other components such as oxygen, nitrogen and minerals. Also in Japan and South Korea, certification schemes have been installed by the private sector to certify bio-based packaging and bio-based plastics (OECD, 2013).

In sum, policy support is needed to facilitate sufficient data collection on biomass availability and sustainability. Policy is furthermore needed to verify sustainability criteria's and labelling for bio-based food packaging.

Invest in local infrastructures to allow optimal and sustainable utilization of biomass resources

Commercialization of biomass generation and utilization is required to meet industrial demand and to substitute fossil-based with bio-based materials. Hence, local infrastructures for biomass need to be enhanced to allow for optimal and sustainable utilization of biomass resources. Moreover, opportunities exist to improve feedstock production in a sustainable way, through yield increase, reuse and degraded land, use of unused land, better land management and/or improved cropping system. Incentives for farmers to collect large quantities of agricultural residues that are generated on farms could help to ensure feedstock supply for bio industries, including for the production of materials for food packaging.

For instance, the U.S. established the Biomass Crop Assistance Programme. It provides payments to rural landowners to establish, produce and deliver biomass feedstock (particularly lignocellulose agricultural residues) to biomass conversion facilities for conversion to heat, power, bio-based products or advanced biofuels. BCAP provides financial assistance to owners and operators of agricultural and non-industrial private forestland who wish to establish, produce and deliver biomass feedstocks. The program provides two types of assistance:

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- *Matching payments may be available for the delivery of eligible material to qualified biomass conversion facilities by eligible material owners. Qualified biomass conversion facilities produce research, heat, power, biobased products, or advanced biofuels from biomass feedstocks.*
 - *Establishment and annual payments may be available to certain producers who enter into contracts with the Commodity Credit Corporation (CCC) to produce eligible biomass crops on contract acres within BCAP project areas.*
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Such a program as the U.S. set up the establishment of infrastructures and logistical capabilities to mobilise all biomass in an environmentally and economically sustainable way. These local infrastructures for biomass utilization can be supported via technical mobilisation of agricultural and forestry waste.

There are, next to financial interventions, also other policy instruments to facilitate and support local infrastructures and logistical capabilities for biomass industries. For example, part of the National Biomass Strategy, Malaysia set up a pilot study for joint venture (JV) collection clusters. JV clusters consist of a number of palm-oil mill owners in the same area to facilitate collaboration between the biomass producers and aggregate the biomass waste streams. The key idea is that the scale provided by the JV clusters will reduce the risk that would need to be taken by individual mill owners. Ideally, JV clusters take ownership in downstream industries, thereby giving the owners of biomass a share in the additional value creation. JV clusters can and should have different investment strategies, e.g., one might be regionally focused on producing bio-plastics from biomass residues, while another might take a complete portfolio perspective by supplying to all possible end users. It is imperative that such partnerships are biomass owner owned and controlled so that the owners are able to choose between different portfolios depending on their investment preference without interference. The government, however, can facilitate the establishment of such partnerships and provide capabilities, expertise and advice where required by the biomass owners (Agensi Inovasia Malaysia, 2013).

[Establish adequate waste management infrastructures for bio-based food packaging](#)

To reap the benefits of compostable food packaging materials, nations worldwide need to ensure that bio-based packaging materials can be composted. It means that countries need to improve their waste management infrastructures and make composting facilities readily for bio-based food packaging materials. Better use of compostable bio-based materials will help to divert organic waste from landfills and incineration to organic recycling. Ensuring composting is particularly relevant for bio-based food packaging, as most materials contaminated with organic residues cannot be recycled, and can only be landfilled or incinerated. Both scenarios are less environmental, and most often also less economically favourable. The recommendation is twofold: first, implement measures that obligate separate collection of bio waste, including bio-based packaging materials. Second, ensure adequate composting facilities in all countries.

The city of San Francisco installed an advanced policy framework to establish an infrastructure for composting, and to increase the rate of composting, which serves as an example. In 2009, the city of San Francisco passed the San Francisco Mandatory recycling and Composting Ordinance. In 2011, the city broke a global record on the quantity of waste composted with 600 tons of organic matter per day. San Francisco adopted an interesting model to offset the cost for collecting and composting all organic waste. The SF Zero Waste program is funded fully from refuse rates charged to customers (about 34 USD per residence per month in 2013, with a discount if you switch to a smaller black “landfill” bin). One company, Recology, handles the collection of the organic waste and passes it along to composting facilities. These facilities then sell the processed compost to everyone from small-scale residential gardeners to huge farms and wineries. The cost of collecting from three bins, including the bin for compostable matter, is entirely offset by selling the recyclables and the compost.

