COMPOSTABLE BY DESIGN PLATFORM

A FRAMEWORK AND BEST PRACTICE GUIDE FOR FIELD-TESTING THE DISINTEGRATION OF COMPOSTABLE PRODUCTS AND PACKAGING IN INDUSTRIAL COMPOSTING FACILITIES

October 2025 - pilot version - not for distribution

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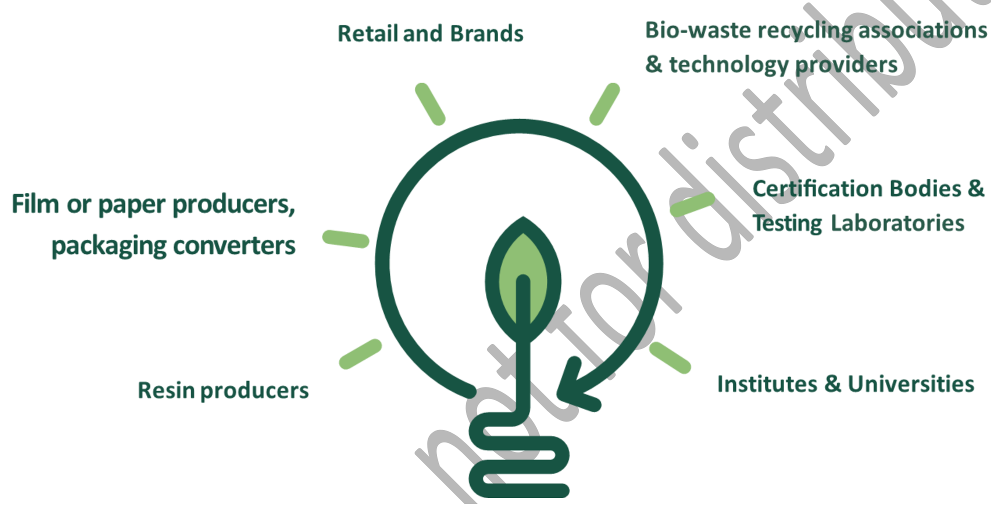
THE COMPOSTABLE BY DESIGN PLATFORM

The Compostable by Design Platform (CbDP) is a cross-value chain initiative promoting collaboration and innovation in compostable packaging and products, and associated bio-waste treatment technologies and processes.

Formed in 2023, its aim is to support the circular economy by building a robust evidence base to strengthen the introduction of compostable items for relevant applications, and to find pathways for them to be recycled by the appropriate bio-waste treatment facilities and infrastructure.



THE VISION

A future where appropriate compostable packaging and products are widely accepted and effectively recycled at scale across bio-waste facilities in Europe supporting sustainable bio-waste management and the circular economy.

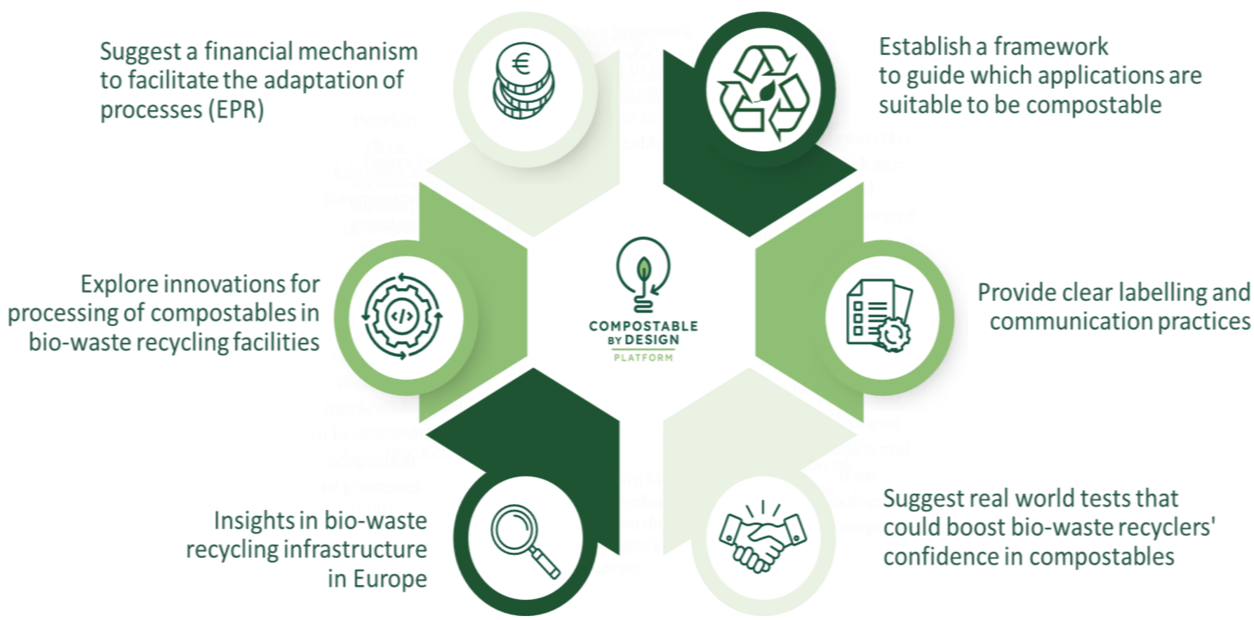
The Platform was founded on the belief that using suitable compostable applications contributes to a circular economy by improving bio-waste recycling, boosting collection rates, and minimising contamination. Recognising that effective solutions require a collective effort, the Platform unites stakeholders across the compostable products value chain, to share experience and collaborate in a pre-competitive working environment.

