Open-BIO

Opening bio-based markets via standards, labelling and procurement

Work package 6

Managed end-of-life options

Deliverable N° 6.1:

Review on centralized composting

Public

Version: 1

Gent, Apr-30-2014

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This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No KBBE/FP7EN/613677.

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List of abbreviations, acronyms and used terms

ABA	Australasian Bioplastics Association
ABNT	*Associação Brasileira de Normas Técnicas* (Brazil)
AFNOR	*Association Française de Normalisation* French National Organization for Standardization
ANSI	American National Standards Institute
AS	Australian Standard
ASTM	American Society for Testing and Materials
Biowaste	Vegetable, garden and fruit waste (definition can vary from country to country)
BNQ	Bureau de Normalization du Québec
BPI	Biodegradable Products Institute
B2B	business-to-business
B2C	business-to-consumer
CEC	Cation Exchange Capacity
CEN	*Comité Européen de Normalisation* European Committee on Normalization
CIC	*Consorzio Italiano Compostatori*
DIN	*Deutsche Industrie Norm* German Industry Standard or German Standardization body
EN	European Norm
ISO	International Standards Organization
JBPA	Japanese BioPlastics Association
KBBPPS	Knowledge Based Bio-based Products' Pre-Standardization
NBR	*Normas Brasileiras*
NEN	*NEderlands Normalisatieinstituut* Netherlands Standardization Institute
NGO	Non-Governmental Organization
SWOT	Strengths, Weaknesses, Opportunities & Threats
TBT	Technical Barriers to Trade
WTO	World Trade Organization
WTT	Waste Treatment Technology

1 Summary

Application of standards, certification schemes and labels has positive long-term effects on the overall development of the European bio-based product market. Appropriate product information that presents correct claims to industry and public procurers is vital for the usage of these new products. Ensuring the sustainable sourcing of raw materials and the effective bio-based content are important additional steps for public confidence. Unambiguous data on their (comparative) functionality and the optimal possible end-of-life options, are needed to underline their positive impact compared to the regular products. Finally, public acceptance comes with clear and harmonized labels on products and packages.

The Open-BIO project aims at increasing the uptake speed of standards, labels and harmonized product information lists for bio-based products. It covers research and demonstration on direct and indirect methods for biomass content determination, biodegradability and eco-toxicity tests. Practical solutions for stakeholders, lab and field tests on for instance sampling or capability of being recycled or digested in a gasifier will be studied. Goal is to copy results one-to-one into European standards and product information lists. These form the basis for a database on bio-based products. A label will be developed in order to clearly distinguish bio-based products on the basis of the functionality laid down in standards. Both the information lists and the labels will be tested on their social acceptance via a set of target groups. New research on isotopes, marine biodegradation and intended end-of-life options such as digestibility and recyclability, distinguishes this project from an on-going FP7 project called KBBPPS. All partners thereof participate in Open-BIO. By participating in the Standardization Committee, CEN/TC 411, on "Bio-based products" (its Secretariat being one of the partners) and by doing pre- and co-normative research for them, Open-BIO allows the European stakeholders to progress.

The work described in this deliverable N° 6.1 “Review on centralized composting” is carried out within the framework of work package 6 “Managed end-of-life options” of the Open-BIO project and more specifically within task 6.1 thereof “Validation of current standards on centralized composting”.

The main objectives of the research towards centralized composting are to:

- Review critically existing standards and practice on centralized composting of (bio-based) products;
- Write a proposal in order to improve the European standards with regard to centralized composting.

This deliverable contains a critical review on available standards and practices and an evaluation of benefits and shortcomings. This research has not been limited to Europe, but was carried out on a worldwide basis.

The review was executed by OWS (leader) with help from Novamont, TUB and AUA.

Summarizing it can be stated that centralized composting (= industrial composting) can be considered as a reliable technology in order to convert organic waste to compost. Currently, industrial composting is a frequently applied technology in several countries and it is expected that the amount of industrial composted biowaste will further increase in the future.

A certain percentage of bio-based products introduced on the market can be treated by industrial composting. This might be the case for (bio-based) waste collection bags, plastics, packaging, teabags, coffee filters, food service ware (cups, plates, etc.), agricultural products (plant pots, clips and twines for climbing plants, etc.), fruit labels, etc. Bio-based solvents, bio-based lubricants and bio-based surfactants are not expected to end up in industrial composting installations, at least not in such amounts that they will influence the performance of the system.

Standards with specifications for industrial compostable materials were developed by the International Organization for Standardization (ISO), the European Committee on Normalization (*Comité Européen de Normalisation,* CEN), the American Society for Testing and Materials (ASTM), the Bureau de normalization du Québec (BNQ), Standards Australia, the *Associação Brasileira de Normas Técnicas* (ABNT), etc.

These standards were not particularly developed for bio-based products, but the definition of "a compostable product" as laid down in these standard specifications is also applicable for "a bio-based compostable product". No particular modifications are required for bio-based products.

The essence of the different standards with regard to industrial compostability is identical. They consist of four criteria which must be fulfilled in order to call a product compostable under industrial composting conditions: (1) chemical characteristics, (2) biodegradability, (3) disintegration and (4) ecotoxicity. However, some small differences exist between the developed standard specifications.

In a next phase of the project, a proposal will be developed in order to improve the European standards EN 13432 and EN 14995 with regard to compostable packaging and plastics, respectively. These standards were published in 2000 and 2006, respectively, and since the publication no revisions were carried through in spite of the fact that more experience has become available. The proposal will try to align the European standards with the recently revised international standards for compostable products (ISO 18606 (2013) and ISO 17088 (2012)).

Website: www.open-bio.eu

2 Introduction

This deliverable contains a review compiled as part of task 6.1 of the Open-BIO project. It serves the following purposes:

- Review on existing standards on centralized composting;
- Review on existing centralized composting practices;
- Definition of the need for further work and developments.

This deliverable, as part of the work carried out within the framework of WP 6 “Managed end-of-life options” of the EU Open-BIO project, aims to give an overview on the state of affairs in this field.

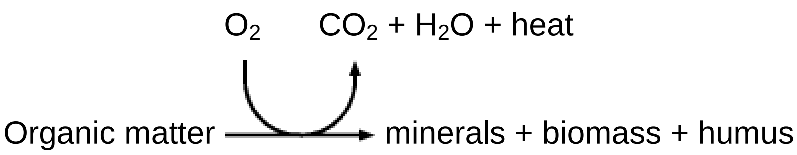
Chapter 3 contains information with regard to the principles and practices of industrial composting. Moreover, also factors affecting the composting process are discussed. Chapter 4 gives an overview of the existing standard specifications for industrial compostable products including a discussion of the differences between the standards. The existing labelling systems for industrial compostable products are summarised in Chapter 5. Finally, Chapter 6 gives a general conclusion and some first ideas for the development of a proposal for improvement of the European standards for industrial compostable products.

This deliverable focusses only on composting under centralized (= industrial) conditions. Composting under decentralized conditions (= home composting and farm composting) is not discussed in this deliverable.