7.3 Mobilizing resources for research and development (R&D) for bio-based food packaging materials

Research will be a prominent tool in making bio-based feedstocks more competitive. Investment in production and R&D in Europe in the bio based food-packaging sector depends on a supportive policy framework. The following policy recommendations to mobilize R&D for bio-based food packaging materials are identified:

resource mobilization for R&D

- DEVELOP PUBLIC AND PRIVATE FUNDING MECHANISMS

While public funding could help, scope exist for leveraging private sector investment via the creation of public private partnerships (PPP) in the area of bio-based products (OECD, 2013). The public-sector research and development agenda should emphasize major technical and economic roadblocks that impede the progress of bio based industrial products. Research priorities should emphasize the development of bio-based products that can compete in performance and cost with fossil-based ones. Further case studies on food and bio-packaging chains should identify the trade-offs between various value chain actors, so as to improve the data on costs of food loss and waste, and quantify bio-packaging benefits.

For instance, the Bio-based Industries Joint Undertaking (BBI JU) initiative of the EU generates €3.7 billion funding via a Public-Private Partnership between the EU and the Bio-based Industries Consortium. Operating under Horizon 2020, it is driven by the Vision and Strategic Innovation and Research Agenda (SIRA) developed by the industry. The objective of the BBI Joint Undertaking is to implement a programme of research and innovation activities in Europe that will assess the availability of renewable biological resources and the development of new bio-refining technologies to sustainably transform these resources into bio-based products, materials and fuels¹. This project directly feeds the knowledge base on bio-based products made out of biomass waste. It for example, finances the project pulp2value, which concentrates on the potential value of residues of the sugar beet production (pulp2value, N.D.).

Furthermore, Japan has installed the Biomass Nippon Strategy in 2006, with the objective to accelerate utilization of biomass and to promote biofuels and bio plastics via financial support for R&D on bio-based industries. It contains a blend of policy instruments, including tax reductions such as property and corporation tax related biomass industrialization and well-developed certification programs to demonstrate the environmental benefits and safety of bio plastics (Ministry of Forestry, Fisheries and Agriculture, N.D.). The strategy has prompted car manufacturers to accelerate their levels of R&D into bio-based plastics, and to raise the bio-based content of their products. For instance, Toyota is planning to switch 20per cent of the plastics used in vehicles to bio-based plastics, and expects to help in its efforts to accomplish its company-wide goal of reductions in CO₂ emissions (Toyota, 2010). The results of Japan's policy instruments illustrates that this type of tax incentives can stimulate the uptake of bio-based alternatives in the private sector.

7.4 The International Coalition on bio-based and sustainable food packaging

In addition to enabling policies on country and city level, there is a need for an international coalition on bio-based food packaging. An international, but also multi-level coalition is important to foster an approach that focuses on the whole biomass value chain, from primary producers to end user and waste treatment. The coalition should focus on four main issues:

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- *Promote biobased food packaging as a function of sustainable development*
 - *Establish evidence on how better application of biobased food packaging can reduce food loss in an environmental friendly manner*
 - *Design guidelines for sustainably utilization of biomass resources*
 - *Provide recommendations on enabling and incentivizing policy frameworks for biobased food packaging*
 - *Communication and awareness raising about benefits of biobased packaging among wider public and decision makers*
-

Promote bio-based food packaging as a function of sustainable development

Sustainable Development Goal 12 promotes sustainable production and consumption patterns, which states: *“Governments, international organizations, the business sector and other non-state actors and individuals should contribute to changing unsustainable consumption and production patterns”*. Aligned, there are an increasing number of countries that adopted policies to support a more sustainable economy, also referred to as bio-economy. Most policies, however, lack a specific target for sustainable food packaging, whereas, it became apparent that the vast majority of sustainable food packaging materials are produced and consumed in an unsustainable manner. While food packaging has an important role to play in achieving SDG 2 in addition to SDG 12. SDG2 reads: *“End hunger, achieve food security and improved nutrition and promote sustainable agriculture”*. The fact that sustainable food packaging clearly contributes to achieving SDGs therefore calls for the establishment of an international coalition that shows how sustainable and bio-based food packaging fosters sustainable development.

Establish evidence on how better application of bio-based food packaging reduces food loss in an environmental friendly manner

It became apparent that there is a limited understanding of the actual environmental and economic benefits and costs of food packaging solutions. The international coalition should therefore clarify this by taking action in a number of ways. First, and foremost, there is a strong need for an international and harmonious methodology to assess the environmental, economic and social of a packaging material and to compare the outcomes of different assessments. Currently, there is a rough guideline for conducting Life Cycle Assessment (LCA), which hinders comparison of the LCA outcomes. Main elements for a global standard to address are general impact categories, fixed assessment of biomass residues as a feedstock and inclusion of litter as an actual end-of-life scenario. Second, in addition to the assessment methodology, there is need to increase the number of LCAs and case-studies applied to food packaging solutions, because of their unique properties. For instance, food-packaging materials can hardly be recycled, have a short use-life and a high chance of being littered, which might not be reflected by LCA studies on bio-based materials, and not specifically to food packaging. Third, there is a need to overcome

the technical barriers to bio-based food packaging derived from biomass residues. Knowledge on bio-based solutions and technical innovations should be promoted and provided by the international coalition.