The Compostable by Design Platform brings together leaders from resin producers to film and paper manufacturers, packaging converters, brands, retailers, logistics providers, bio-waste management experts, certification bodies, testing laboratories, academic institutions, and beyond.

The Platform has identified the following essential deliverables in primary focus:

- Create a harmonised framework for field-testing the disintegration of Compostable Products and Packaging in Industrial Composting Facilities
- Design recommendations for compostable packaging and products
- Framework for EPR for compostable packaging and products
- Insights into European bio-waste recycling infrastructure and technologies

We have identified the following elements to catalyse change:



Further information about the Compostable by Design Platform, including sponsorship, can be found at www.compostablebydesign.com.

ACKNOWLEDGEMENTS

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Composting and Testing Experts:

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Anthesis Group and Ceres Waste, Renewables and Environment co-ordinated the workstream and led the development of this document in 2023/24 and 2024/25 respectively.

ABBREVIATIONS

µm	Micrometre or Micron
AD	Anaerobic Digestion
CbDP	Compostable by Design Platform
C:N	Carbon-to-nitrogen ratio
CO_2	Carbon Dioxide
EN	European Norm
EoL	End-of-life
EU	European Union
EU27	The 27 member states of the European Union
EPR	Extended Producer Responsibility
GHG	Greenhouse Gas
HC	Home Composting
IC	Industrial Composting
IVC	In-vessel Composting
PA	Polyamide
PBAT	Polybutyrate Adipate Terephthalate
PBS	Polybutylene Succinate
PCL	Polycaprolactone
PE	Polyethylene
PET	Polyethylene Terephthalate
PHA	Polyhydroxyalkanoate
PLA	Polylactic Acid
PPC	Polypropylenecarbonate
PP	Polypropylene
ppm	Parts per Million
PPWD	Packaging and Packaging Waste Directive
PPWR	Packaging and Packaging Waste Regulation
SSSU	System Single Serve Units
SUP	Single Use Plastic
TPS	Thermoplastic Starch

INTRODUCTION

In order for compostable packaging and products (compostable items) to fulfil their true potential, it is essential that they are supported by robust and effective collection and treatment pathways. It is therefore essential that the bio-waste treatment sector and composting facility operators have the confidence to accept appropriate formats of compostable items into their facilities.

The research and interviews carried out by the CbDP in a separate workstream evaluating food waste treatment across Europe have shown that a wide range of composting technologies are being used and that their basic processing parameters can vary significantly. This creates challenges for designers of compostable packaging and products who try to ensure their items will disintegrate successfully in a range of different composting processes.

Field-testing of the levels of disintegration under different conditions can be an important step to supplement laboratory testing, enabling composting facility operators to:

- Test the actual disintegration of compostable packaging and products within real life conditions,
- Understand the impact of variable composting conditions, and
- Understand how compostable items will disintegrate during the composting process.