3 Basics of industrial composting

3.1 Principle

Composting is the controlled biological transformation of organic waste under aerobic conditions, i.e. in the presence of oxygen, by indigenous micro-organisms such as bacteria, actinomycetes, yeasts and fungi. The degradation of the organic matter leads to the release of CO_2, H_2O and heat and to the production of plant-available minerals, biomass and humus [1,2,3].



According to the international standard ISO 15270 “Plastics – Guidelines for the recovery and recycling of plastics waste” composting is considered to be an organic or biologic recycling option for biodegradable plastics. There is generally no need to separate biodegradable contaminants such as foodstuffs or vegetable matter residues from the plastics that meet the biodegradability and compostability requirements of standard specifications with regard to compostable products.

In average, 65% of the organic matter is transformed during the 12 weeks of active composting under industrial conditions, resulting in a decrease in volume of approximately 50%. The remaining organic matter will degrade at a much slower rate, thereby slowly releasing nutrients for plant life, and the humus present in the compost improves the soil structure, by binding to the soil particles and as such providing a stable structure and good water retention in the soil. Hence, compost can be considered as a long-term biofertilizer on the one hand, and as a soil conditioner on the other hand. The high temperatures, which are reached during the industrial composting process, guarantee the kill off of pathogens and thus eliminate environmental risks when applying compost in soil [3,4,5].

3.2 Process

A schematic overview of the composting process is given in Figure 1 [6,7].

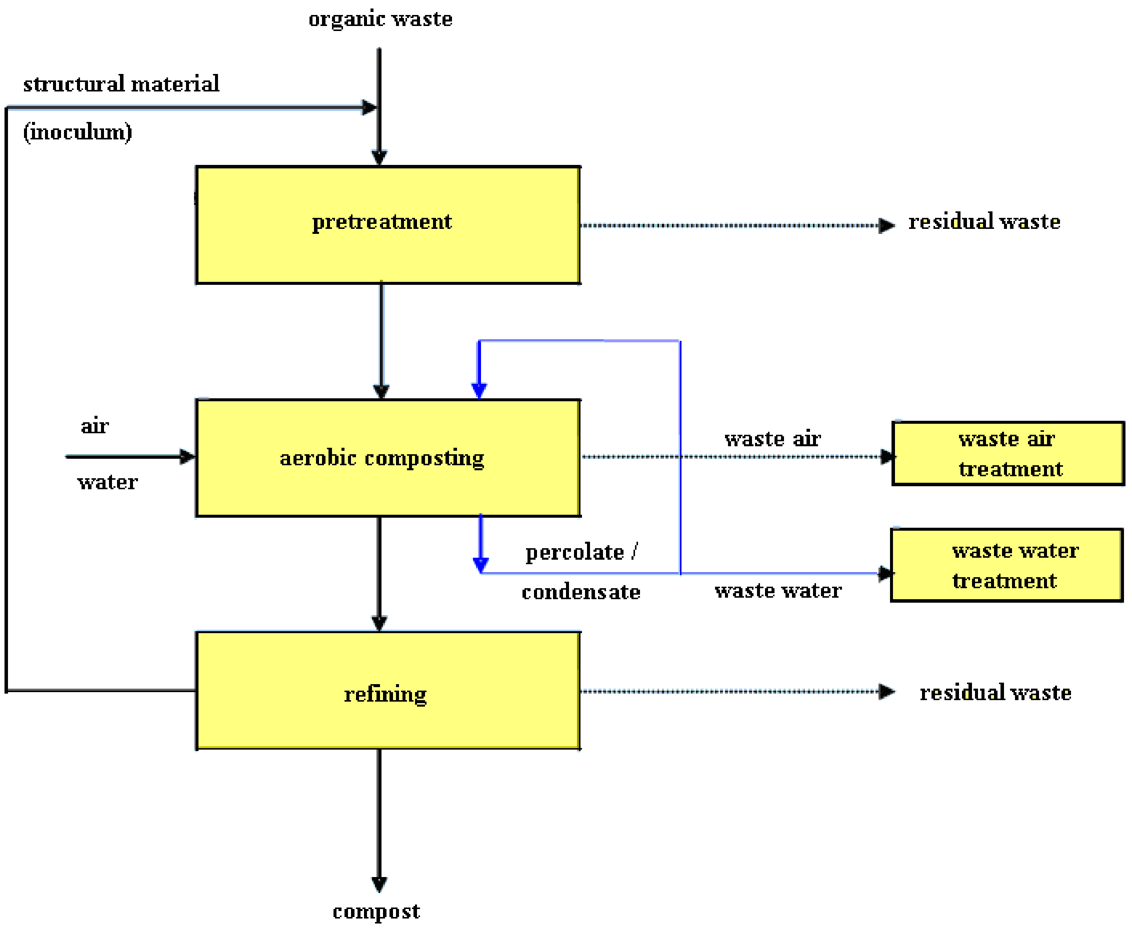


Figure 1. Schematic overview of the composting process.

3.2.1 Input

Organic fractions, characterized by a good or considerable biodegradability, can be used as input material for an industrial composting process. Some examples of suitable input materials are vegetable, garden and fruit waste, vegetable waste from agriculture, vegetable waste from the food sector, trimmings, clippings, shredded wood, digestate, etc. [8].

3.2.2 Pre-treatment phase

The pre-treatment phase is used to optimize the material characteristics of the waste, such as C/N ratio, moisture content and structure, as well as to remove contaminants and reduce obstructive materials that could hinder the composting process. Equipment which is used include tipping floors, front end loaders, bag openers, shredders, screw mills, mixing drums, screens, magnetic separators, grinding equipment, centrifuges for dewatering, etc. [3].

3.2.3 Composting phase

Based on the evolution in the microbial activity and the corresponding temperatures, the composting phase can be divided into two sub-phases: a first, high rate decomposition phase or preliminary phase and a second, slow rate decomposition phase, also known as maturation or stabilization phase (see Figure 2). The first phase yields a decontaminated but unstable intermediate called fresh compost, which is transformed into a ready to use matured compost in the second phase [3,9].