Design guidelines for sustainable utilization of biomass and biomass residues

One of the main challenges is sustainable production and efficient utilization of biomass, without overexploitation. Production increase and a better use of biomass, including residues, are both required. A guiding principle towards more efficient use of biomass in the wood sector is the idea of cascading use, a strategy to use a material in the most resource-efficient manner, as many times before it is used as energy. There is, however, potential for increased cascading use and clarification on how it can be practically applied to different biomass resources, including food waste and agriculture. Moreover, stringent guidelines are needed to avoid harmful competition for biomass residues between bio-based industries, the food sector and natural conservation.

Provide recommendations on enabling and incentivizing policy frameworks for bio-based food packaging

Both cities and nations have the capability to institute enabling and incentivizing policy instruments for bio-based food packaging. Hence, it is important that cities exchange their lessons learned in reducing consumption and production of unsustainable food packaging materials and promoting sustainable alternatives, such as bio-based and compostable materials. Hence, cities and countries with an urgent need to tackle the environmental and economic burden caused by food packaging, and countries and cities that instituted effective policy instruments to support the market bio-based food packaging should be part of the coalition. The coalition should provide communication services by organizing conferences on supportive policies for bio-based packaging and design guidelines for enabling and incentivizing policy frameworks.

Communication and awareness raising about benefits of bio-based packaging among wider public and decision makers

Engagement and awareness among policy makers on the role of food packaging in achieving the SDGs is needed on local, national and international level. The international coalition could provide unambiguous, harmonious and clear information on the costs and benefits of sustainable biobased food packaging. It furthermore could include an overview of the main challenges and opportunities to substitute fossil-based with biobased food packaging.

Raising public awareness about the biobased and compostable alternatives to fossil based food packaging can include beginning an information campaign directed at the public in the most polluting cities. Additionally, cooperation to improve legitimacy and market pull for sustainable bio-based food packaging, via joint public dialogue campaigns, is needed. Furthermore, a dialogue with civil society and the interested public to make the transition to biobased and compostable food packaging and its role in achieving shared vision of a sustainable future is needed. We will introduce bioeconomy topics into ongoing discussions on how to achieve the Sustainable Development Goals at the international and national levels.

Suggested stakeholders for the international and multi-level coalition on bio-based food packaging

This section suggests what stakeholders can be included in a coalition for bio-based food packaging to ensure the international and multi-level component of the coalition, including but not limited to;

- International Organizations
- Governments
- Research institutes
- The packaging sector
- The food sector

International Organizations

International organizations have the capability to approach issues, such as bio-based food packaging, with an interdisciplinary and international approach, which is highly recommended in case of bio-based packaging.

Food and Agriculture Organization (FAO)

Indications are that FAO has a unique potential to deploy its interdisciplinary knowledge on forestry, agriculture and food industries into a concerted effort to capture the many opportunities in bio-based packaging. FAO also has the important mandate to particularly take the needs and interests of developing countries into consideration. Hence, it should take a lead in the coalition and ensure that both developing and developed countries and cities can participate in a global transition to bio-based food packaging and its contribution to sustainable development.

The European Bio-based Industries consortium (BBI)

The BBI is a public-private partnership in the EU with the objective to facilitate the transition of an European industrial sector depending on fossil-based resources to bio-based feedstock. Hence, they can contribute their expertise to the purpose of substituting fossil-based food packaging with bio-based food packaging also meets their interest.

United Nations Environment Programme (UNEP)

UNEP works to promote resource efficiency and sustainable consumption and production (SCP) in both developed and developing countries. The focus is on achieving increased understanding and implementation by public and private decision makers, as well as civil society, of policies and actions for resource efficiency and sustainable consumption and production. This includes the promotion of sustainable resource management in a life cycle perspective for goods and services.

Governments

Governments on both country and city level act as regulators and should exchange lessons learned on implementing enabling and incentivizing policy frameworks for bio-based food packaging. They can take an active role in the establishment of guidelines for supportive policies on bio-based packaging.

Country-level: China, The Philippines, Thailand, Vietnam, and Indonesia

A recent study of Mc Kinsey and Ocean Conservancy points out that only 5 countries are responsible for 60 per cent of the plastic debris in the marine environment. Finding appropriate strategies for tackling the plastic pollution originating from the food and beverage sector in those countries therefore becomes especially relevant.