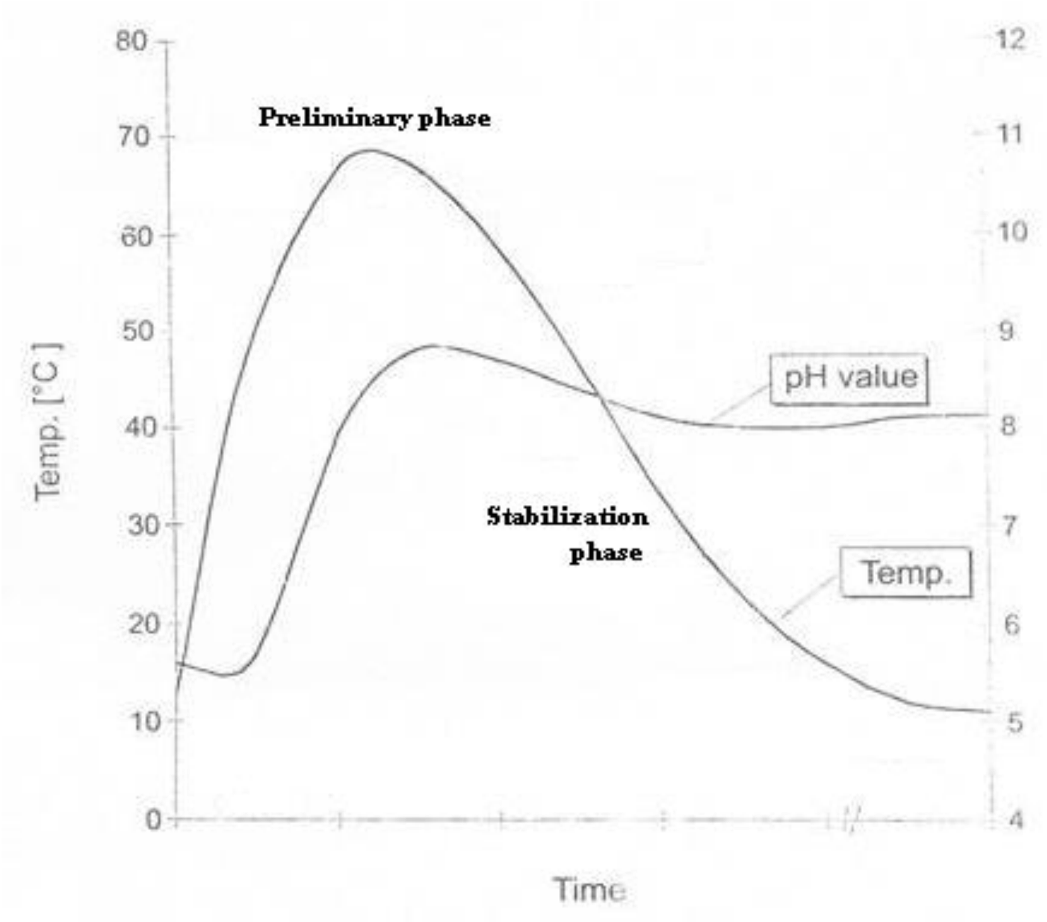


Figure 2. Typical temperature and acidity profile during composting.

3.2.3.1 Stability and maturity

The degree of maturation depends on the amount of readily biodegradable organic matter and can be expressed by the so-called ‘Rottegrad’, which is based on the potential heating ability of aerobic compost as shown in Table 1 [1,4].

Fresh compost is a hygienized product that still contains a significant amount of readily biodegradable organic matter. The resulting microbial activity can negatively affect plant growth since micro-organisms will compete for the use of oxygen and nitrogen and, moreover, they may partially attack plant roots. Therefore, fresh composts should be only readily applied in absence of plants, foreseeing a sufficient in-soil stabilization period between compost application and seeding [4,6].

Mature or stable compost has reached an advanced stage of decomposition and will thus contain only small amounts of readily biodegradable organic matter, resulting in a low and constant level of microbial activity. Full stability can only be obtained after a sufficiently long composting period, typically 12 weeks [4,6,10].

Table 1. Levels of Rottegrad based on the potential heating ability of compost.

Rottegrad	Maximum temperature	Product description
I	> 60 °C	Raw
II	50 – 60 °C	Fresh
III	40 – 50 °C	Fresh/Mature
IV	30 – 40 °C	Mature
V	< 30 °C	Mature

A generally-accepted, stricter definition of ‘stability’ and ‘maturity’ is not available and apart from the Rottegrad, several methods and corresponding parameters exist to describe the stability of compost, such as age, C/N ratio, cation exchange capacity (CEC), lipid extraction, carbon-dioxide evolution and mechanical or electronic oxygen-uptake [9].

3.2.3.2 Preliminary phase

After an initial incubation period of 0.5 to 2 days, the easily degradable material, like sugars and starch, are decomposed by bacteria at a high rate during a period of one or several weeks. During this period, effluents and noxious odours are generated and need to be strictly controlled and treated prior to the release in the environment. Temperature will initially rise to about 45°C in the so-called mesophilic incubation phase, after which it will further increase to 60-70°C in the so-called thermophilic phase. At temperatures around 58°C, the decomposition rate finds itself at its optimum. Hygienization of the material occurs when pathogens are killed and any seeds present are sterilized (see also chapter 3.3.3) [2,3].

3.2.3.3 Stabilization phase

Once the majority of the easily degradable materials starts to vanish, the bacterial activity slows down and temperatures will gradually drop off to a lower, stable level (approximately 40°C). It is the start of the much slower degradation of more complex materials, e.g. lignin (one of the basic substances of wood), by bacteria and, in particular, by fungi.

The duration of the preliminary phase and the stabilization phase varies in function of the composting system. Windrow and static pile systems are comparable in process time, while more complex composting systems (in-vessel composting systems, etc.) or composting systems with higher turning frequencies are characterised by a shorter duration. Some examples are given in Table 2.

Table 2. Duration of some industrial composting processes [11,12,13,14].

Example	Preliminary phase	Stabilisation phase
Windrow composting system	3 – 9 weeks depending on type of material and frequency of turning	
Aerated static pile composting system	3 – 5 weeks	
Windrow composting system covered with GORE™ Cover System (Central Europe)	8 weeks	
Windrow composting system covered with GORE™ Cover System (South Europe)	6 weeks	
Closed hall windrow composting system (WIPS - Belgium)	8 weeks	Some additional weeks
Tunnel composting	7 – 21 days	4 – 8 weeks (composting in piles)
Automated in-vessel composting system (Laois Council Canteen Composting Programme – Ireland)	2 weeks	4 – 6 weeks

3.2.4 Post-treatment

3.2.4.1 Sieving and recirculation

Whereas easily biodegradable substances are largely degraded during the preliminary composting phase, some other organic materials, e.g. woody substances, branches, shells, fruit peels, but also corncobs and hard plant leaves, will need a longer degradation period. Therefore, recirculation of these materials after the preliminary phase or even after the stabilization phase is necessary and is implemented by adding a sieving step, whereby the oversize fraction is sent back to the start of the process. Although the overall retention time is slightly increased by recirculation, it is an advantageous methodology: the recirculated wood and hard plant material improve the structure of the incoming waste (see also chapter 3.3.1.3) and consequently, the need for addition of extra structural material, which may be not readily available on site, is diminished.

3.2.4.2 Refining

The oversize fraction is removed and recirculated and the resulting compost is prepared for use. The compost is cleaned to remove all remaining impurities like plastics, ceramics, stones and glass, and is sieved according to the various commercial requirements. Bagging equipment may be used to pack products destined for the retail market. Bulk material for agricultural use is stored in sheltered areas awaiting seasonal application [3].

3.2.5 Output

At the end of the composting process mature compost is obtained. Compost can be used as soil amendment, fertilizer, mulch, etc. The most common markets are agriculture and horticulture [15].

In order to ensure the good quality of compost, national standards for compost have been set in Finland, the Flemish region, Germany and Italy. The criteria prescribed in these standards have been effective in making compost adequate for agricultural use, wholesale and private gardening [16].

The amount of produced compost will vary in function of the input material. When 1000 kg of vegetable, garden and fruit waste is composted, approximately 350 – 420 kg compost will be obtained at the end of the process [8].

3.3 Factors affecting the composting process

There are a number of factors affecting the composting process which should lie within an optimum range in order to ensure a rapid and effective composting process [2].

3.3.1 Material characteristics

3.3.1.1 C/N ratio

During composting, micro-organisms require carbon (C) for growth and energy and nitrogen (N) for protein synthesis. Optimum composting conditions are obtained at C/N ratios of 20 to 30. At higher C/N ratios, certainly above 40, the microbial population will lack nitrogen and the composting process will slow down. At lower C/N ratios, excess nitrogen will be released as ammonia (NH_3), causing odour and environmental problems [2,3].

As the C/N ratio entirely depends on the composition of the incoming waste and as such cannot be controlled, the C/N ratio can be adjusted in the pre-treatment phase by mixing different types of waste. Tree cuttings, paper and cardboard or biopolymers can be added in order to compensate for the rather low C/N ratio of grass or vegetable and fruit waste (see Table 3). During the composting process, the C/N ratio will gradually decrease to an average value of 10; the excess carbon is converted to and released as CO_2, yielding energy to the organisms [1,3].

3.3.1.2 Moisture content

The optimum moisture content of organic wastes for composting ranges from 45% to 55%. If the moisture content drops below 30%, all microbial activity stops. On the other hand, if the moisture content exceeds 70%, aeration of the organic waste becomes very difficult and an-aerobic conditions may prevail [2,3].

The moisture content can be adjusted in the pre-treatment phase by mixing different types of waste. During the composting phase, evaporation will naturally occur as a result of the elevated temperatures and aeration. The moisture content is then adjusted by water supply systems or via aeration. Approximately 100 litres per ton organic waste needs to be added during the composting process in a tunnel composting system. The humidity at end ideally lies between 30% and 35% [1,8].

3.3.1.3 Structure

A small particle size is advantageous for the composting process, as it provides a higher surface to volume ratio. At the same time, too fine material will result in compaction, loss of porosity, and therefore a higher chance on anaerobic conditions. Hence, the feedstock ideally contains a good mixture of fine materials, such as fruit and vegetable waste, and coarse or more porous materials, such as garden waste or mulch [2,3].
When the structure is too fine, a sufficient amount of coarse material should thus be added. The different types of materials are thoroughly mixed in the pre-treatment step by mixing

drums [3]. Some typical values for the C/N ratio, the moisture content and the structure of some biodegradable materials are given in Table 3.

Table 3. Main characteristics of some biodegradable materials.

Material	C/N ratio	Moisture content (%)	Structure
Optimum value	***20 – 30***	***45 – 55***	***Loose for air access***
Grass	12 – 20	80 – 90	Poor
Food, vegetable waste	12 – 25	70 – 90	Poor
Leaves	30 – 60	40 – 50	Average
Tree and bush clippings	100 – 150	Moist to dry	Good
Paper/paperboard	200 – 400	5 – 20	Average
Biopolymers	> 100	0 – 20	Average

3.3.2 pH value

A neutral pH is preferred, however, a lot of microorganisms can operate at pH values ranging from 5.0 to 9.0. During the composting process, a typical and self-regulated evolution of the pH value can be observed (see Figure 2) and problems do normally not arise as long as other factors, like aeration, are well maintained [2,4].

3.3.3 Temperature

In order to guarantee a sanitized, hygienically product and the exclusion of germs, industrial composting plants are legislatively bound to execute a certain period of composting at high temperatures (see Table 4). The international standard for the determination of the degree of disintegration of plastic materials (ISO 16929) prescribes temperatures above 60°C for at least 1 week. On the other hand, temperatures should not increase above 75°C, as this results in inhibition and/or die-off of the microorganisms. Optimum decomposition rates are reported to lie around 58°C [3,17,18].

Table 4. Legislation on hygienization in industrial composting.

Country	Required temperature	Required period
Austria	≥ 64°C	≥ 4 days
Germany: open system closed system	≥ 55°C or ≥ 65°C ≥ 60°C	≥ 2 weeks resp. ≥ 1 week ≥ 1 week
Denmark:	≥ 55°C ≥ 70°C	≥ 2 weeks ≥ 1 hour
Netherlands	depending on technology	

On European level no legislation is established with regard to hygienization requirements in industrial composting systems. In the Working Document “Sludge and biowaste” of the European Commission (21 September 2010) following sanitary restrictions for treated bio-waste related to the composting process were proposed:

- Windrow composting ensuring that all material maintains a temperature of at least 55°C for at least four hours between each turning. The heaps shall be turned at least three times and in any case a complete stabilisation of the material shall be reached,
- In-vessel composting ensuring that all material maintains a temperature of at least 55°C for at least four hours and reaches complete stabilisation.

The temperature is highly depending on the microbial activity (see also chapter 3.2.3). If necessary, the temperature can be increased (or decreased) by increasing (or decreasing) the aeration.

3.3.4 Aeration/Oxygen Supply

A continuous and homogeneous supply of oxygen is required to ensure overall aerobic conditions. A rule-of-thumb in the composting sector says that the organic waste must contain at least 30% of free air space to achieve optimum aeration [2].

3.4 Composting methods

Composting methods are manifold. Generally, the differences only concern the first phase of the composting process, i.e. the preliminary phase (see also chapter on the composting phase). The subsequent stabilization phase generally takes place in piles. Basically, a distinction can be made according to the handling or moving of the material, which can take place in batch (static methods, e.g. windrow composting, tunnel composting), semi-continuously (semi static methods, e.g. table composting) or continuously (dynamic methods, e.g. drum reactors) [1,4].

In Germany the composting systems were divided in different categories called “Baumuster”. An overview of these categories is given in Table 5.

In the following, the most important methods for industrial scale composting will be discussed.

3.4.1 Composting in piles

3.4.1.1 Windrow composting

Windrow composting is a simple method with low investment costs and a low level of process control. In this method the waste is piled in triangular or rectangular heaps, which are turned to enhance aeration and homogenization (see Figure 3). The need of turning can be reduced by installing air piping under the pile, providing passive aeration (chimney effect) or aeration by over- or under pressure. The windrows can be placed in open air or in a closed hall (see Figure 3) [1,4,20].

When windrow composting is used for the treatment of fresh organic waste, it should be executed in closed halls, in order to control the effluents and noxious odours, which are released during the preliminary decomposition phase. For the stabilization phase, however, open air and roofed windrow systems are widely used, as its requirements for aeration, moistening and air control are less stringent [4].

Table 5. Overview Baumuster composting categories [19].