City level: San Francisco

Cities are key actors in developing an international coalition. Mutual learning within and between cities and more resources for peer-to-peer exchanges at the international level are essential. San Francisco could serve as a showcase of a city that instituted an advanced policy framework for promoting bio-based food packaging. In 2006, the city instituted a ban on Extruded Polystyrene (EPS) food packaging, and actively promoted bio-based, compostable and/or recyclable alternatives. Furthermore, in 2009, the city enacted the recycling and composting ordinance, which resulted in a well-established composting infrastructure that processes bio-based materials.

Research institutes

Research institutes can deploy their expertise on technical innovations and creative solutions on bioconversion technologies, bio-based packaging and mobilisation of biomass resources. Research and innovation is needed to overcome the key barriers to bio-based food packaging, and the coalition should ensure that this information is publically available and provided to the key stakeholders in the value chain for bio-based food packaging.

Wageningen UR: Bio-based and food research department

Wageningen UR Food & Bio based Research has an excellent expertise in developing chemicals and materials that use biomass instead of fossil resources. Their in-depth knowledge on bio-based products, chemicals and materials covers the entire chain, from raw materials through processing to end product.

Nova Institute

Nova Institute is a private consultancy firm. It has expertise and knowledge on feedstock supply, techno-economic evaluation, market research, dissemination, project management and policy for a sustainable bio-based economy. They, furthermore, provide communication services, by facilitating and organizing conferences on bio-based packaging and recent technological innovations.

Consultancy companies

Consultancy firms indicates both the industry of, and the practice of, helping organizations improve their performance, primarily through development of plans for improvement. In other words, consultancy firms have the unique capability to assist the value chain of food packaging to improve their sustainable performances.

Mac Arthur Foundation

Mac Arthur Foundation has a program on 'Climate Solutions', meaning that it has expertise on environmental sustainability. It published a report, in collaboration with the World Economic Forum, titled The New Plastic Economy, in which a variety of strategies to reduce pollution caused by plastic waste are discussed.

World Economic Forum

World Economic Forum is a not-for-profit organization that publishes reports on three key areas: mastering the Fourth Industrial Revolution, Solving the problems of the Global Commons and Addressing global security issues. It recently published a report The New Plastic Economy, in collaboration with the Mac Arthur Foundation, illustrating their interest and expertise in plastic packaging.

Non-governmental organizations (NGOs)

NGOs are needed for to address and represent social and environmental concerns related to bio-based packaging, sustainable utilization of biomass and the establishment of appropriate waste management infrastructures.

Sustainable packaging coalition (SPC)

The SPC promotes sustainable packaging solutions, including bio-based and compostable solutions, along the value chain. It provides a forum for supply chain collaboration, share best practices and designs guidelines, support innovation an effective new technologies and education, resources and tools to promote sustainable packaging.

World Wildlife Fund (WWF)

WWF works with business and industry to help them make informed, sustainable material choices for their products and packaging. Their work focuses on the major commodities that go into packaging, which come in many different forms and materials, and how to integrate sustainability into the decisions and trade-offs that must be evaluated across a product's lifecycle.

Surf rider Foundation

Surf rider Foundation is an NGO that campaigns for a clean marine environment. Plastic pollution of the marine environment is one of their focus areas, in which they highlight enabling and incentivizing policy frameworks to tackle plastic leakage in the marine environment.

The packaging sector

The packaging sector needs to promote and implement bio-based packaging solutions along the packaging value chain. It furthermore can channel knowledge on innovations on bioconversion technologies along the value chain and assist in the establishment of case studies on how better application of bio-based food packaging reduces food loss in an environmental friendly manner.

Asian Packaging Federation (APF)

The objective of APF is to enhance cross-country co-operation among all packaging-related bodies, covering a gamut of subjects like training and education, package development, environmental aspects as well as laws and regulations.

African Packaging Organisation (APO)

The objective of APO is to promote effective and sustainable packaging solution to its countries. It commits itself to the promotion of environmental; friendly packaging and management of packaging waste;

World Packaging Organisation (WPO)

The WPO promotes education on packaging through meetings, special activities and publications, including this web site; to sponsor an international packaging design awards program; and to facilitate contact and exchange among the various national institutes of packaging.

Food sector

The food sector represents the end-user of the packaging product. Hence, it becomes highly relevant that the food sector is encouraged to substitute fossil-based food packaging with bio-based food packaging. Moreover, the food sector has to provide feedback on the functionality of bio-based food packaging.

The Bio-plastic Food Alliance (BFA)

The BFA was formed by some of the world's leading consumer brand companies as a precompetitive, multi-stakeholder forum focused on increasing awareness around the environmental and social performance of potential feedstock sources for bio-based plastics. Founding members of the BFA include: The Coca-Cola Company, Danone, Ford Motor Company, Nestle, Nike, Inc., P&G and Unilever. These global companies, together with respected academic and NGO thought leaders, are all committed to using informed science and critical thinking to help guide the responsible selection of feedstocks for biobased plastics in order to encourage a more sustainable flow of materials, helping to create lasting value for present and future generations.