1	2	3	4	5	6		7
Boxes/ Container	**Briquets**	**Tunnel/ Line**	**Trommel**	**Windrows**	**Open Windrows**		**Windrow enclosed (Membrane-Cover)**
				Enclosed	**Open**	**Roofed over**	
1.1 Herhof boxen	**2.1** Brikollare (42 d)	**3.1** Gicom-tunnel	**4.1** Envital	**5.1** Horst-Horstmann/ Kompo Plus/ Sutco Kompoflex (7 w)	**6.1** Dreiecksmiete belüftet	**6.7** Tafelmiete, belüftet	**7.1** GORE™ Cover (6 w)
	2.1 A Brikollare (21 d)			**5.1 A** Horst-mann/ Kompo Plus/ Sutco Kompoflex (10 d)			
1.2 Biodegma		**3.2** Bioferm-tunnel		**5.2** Bühler Wendelin	**6.2** Dreiecksmiete unbelüftet	**6.8** Dreiecksmiete unbelüftet	**7.2** GORE™ Cover (14 d)
1.3 ML-container		**3.3** Geotec-tunnel (14 d)		**5.3** AE und Koch	**6.3** Tafelmiete (I), unbelüftet		**7.3** Humivit/Plus
1.4 BRV-boxen		**3.3 A** Geotec-tunnel (7d)		**5.4** Thyssen-Dynacomp	**6.5** Tafelmiete, belüftet		
		3.4 Linde KCA-tunnel		**5.5** Stratmann	**6.6** Tafelmiete (II), unbelüftet		
		3.5 Sutco-Biofix Zeile		**5.6** KNO Bremen	**6.9** WURM Komp-Aktiv		
		3.6 Horst-Horstmann WTT-tunnel					

Figure 3. Open air windrow system (left) and a closed hall windrow system (right).

3.4.1.2 Table composting

Table composting takes place in a hermetically sealed composting hall, in which the bio-waste is piled up into a stack and constantly aerated through perforated floor panels. A fully automatic turning machine moves the organic matter from one end where new shredded organic matter is added to the other end where the finished compost can be removed (see Figure 4 and Figure 5). The resulting outlet gas can be cleaned using a biofilter. It takes 8-12 weeks for the compost to mature [5,21].

Figure 4. A fully automated turning machine.

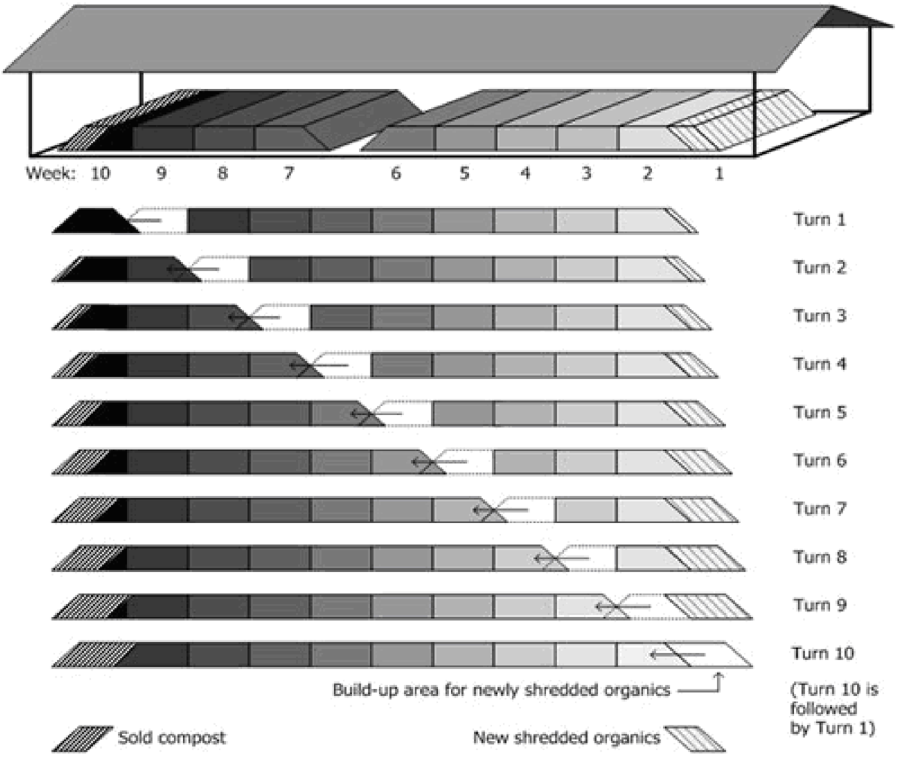


Figure 5. Schematic overview of turning of table composting piles.

Compared to windrow systems, compost tables have the advantage that they allow a semi-continuous composting process, while windrow composting is a batch process. Moreover, composting tables need less space, the aeration conditions are more homogeneous and aeration and watering can be adjusted according to the decomposition phase [5].

3.4.1.3 Row composting

Composting in rows is similar to table composting, differing only in the fact that the piles are subdivided and sheltered, creating several smaller closed tables next to each other. Compared to the table system, the system is less straight forward, but has the main advantage that the overall construction does not need protection against aggressive composting gases, and that each table can be monitored independently [4].

3.4.2 Tunnel composting

In this method preliminary decomposition takes place in closed tunnels or containers (also called biocell reactors). The tunnels can be loaded by wheel loaders or automatically, and are provided with aeration, moistening and temperature control systems. Because of their small volume, the method allows for a precise monitoring of process parameters and control of emissions. In some cases, the material is led through several tunnels and is sieved in between. Preliminary decomposition in tunnels takes between 7-21 days and produces a fresh compost, which can be turned into mature compost in about 4-8 weeks by composting in piles [1,4,22].

3.4.3 Drum reactors

One of the dynamic preliminary decomposition methods are drum reactors (Figure 6). The organic waste follows a helical course from entry to exit and is thoroughly and continuously rotated and mixed by the drum's revolutions. This is an advantage, since it allows the processing of composting feedstocks from all sources, with constant variations in type and composition. In the drum the stock is further comminuted in a selective and controlled manner, according to residence time [1].

Figure 6. Drum composting reactor [23].

3.5 Drivers

In Europe the Landfill Directive (1999/31/EC) obliges the Member States to reduce the amount of landfilled biodegradable municipal waste to 35% of the levels of 1995 by 2016 (for some countries by 2020). The Landfill Directive does not prescribe specific treatment options, but industrial composting is encouraged in the Waste Framework Directive (2008/98/EC). According to Article 22 of the Waste Framework Directive, each member state shall take measures to encourage (1) the separate collection of biowaste with a view to the composting and digestion of biowaste, (2) the treatment of biowaste in a way that fulfils a high level of environmental protection and (3) the use of environmentally safe materials produced from biowaste [24,25].

In Canada the responsibility for waste lies at provincial level, not at federal level. Composting is broadly supported amongst the Provinces although the development is limited in some Provinces due to large distances and low population densities. Especially in Provinces with high population densities (e.g. Ontario) composting is promoted [26].