Food processing companies

Unilever and Mars are both global leaders in the food sector. Mars, for instance, has recently entered into a partnership with Rodenburg Polymers to develop bio-based packaging for their candy bars. It shows their interest and investment potential in bio-based packaging solutions and serves as a example to the whole food industry.

8. Way forward for FAO

With its expertise and resources, FAO is well positioned to support countries in achieving the SDGs. FAO has a unique potential to deploy its inter-disciplinary knowledge on forestry, agriculture and food industries into a concerted effort to capture the many opportunities in bio-based packaging, and with contributions to the SDGs and strategic goals of the organization.

FAO could take a lead in the establishment of an international and coalition on sustainable and bio-based food packaging. FAO's international and interdisciplinary network and expertise enables the organization to mobilize all relevant stakeholders and support important activities of the coalition. It has the capacity and capability to develop guidelines for sustainable utilization of biomass and biomass residues. It might deploy its expertise in land-use management and include main interests of forestry, agriculture, environmental conservation and environmental management in both developing economies and developed economies. Within the coalition, and in collaboration with coastal cities, it could establish evidence on how better application of bio-based food packaging reduces food loss in an environmental friendly manner. Substituting fossil-based food packaging with locally sourced, sustainable and bio-based food packaging alternatives requires local level initiatives, which are often spearheaded by cities and sub-national administrations. These can be facilitated and initiated by the coalition. The establishment of the international coalition will lead to two organizational outcomes. First, agribusinesses and agrifood chains that are more inclusive and efficient are developed and implemented by the public and private sectors. Additionally, value chain actors are provided with technical and managerial support to promote inclusive, efficient and sustainable agrifood chains.

FAO has the mandate to support countries, particularly developing and emerging economies, to participate in a global transition to bio-based packaging in a way that contributes to sustainable development. The organization therefore could facilitate in the development and design of guidelines for enabling and incentivizing policy frameworks for bio-based food packaging that also suit the conditions of emerging economies and developing countries.

This report might serve as a starting point for FAO, as an exploration how food packaging can play a role in sustainable development. Now, the time has arrived to take action and facilitate a global transition from fossil-based to more sustainable, bio-based and compostable food packaging solutions.

Appendix A: Bio-based plastics approved for food contact

Table 2: Bio-based plastics approved for food contact in the EU (Food packaging Forum, 2014)

Starch-based polymers	Biodegradable polysaccharide Alternative for polystyrene (PS) Used in food packaging, disposable tableware and cutlery, coffee machine capsules, bottles
Cellulose-based polymers	Biodegradable polysaccharide Low water vapour barrier, poor mechanical properties, bad processability, brittleness (pure cellulosic polymer) Regulated under <u>2007/42/EC</u> Coated, compostable cellulose films Used in the packaging of bread, fruits, meat, dried products, etc.
Poly lactide (PLA)	Biodegradable, thermoplastic polyester Possible alternative of low- and high-density polyethylene (LDPE and HDPE), polystyrene (PS), and poly terephthalate (PET) Transparent, rigid containers, bags, jars, films
Polyhydroxyalkanoates (PHA)	Biodegradable polyester Family of many, chemically different polymers Brittleness, stiffness, thermal instability
Biobased polypropylene (PP) and polyethylene (PE)	Non-biodegradable vinyl polymer Mainly based on sugar cane Identical physicochemical properties
Partially bio based (PET)	Alternative to conventional PET Up to 30per cent bio based raw materials Used in bottles
Bio based polyethylene furanoate (PEF)	Non-biodegradable aromatic polyester Better barrier function than PET Up to 100per cent bio based raw materials May be used in the future in bottles, fibres, films
Aliphatic (co)polyesters	Biodegradable polymers Include e.g. polybutylene succinate (PBS), polyethylene succinate (PES), and polyethylene adipate (PEA) Used in disposable cutlery
Aliphatic-aromatic (co)polyesters	Biodegradable polymers Include e.g. polybutylene adipate terephthalate (PBAT), polybutylene succinate terephthalate (PBST). Used as fast food disposable packaging, PBAT for plastic films
Polycaprolactone (PCL)	Biodegradable polyester Low melting temperature, easily biodegradable Used in medical applications, as PCL blends in FCMs

Polyvinyl alcohol (PVOH)	Biodegradable vinyl polymer Used for coatings, adhesives, and as additive in paper and board production
Polyamides (PA)	Non-biodegradable polymer Used in high-performance polymers, not commonly in FCMs
Others	Animal (chitosan) and protein (soy protein isolate, gluten and in) based bio plastics

Appendix B: Bans and ordinances for EPS food packages

Bans installed in cities in the United States (Adopted from Surf rider Foundation, N.D.)

CALIFORNIA - 65 Ordinances that cover restaurants:

- Alameda (2008) Expanded polystyrene ban, requirement that all takeout food packaging be compostable or recyclable.
- Albany (2008) Expanded polystyrene ban, requirement that all takeout food packaging be compostable or recyclable.
- Belmont (2012) Expanded polystyrene ban that is essentially an extension of the San Mateo County ordinance, adopted by reference and effective October 2012.
- Berkeley (1988) One of the first EPS foam foodware ordinances passed in 1988 and effective January 1990.
- Burlingame (2011) Expanded polystyrene ban referencing San Mateo County's ordinance on May 16, 2011 and effective January 2012.
- Calabasas (2008) Expanded polystyrene ban, requirement that all takeout food packaging be returnable, recyclable, biodegradable or degradable. [Click here for details](#).
- Capitola (2012) Prohibits the sale of expanded polystyrene products as part of the 2009 Plastics Ordinance that was expanded in 2012.
- Carmel (1989) Expanded polystyrene ban for restaurants passed in 1989.
- Carpinteria (effective September 1, 2009) Ban on non-recyclable plastic food takeout containers, including expanded polystyrene. Chapter 8.5 of Municipal Code.
- Dana Point (adopted February 21, 2012) Ban on expanded polystyrene food containers. Effective six months after adoption date.
- Del Ray Oaks (effective July 1, 2010) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable.
- El Cerrito - On September 17th, the El Cerrito City Council finalized a polystyrene foam foodware ordinance for restaurants. Effective January 1st, 2014.
- Emeryville (2008) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable.
- Fairfax (1993) Expanded polystyrene ban for all restaurants and food retail vendors. Title 8.16 of Municipal Code.
- Foster City (effective April 1, 2012) Polystyrene ban for restaurants and food vendors, adopted October 17, 2011.
- Fremont (effective January 1, 2011) Expanded polystyrene ban for food vendors, requirement that all takeout food packaging be recyclable or compostable.
- Half Moon Bay (effective August 1, 2011) Half Moon Bay passed an ordinance, referencing San Mateo County's polystyrene food container ban, on May 17, 2011.
- Hayward (effective July 2011) Expanded polystyrene ban for restaurant vendors, requirement that takeout food packaging be recyclable or compostable.
- Hercules (2008) Expanded polystyrene ban. Sec.5-3109, Title 5, Chapter 3 of Municipal Code.
- Hermosa Beach (2012) Polystyrene container ban. Effective March 2013.

- Laguna Beach (2008) Polystyrene ban, requirement that all plastic takeout food packaging be recyclable. Title 7.05 of Municipal Code.
- Livermore (2010) Food vendors are required to use recyclable or compostable takeout food packaging.
- Los Altos Hills (February 1, 2012) Ban on eps and non-recyclable plastic food containers.
- Malibu (2005) Expanded polystyrene ban. Title 9.24 of Municipal Code.
- Manhattan Beach (2013) In September 2013 the Manhattan beach updated their CFC processed polystyrene food packaging ban from 1988. The new ordinance bans foam and clear polystyrene containers at restaurants.
- Marin County (effective January 1, 2010) Expanded polystyrene ban.
- Marina (2011) Expanded polystyrene food container ban. Requires the use of recyclable or compostable takeout food packaging unless alternatives are unavailable.
- Menlo Park (2012) Adopted San Mateo County ordinance by reference in August of 2012. Effective 11/1/12.
- Millbrae (2008) Polystyrene ban, requirement that all plastic takeout food packaging be recyclable or compostable.
- Mill Valley (2009) Food vendors and city facilities are prohibited from using expanded polystyrene foam food containers.
- Monterey City (2009) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable.
- Monterey County (effective November 2010) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable. Title 10, Chapter 10.42 of Municipal Code.
- Morgan Hill (2014) In October 2013, Morgan Hill City Council approved an expanded polystyrene foodware ban similar to other ordinances in Santa Clara County. Effective April 22, 2014.
- Newport Beach (2008) Expanded polystyrene ban. Title 6, Section 5 of Municipal Code.
- Novato (2013) City Council approved a polystyrene foodware ban for restaurants in May 2013 that is effective January 1, 2014.
- Oakland (2007) Expanded polystyrene ban, requirement that all takeout food packaging be compostable. Businesses that generate a large portion of litter must pay a litter fee. Title 8.07 of Municipal Code.
- Pacific Grove (2008) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable. Title 11, Chapter 11.99 of Municipal Code.
- Pacifica (effective January 1, 2010) Expanded polystyrene ban.
- Palo Alto (effective April 22, 2010) Expanded polystyrene ban.
- Pittsburg (1993) CFC processed polystyrene ban. Title 8.06.210 of Municipal Code.
- Portola Valley (effective October 25, 2012) Polystyrene ban (San Mateo County ordinance).
- Pleasanton - In April 2013 Pleasanton City Council passed an expanded polystyrene foam ban for food vendors effective July 2013.
- Redwood City (effective January 1, 2013) Polysytrene ban (San Mateo County ordinance).
- Richmond (effective August 5, 2010) Polystyrene ban, requirement that all plastic takeout food packaging be compostable.
- Salinas (passed August 16, 2011) Expanded polystyrene ban on takeout containers
- San Bruno (effective April 1, 2010) Polystyrene ban, requirement that all plastic takeout food packaging be recyclable or compostable.
- San Carlos (effective July 1, 2012) Adopted the San Mateo County ordinance by reference. Chapter 8.27 of Municipal Code.