In the United States of America the most significant driver of the initial growth in the compost market was the implementation of bans by over 20 states on organics being disposed of in landfills [27].

3.6 SWOT analysis

a. Strengths

Production of compost:

The produced compost is considered a soil improver. The application of compost improves the physical, biological and chemical soil properties and carbon is incorporated in the soil. Moreover compost is considered an organic fertiliser as it contains nitrogen, phosphate, potassium, magnesium and calcium. Finally compost can also be used in order to replace peat and bark in growing media. In growing media for hobby gardening 40 – 50 vol.-% compost can be used, while in growing media for professional use 20 – 30 vol.-% compost can be used [28].

Simplicity:

The industrial composting process is characterised by a higher simplicity when compared to anaerobic digestion. Therefore, composting technologies can be considered to be reliable systems in order to convert organic waste to compost.

Low investment cost:

Investment cost for industrial composting is lower when compared to anaerobic digestion.

b. Weaknesses

No energy production:

Whereas anaerobic digestion yields biogas (= energy), no energy is produced during the composting process. In contrast energy is required for the turning and the aeration of the compost.

Air emissions during the process:

During the composting process gaseous emissions (e.g. carbon dioxide, ammonia, volatile organic compounds, bio aerosols, particulates, methane, nitrous oxide, etc.) can be formed, which are often associated with odour emissions. The emissions can be reduced in closed systems using biofilters. In open systems, however, industrial composting can lead to emissions and odour.

Difficulties in marketing:

Compost producers have often difficulties in the marketing of their product due to a lack of understanding of potential use sectors. When compared to competing products, declaration, advertisement and marketing are often less developed [28].

c. Opportunities

Reduction of biowaste going to landfills:

Composting is a valid recovery route for biowaste in order to reduce the amount of landfilled biowaste.

d. Threats

Replacement by end-of-life systems with energy recuperation:

The energy of the biowaste is lost during the composting process. From energetic point of view alternative techniques (e.g. anaerobic digestion) will be more suitable.

Price of compost:
The price of bulk compost is still lower than the production costs (i.e. the costs of treating biological wastes in a composting plant). In central Europe the price for compost for agricultural use is rarely higher than 5 euro per tonne compost, while the cost for composting is estimated at 35 to 60 euro per tonne of waste for best practice plants in closed systems and 20 euro per tonne of waste for low tech windrow composting. The sale of compost becomes more difficult in countries where there exists a competition with manure (e.g. Belgium, The Netherlands). The low price of compost forms a limitation to the distances over which the transport of compost for applications in agriculture is still possible from economic point of view [28].

3.7 Outlook

Composting is currently applied as a stand-alone process or as a stabilisation phase after an anaerobic digestion process. During the last years the capacity at composting and anaerobic digestion plants has increased significantly in several European countries (Finland, Germany, Hungary, Italy). For the future, it is expected that the amount of industrial composted bio-waste in Europe will increase from 18.7 Mt in 2008 to 27.6 Mt in 2020, which corresponds to an increase of 48% (baseline scenario) [16,29].

Currently approximately 60% of the Canadian population have access to composting (350 composting facilities) and it is anticipated that the composting industry will further increase [26].

4 Standard specifications for industrial compostable products

The definition of products that are compostable under industrial composting conditions is laid down in several standards.

Formal standards are developed through a process of collaboration among stakeholders and they are approved and published by recognized standardization bodies. Three levels of formal standardization processes can be distinguished: national standardization conducted by national standardization bodies (like DIN, NEN, AFNOR, ANSI, ABNT, etc.), European standardization coordinated at CEN, and finally international standardization at the ISO level.

ISO, the International Organization for Standardization, is a network of national standards bodies, in which consensus on voluntary international standards is organized. Standards at ISO are usually developed in response to requests from industry or other stakeholders such as consumer groups. Its technical committees are made up of experts from the relevant industry, but also from consumer associations, academia, NGOs and government. These experts negotiate all aspects of the standard, including its scope, key definitions and content.

International standards are one way of overcoming technical barriers in international trade that may arise from differences among technical regulations and standards developed independently and separately by each country. The Agreement on Technical Barriers to Trade (TBT) obliges WTO Members to ensure that national regulations, standards, testing and certification procedures do not create unnecessary obstacles to trade. By referring to harmonized international standards, national legislators can take care that technical regulations conform to WTO rules. The European Commission, in co-operation with the national standardization bodies promotes the use of international standards and supports their transposition in the EU.

Furthermore, it is important to appreciate the advantages of European standardization in support of Community legislation and policies. Drawing on European standards allows for more flexible and less stringent forms of legislation in areas where, otherwise, any detail would have to be determined by the legislative act itself. CEN, the European Committee for Standardization, brings together the National Standardization Bodies of 33 European countries. The fact that each European Standard (EN) automatically also becomes the national standard in these countries makes it much easier for businesses to sell their goods or services to customers throughout the European Single Market. (This automatism explains why DIN V 54900 was withdrawn and replaced by DIN EN 13432.)

The standards with specifications for industrial compostable materials were developed by the International Organization for Standardization (ISO), the European Committee on Normalization (*Comité Européen de Normalisation,* CEN), the American Society for Testing and Materials (ASTM), the Bureau de normalization du Québec (BNQ), Standards Australia, the *Asso-*

ciação Brasileira de Normas Técnicas (ABNT), the German Institute on Normalisation (*Deutsches Institut für Normung,* DIN), etc.

An overview of standards on industrial compostability is given in Table 6 [30, 31]. These standards were not particularly developed for bio-based products, but the definition of "a compostable product" as laid down in these standard specifications is also applicable for "a bio-based compostable product". No particular modifications are required for bio-based products.

Table 6. Overview of standard specifications for industrial compostable materials.

Standard specification	Description
EN 13432 (2000)	Packaging - Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging
EN 14995 (2006)	Plastics - Evaluation of compostability - Test scheme and specifications
ISO 18606 (2013)	Packaging and the environment – Organic recycling
ISO 17088 (2012)	Specification for compostable plastics
ASTM D 6400-12	Standard Specification for Labeling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities
ASTM D 6868-11	Standard Specification for Labeling of End Items that Incorporate Plastics and Polymers as Coatings or Additives with Paper and Other Substrates Designed to be Aerobically Composted in Municipal or Industrial Facilities
CAN/BNQ 0017-088/2010*	Specifications for compostable plastics
AS 4736 (2006)	Biodegradable plastics – Biodegradable plastics suitable for composting and other microbial treatment
ABNT NBR 15448-2 (2008)	Degradable plastic packaging and/or plastic packaging from renewable sources – Part 2: Biodegradation and composting – Requirements and testing methods
DIN V 54900 (1997-1998)**	Testing of compostability of plastics

* CAN/BNQ 0017-088/2010 = ISO 17088 with Canadian deviation related towards marking and labelling.
**Withdrawal in February 2004 and replaced by DIN EN 13432 [32].