- San Clemente (effective July 1, 2011) Government facility expanded polystyrene ban in 2004. City Council passed a citywide ban for food vendors in 2011.
- San Francisco (2007) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable.
- San Jose (2010/2013) Government facility expanded polystyrene ban for special events established in 2010. Citywide EPS foam ban for restaurants/food vendors passed in 2013.
- San Leandro (effective November 1, 2012) Expanded polystyrene food container ban, adopted October 2011.
- San Mateo City (2013) Ordinance includes a ban on all polystyrene foodware at food vendors with limited exceptions passed by City Council in May 2013.
- San Mateo County (2008 and 2011) Government facility polystyrene ban passed in 2008. An expanded ban for the rest of unincorporated San Mateo County was passed in 2011, effective July 1, 2011.
- San Rafael (2013) City Council passed a polystyrene foam ordinance in September 2012 that is effective September 2013.
- Santa Clara County (Effective February 1, 2013) The Santa Clara County Board of Supervisors adopted an eps takeout container ban for unincorporated parts of Santa Clara County on June 5, 2012.
- Santa Cruz City (2012) Ban on sale of all foam polystyrene products. Prior to 2012, the City banned the distribution of expanded polystyrene food containers, with a requirement that the food packaging be recyclable or compostable.
- Santa Cruz County (2008 and 2012) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable. Title 5, Section 46 of Municipal Code. The ban was expanded to prohibit the sale of all expanded polystyrene products in stores on April 17, 2012.
- Santa Monica (2007) Polystyrene ban with requirement that all plastic takeout food packaging be recyclable. Visit their website for more information.
- Sausalito (effective September 1, 2008) Food vendors and city facilities and events are prohibited from using expanded polystyrene foam food containers.
- Scotts Valley (2009) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable.
- Seaside (effective August 4, 2010) Polystyrene ban with requirement that all plastic takeout food packaging be recyclable or compostable.
- South San Francisco (2008) Polystyrene ban, requirement that all plastic takeout food packaging be recyclable or compostable.
- Watsonville (2009) Expanded polystyrene ban, requirement that all takeout food packaging be recyclable or compostable. Title 6, Chapter 6 of Municipal Code.
- West Hollywood (adopted 1990) Polystyrene ban for restaurants and food vendors.
- Yountville (1989) Expanded polystyrene food container ban.
- OTHER CA Ordinances and Mandates covering Government facilities or specific venues (10):
- Aliso Viejo (2005) Government facility expanded polystyrene ban. Ordinance #2004-060
- Huntington Beach (2005) Government facility and city-sponsored event expanded polystyrene ban. See page 12.
- Laguna Hills (2008) Government facility expanded polystyrene ban.
- Laguna Woods (2004) Government facility expanded polystyrene ban.
- Los Angeles City (2008) Government facility expanded polystyrene ban. Chapter IV, Article 13 of Municipal Code.
- Los Angeles County (2008) Government facility expanded polystyrene ban.

- Orange County (2005/6) Government facility expanded polystyrene ban.
- San Juan Capistrano (2004) Government facility expanded polystyrene ban.
- Sonoma County (adopted 1989) Government facility expanded polystyrene ban. Title 19, Section 19.6-1 of Municipal Code.
- Ventura County (2004) Government facility and county-sponsored event expanded polystyrene ban established by County Board of Supervisors 2004 resolution.

FLORIDA

- Bal Harbour (2014) Ordinance prohibiting polystyrene at all stores, restaurants and beaches.
- Bay Harbor Islands (2015) Ordinance prohibiting polystyrene in restaurants.
- Coral Gables (2016) Ordinance prohibiting use of polystyrene by chain stores, chain food stores, city vendors and at special events.
- Hollywood (1996) Ordinance prohibiting the use of all plastic single-use foodware at restaurants east of the Intercoastal Waterway
- Key Biscayne (2014) Ordinance prohibiting polystyrene on beaches and in local parks. Also prohibits city contractors and city facilities from utilizing polystyrene.
- Miami Beach (2014) Ordinance prohibiting the sale/use of polystyrene food service articles at all city parks, buildings, events and sidewalk cafes.
- North Bay Village (2015)
- Surfside (2015)

MAINE

- Statewide (adopted 1993) bans use of expanded polystyrene for serving individual portions of food or a beverage at a facility or function of the State or of a political subdivision unless containers are recycled (which is near-to impossible).
- Town of Freeport (1990) Town ordinance prohibits restaurants, retail food vendors, and town vendors from selling or serving prepared food in EPS products, and food packagers from packaging meat, eggs, bakery products or other food in EPS containers.
- City of Portland (adopted April 2015) - Ordinance bans sale and use of expanded polystyrene food and beverage containers.

MASSACHUSETTS

- Town of Amherst (2012) Town bylaw banning expanded polystyrene (EPS) foam foodware at restaurants in town. Effective January 1, 2014.
- Town of Brookline (2013) City ordinance banning all types of polystyrene foodware at restaurants passed November 2012 and effective by December 2013.
- Town of Great Barrington (1990) Town ordinance banning polystyrene food or beverage containers at retailers.
- City and County of Nantucket - more info needed.
- City of Somerville (2014) City ordinance bans the use of EPS foam containers and cups at takeout food establishments effective May 2014.
- Town of Williamstown (2015) ordinance prohibits retailers from sale, use and distribution of foam and rigid polystyrene in packaging material and food service ware, including straws, but adds

exceptions for biodegradable, marine-degradable, compostable, reusable, and recyclable products.

NEW JERSEY

- Rahway (1997) City ordinance bans retail food vendors located within the City of Rahway from selling, giving or providing eating utensils or food containers to any consumer within the City of Rahway if said eating utensil or food container is composed of polystyrene or polyvinyl chloride.

NEW YORK

- Albany County (2014) County legislators passed an expanded polystyrene ban for chain restaurants with 15 or more locations nationwide. Passed in November 2013 and effective May 2014.
- City of Glen Cove (1988) City ordinance banning all types of polystyrene foodware at restaurants.

OREGON

- Portland (2008) City ordinance prohibits restaurants and retail food vendors from serving prepared food in styrofoam products (both on premises and take-out), exempts non-profits. Part of the city policy of the City of Portland to reduce the amount of solid waste, both generated and disposed of, by promoting aggressive waste prevention and recycling activities.

TEXAS

- San Marcos (2012) City ordinance prohibits any person to use, carry, dispose, or possess styrofoam products in any city park or in or upon the waters of the San Marcos River. Styrofoam products include but are not limited to coolers, ice chests, cups, plates, toys, floats, kickboards, rings or swimgear. (Styrofoam linings used as floatation devices or dock supports are exempt from this section if fully encapsulated by water-based acrylic or latex coating, or fully enclosed within the structural framework of a boat.)

WASHINGTON

- Issaquah (2009) City ordinance banning all types of polystyrene foodware at 'food service businesses' such as restaurants, food trucks, etc.
- San Juan County (2010) County ordinance banning expanded polystyrene foam foodware at 'food service businesses.'
- Seattle (2009) City ordinance banning all types of polystyrene foodware at restaurants in phases.

WASHINGTON DC

- The Washington DC City Council (2014) passed the Sustainable DC Omnibus Act of 2013, including a ban on EPS foam.

Additional bans found outside the United States

INTERNATIONAL

- Guyana (2014) In August 2013, the Government announced plans to ban expanded polystyrene foodware effective in May 2014 (Surfrider Foundation, N.D.)
- Haiti (2012) Haiti's government ordered a plastic bag and foam foodware ban effective October 2012 but early reports claim a lack of enforcement as alternatives are sourced (Surfrider Foundation, N.D.)
- Philippines (2013) - The Philippines financial capital of Makati has banned disposable plastic shopping bags and EPS foam food containers starting in June 2013. The law is partly to help deal with increased flooding from plastic litter (Reilly, J. 2013)
- Toronto-Canada (2007) began a ban on Styrofoam packaging products in 2007. It was the first city in Canada to officially begin the ban on plastic products. The process began with extra charges on stores and restaurants using plastic or foam products. Today, retailers face steep fines for breaking the city's ban (Erikson, N.D.)
- Paris- France (2007) installed ban on Styrofoam in 2007 (Erikson, N.D.)
- Corsica-France (1999) the first to ban foams in 1999 in France. (Erikson, N.D.)
- Taiwan (2015) The Environmental Protection Administration (EPA) placed a ban on disposable tableware, including polystyrene foam containers, and plastic bags in 2015 (Ming-husan and Wu, 2015)
- Malaysia- (2013) The town of Sibu in the Sarawa region instituted a ban on EPS food and beverage packaging. (Tan Ker Wei, 2014).
- Antarctica (1978) The Antarctic Conservation act of 1978 contains a ban for styrofoam on Antarctica (Erikson, N.D.).

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