These norms all have a different geographical value. EN 13432 and EN 14995 are mainly referred to in Europe, while ASTM D 6400 and ASTM D 6868 are mainly in the United States, CAN/BNQ 0017-088 in Canada, AS 4736 in Australia and ABNT NBR 15448-2 (2008) in Brazil. ISO 17088 and ISO 18606 have a global character. The European standard EN 13432 is prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to support the implementation of the European Council and Parliament Directive on Packaging and Packaging Waste (94/62/EC). This implies that any product that fulfills the requirements of EN 13432 also fulfills the basic requirements for compostable packaging as they are laid down in the Directive on Packaging and Packaging Waste. EN 13432 has as such a harmonized character [33].

These standards are very similar in all essential aspects, but differ in certain details. All standards for industrial compostable materials consist of four criteria which must be fulfilled in order to call a product compostable:

Chemical characteristics: The product must contain at least 50% organic matter and may not may not exceed the heavy metal and/or fluorine limits as specified in

1. Table 7. The limit values for heavy metals and/or fluorine vary between the different standards. The ISO standards refer to the legislation in the country where the final product will be placed on the market or will be disposed of.

2. Biodegradability: The products should biodegrade for at least 90% (absolute or relative when compared to the reference) within 6 months under controlled composting conditions. Biodegradation, or mineralization, is defined as the conversion of the organic C to CO_2 and can considered to be the degradation on a chemical level. Consequently, this characteristic is linked to the chemical composition.

3. Disintegration: Unlike the other criteria, the third requirement refers to the physical form of the product instead of to the chemical composition. The product, under the form which enters the market, should, within a timeframe of 12 weeks, fragment sufficiently to visually undetectable components (< 2 mm) under controlled composting conditions. Consequently, this characteristic is linked to the thickness and the physical construction (e.g. laminate, coating, etc.) of the sample.

4. Ecotoxicity: The compost obtained at the end of the composting trial, eventually containing undegraded residuals from the product, should not pose any negative effects to the germination and growth of plants (and also earthworms in case of AS 4736).

Table 7. Heavy metal and fluorine limits as prescribed by different norms on compostability.

Element	Limit values (ppm on total solids)			
	Europe* EN 13432 (2000) EN 14995 (2006)	USA** ASTM D 6400-12 ASTM D 6868-11	Canada BNQ 0017-088/2010	Brazil NBR 15448-2
Zn	150	1400	463	150
Cu	50	750	189	50
Ni	25	210	45	25
Cd	0.5	19.5	5	0.5
Pb	50	150	125	50
Hg	0.5	8.5	1	0.5
Cr	50	-	265	50
Mo	1	-	5	1
Se	0.75	50	4	0.75
As	5	20.5	19	5
F	100	-	-	100
Co	-	-	38	10

* The elements as prescribed by EN 13432 are identical to the ones prescribed by AS 4736(Australia).
** Maximum levels for USA (according to ASTM D 6400-12 and ASTM D 6868-11 heavy metal content must be less than 50% of those prescribed for sludges or composts in the country where the product is sold).

Although the essence of the different standards with regard to industrial compostability is identical, some small differences exist. An overview of the main differences is given below.

1. Chemical characteristics:

It can be stated that the Brazilian norm is the most severe norm when it comes to chemical characteristics. The limit values of the Brazilian norm are identical to the limit values of the European norms (EN 13432 and EN 14995) and the Australian norm (AS 4736), but additionally a limit value for Co is determined.

The limit values of the European norms are based on the ecological criteria for the award of the Community eco-label for soil improvers (EC OJL, 219, 7.8.98, p. 39) and are set at 50% of the maximum concentration of those requirements.

The limit values of ASTM D 6400 and ASTM D 6868 are considerably higher when compared to the limit values of the European norms, the Australian norm and the Brazilian norm. Moreover, no limit values for Cr, Mo, F and Co are prescribed in the American standards.

The limit values of BNQ 0017-088/2010 are higher than the limit values of the European norms, the Austrian norm and the Brazilian norm, but lower when compared to the limit values of the American standard. Similar to the Brazilian norm also a limit value for Co is determined in the Canadian norm.

2. Biodegradability:

The European norms EN 13432 and EN 14995 are less severe when compared to the American and international standards. EN 13432 and EN 14995 prescribe that information on biodegradability of the material or each significant organic constituent (= any organic constituent present in more than 1% of dry weight of the final material) needs to be determined, and, in addition, it is defined that the total proportion of organic constituents without determined biodegradability shall not exceed 5%.

ISO 17088, ISO 18606 and ASTM D 6400 are more stringent. The ultimate aerobic biodegradability needs to be determined for the whole material or for each organic constituent. Constituents that are present at concentrations of less than 1% do not need to demonstrate biodegradability, but the sum of such constituents shall not exceed 5%. Moreover, additionally it is prescribed that for organic constituents that are present in the material at a concentration between 1% and 10% (by dry mass), the level of biodegradation shall be determined separately.

ASTM D 6868 is more stringent when compared to ISO 17088, ISO 18606 and ASTM D 6400 as it prescribes that the plastic coating as such must also meet the requirements of ASTM D 6400.

In the Australian standard AS 4736, even another approach is followed. It writes that biodegradability shall be determined for all organic constituents of the plastic as a total material including dyes, inks and colours.

Finally, the Brazilian norm NBR 15448-2 is also more stringent when compared to its European equivalents. It requires that each component of the packaging material (> 1% on dry mass of the packaging material) must have its biodegradability determined. Moreover, the sum of components without determined biodegradability may not exceed 5%.

There also exists a difference between the allowed test methods to determine biodegradation. An overview of the allowed test methods is given in Table 8. The underlined test method is the proposed test method, but in case this method is inappropriate for the type and the properties of the material, also alternative methods are allowed. The proposed test methods determine biodegradability under controlled composting conditions, while the alternative test methods determine biodegradability in an aqueous medium.

Another difference is related towards exemptions for biodegradability testing. EN 13432, ISO 18606 and NBR 15488-2 prescribe that chemically unmodified packaging materials and constituents of natural origin, such as wood fibre, cotton fibre, starch, paper pulp, bagasse, jute, etc. shall be accepted as being biodegradable without testing. A comparable clause is incorporated in ASTM D 6868, but additionally it is required that materials of natural origin must demonstrate that at least 95% of their carbon comes from biobased sources, using ASTM D 6866 “Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and

Gaseous Samples Using Radiocarbon Analysis". Such exemption clause is not mentioned in the standards for compostable plastics (EN 14995, ASTM D 6400 & ISO 17088).

Table 8. Overview of allowed test methods in order to demonstrate biodegradability.

	EN 13432 (2000)	EN 14995 (2006)	ISO 18606 (2013)	ISO 17088 (2012)	ASTM D 6868-11	ASTM D 6400-12	AS 4736 (2006)	NBR 15448-2 (2008)
ISO 14855-1 – Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 1: General method	×	×	×	×	×	×	×	×
ISO 14855-2 – Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 2: Gravimetric measurement of carbon dioxide evolved in a laboratory-scale test			×	×		×		
ISO 14851 – Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – Method by measuring the oxygen demand in a closed respirometer	×	×	×		×		×	
ISO 14852 – Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium – Method by analysis of evolved carbon dioxide	×	×	×		×		×	
ASTM D 5338 – Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions. Incorporating Thermophilic Temperatures				×	×	×		

3. Disintegration

The allowed test methods in order to determine the disintegration of a product are given in Table 9. The underlined test method is the proposed test method. According to the compostability standards at least 90% disintegration needs to be obtained within a period of 12 weeks. As illustrated in Table 2 the more advanced 'high-tech' composting installations use shorter composting periods, claiming that this is too short to treat compostable products. Therefore, some installations refuse to accept compostable products in their installations. In order to overcome this barrier, it might be an option to shorten the duration of the disintegration test when revising the standards. However, it must be noticed that compostable plastics are normally certified at their maximum thickness, disintegrating sufficiently within the prescribed 12 weeks period. In reality however, the vast majority of the compostable plastics on the market have a (much) lower thickness, as such disintegrating faster and in a shorter timeframe.

Table 9. Overview of allowed test methods in order to demonstrate disintegration.

	EN 13432 (2000)	EN 14995 (2006)	ISO 18606 (2013)	ISO 17088 (2012)	ASTM D 6868-11	ASTM D 6400-12	AS 4736 (2006)	NBR 15448-2 (2008)
Controlled pilot-scale test	×							
ISO 16929 – Plastics – Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test		×	×	×	×	×	×	
Test in a full-scale treatment facility	×	×	×					
ISO 20200 – Plastics – Determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory-scale test			×	×		×		
ISO 14855-1 – Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 1: General method				×				
ASTM D 5338 – Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions, Incorporating Thermophilic Temperatures				×	×			
EN 14045 – Packaging. Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions								×

4. <u>Ecotoxicity</u>

Toxicological effects are related towards the concentration in which a test material is added to the inoculum at start of the composting test. The test concentration is not defined in the specifications on compostability. Only in the international test method for the determination of the degree of disintegration ISO 16929, the amount of test material for subsequent ecotoxicity tests is clearly defined (10%). The test item concentration for ecotoxicity (10%) is determined in the by-laws of the certification institutes.

The European, international, American and Brazilian standards for evaluation of compostability only require the evaluation of toxic effects towards the germination and the growth of plants, while the Australian standard also requires evaluation of toxic effects towards earthworms.

5 Labelling systems for industrial compostable products

The standards referred to in chapter 4 are used by different certification agencies that offer certification schemes for materials compostable under industrial composting conditions. An overview of the existing certification agencies and their logos for industrial compostability is given in Table 10.

Within Europe there are several certification logos available. This is also the situation European Bioplastics is lobbying for as it eliminates a monopoly and forces the different certification bodies to continuously update their system and follow the rapidly developing market. On the other hand, this is not the ideal situation for bioplastic producers as now different bodies need to be contacted in order to certify their products throughout Europe. Also towards communication a multitude of logos provides problems.

On a business-to-business (B2B) level the OK compost logo and the seedling logo are both equally well known, whereas on a business-to-consumer (B2C) level each has geographical preferences. The OK compost logo is well known in Belgium, Italy, Spain, France and Luxembourg, while the seedling logo is well known in the Netherlands, Germany, the United Kingdom, Poland, Swiss and Austria.

The seedling logo is the registered trademark of European Bioplastics. The seedling logo is awarded by the German certifier DIN CERTCO since 1997 and by the Belgium certifier Vinçotte since 2012. DIN CERTCO has different licensees for the seedling logo (REA in the United Kingdom, COBRO in Poland and AIMPLAS in Spain).

Table 10. Overview of existing certification agencies for (industrial) compostable products.

Organization	Norm	Logo
DIN CERTCO (Germany)	EN 13432 (option: ASTM D 6400, EN 14995, ISO 17088, ISO 18606 & AS 4736)	
	EN 13432 (option: ASTM D 6400, EN 14995 & ISO 17088)	(*)
Vinçotte (Belgium)	EN 13432	
	EN 13432 (option: ASTM D 6400, EN 14995 & ISO 17088)	(*)
Biodegradable Products Institute (BPI) (United States)	ASTM D 6400 & ASTM D 6868	
Cedar Grove (United States)	ASTM D 6400 & ASTM D 6868 with additionally full-scale test	
Japanese Bioplastics Association (JBPA)	Green PLA certification scheme	
Australasian Bioplastics Association (ABA)	AS 4736	
Jätelaitosyhdistys (Finland)	EN 13432	
Consorzio Italiano Compostatori (CIC) (Italy)	Based on EN 13432 with additionally full-scale test	
Departament de Medi Ambient i Habitatge Catalonia (Spain)	Unclear Presumable based on EN 13432	
SP Technical Research Institute of Sweden	SPCR 141	
Environmentally Biodegradable Polymer Association (Taiwan)	CNS14433, CNS14478, CNS14432 & CNS900332	

* Registered trademark of European Bioplastics.

6 Conclusions and suggestions for further work

Centralized composting (= industrial composting) can be considered as a reliable technology in order to convert organic waste to compost. Currently, industrial composting is a frequently applied technology in several countries and it is expected that the amount of industrial composted biowaste will further increase in the future.

A certain percentage of bio-based products introduced on the market can be treated by industrial composting. This might be the case for (bio-based) waste collection bags, plastics, packaging, teabags, coffee filters, food service ware (cups, plates, etc.), agricultural products (plant pots, clips and twines for climbing plants, etc.), fruit labels, etc. Bio-based solvents, bio-based lubricants and bio-based surfactants are not expected to end up in industrial composting installations, at least not in such amounts that they will influence the performance of the system.

Standards with specifications for industrial compostable materials were developed by the International Organization for Standardization (ISO), the European Committee on Normalization (*Comité Européen de Normalisation,* CEN), the American Society for Testing and Materials (ASTM), the Bureau de normalization du Québec (BNQ), Standards Australia, the *Associação Brasileira de Normas Técnicas* (ABNT), etc.

These standards were not particularly developed for bio-based products, but the definition of "a compostable product" as laid down in these standard specifications is also applicable for "a bio-based compostable product". No particular modifications are required for bio-based products.

The essence of the different standards with regard to industrial compostability is identical. They consist of four criteria which must be fulfilled in order to call a product compostable under industrial composting conditions: (1) chemical characteristics, (2) biodegradability, (3) disintegration and (4) ecotoxicity. However, some small differences exist between the developed standard specifications.

In a next phase of the project, a proposal will be developed in order to improve the European standards EN 13432 and EN 14995 with regard to compostable packaging and plastics, respectively. These standards were published in 2000 and 2006, respectively, and since the publication no revisions were carried through in spite of the fact that more experience has become available. The proposal will try to align the European standards with the recently revised international standards for compostable products (ISO 18606 (2013) and ISO 17088 (2012)).

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