Disintegration is the physical breakdown of a material into very small fragments due to physical, chemical, or microbiological processes. It is one of four aspects that are specified in standards covering the **compostability** of packaging and non-packaging items; the others being characterisation of the component materials, biodegradation and effects on the quality of the resulting **compost** or **digestate**. Due to the nature of the test methods and equipment required for these latter three aspects, analysis necessarily needs to be carried out in a laboratory. Disintegration testing can, however, be carried out either in a laboratory under controlled conditions or in large-scale **composting facilities**[1].

Disintegration testing in operational composting facilities provides useful data on how different compostable packaging and non-packaging products (**compostable items**) breakdown in real-world environments. However, challenges due to the lack of a pan-European field-test method, the variability in processing conditions and the way in which samples are prepared, composted and recovered for analysis, place limitations on the interpretation and comparability of the results.

Harmonising and standardising field-testing methods would improve the reliability and interpretation of testing outcomes in real world conditions; meaning that test results obtained in one country could be accepted within another.

This could reduce the need for multiple testing, where testing under 'real world' conditions is chosen as the method of disintegration testing or is wanted in addition to disintegration testing under lab-

[1] This document focusses on **disintegration testing** in **large-scale (industrial) composting facilities**.

controlled conditions. In the longer term, a harmonised field-testing protocol could feed into standards such as EN 13432 where the inclusion of field-testing is not currently harmonised.

Therefore, a comprehensive disintegration field-testing protocol should:

- Support field-testing alongside laboratory testing to verify results under 'real world conditions',
- Provide a base for more formal compostability certification schemes or standards,
- Support the design process of new compostable items informing on design and specifications[2],
- Increase confidence of composting facility operators that compostable items perform as intended,
- Support communication measures and labelling to reassure users and consumers that compostable items can be recycled as part of the bio-waste stream.

This guidance document aims to provide a framework for the harmonisation of field-testing disintegration methods applicable across the diverse range of **industrial composting** operations in Europe in order to support consistent interpretation of results. It was developed through collaborative working of cross-value chain stakeholders within the Compostable by Design Platform (CbDP), led by composting associations, biodegradation testing organisations and other composting industry experts.

The information in this report has been divided into five main chapters, containing the following:

- **Chapter 1 Standards & product certification:** examines the differences between standards and the certification of products to set the scene for this guidance document. These are terms that are often used interchangeably but at a technical level they have different meanings.
- **Chapter 2 Composting:** This characterises and describes the operations of composting facilities in order to provide contextual information. It describes the composting process, composting methods and operational parameters.
- **Chapter 3 Compost Quality:** This describes compost quality criteria, and the regulatory landscape which industrial composters must navigate, focusing on the EU Fertilising Products Regulation It also identifies criteria under which compostability is a preferred end-of-life option.
- **Chapter 4 Field-Testing Guidance:** This chapter is the main focus of this document and provides technical guidance on undertaking field-testing of compostable products and packaging. It describes the key elements needed to conduct a disintegration study including field-testing methods, sample preparation, data collection, analysis and interpretation.
- **Chapter 5 Existing Field-Testing Protocols:** This provides a comparison of field-testing protocols in place in Ireland, Italy and North America to provide examples of existing national protocols.
- **Appendix:** Outlook on how compostable items could be addressed in anaerobic digestion processes, which is planned to be investigated further in future work of the CbDP.

The CbDP envisages that this framework protocol will support collaboration along the supply chain and support the development of field-testing of compostable items across Europe.

[2] Compostable by Design Guidelines - Design Recommendations for Compostable Packaging and Products

1 CHAPTER 1: STANDARDS AND PRODUCT CERTIFICATION

This section describes the differences between **standards** and the **certification** of products. These are terms that are often used interchangeably but at a technical level they have different meanings.

1.1.1 STANDARDS

Standards are formal documents that establish uniform criteria, methods, processes and practices to ensure quality, safety and compatibility across products, services and systems. They are developed by experts and stakeholders organised within standards development organisations through a structured, consensus-based process. Within Europe, the European Committee for Standardization (CEN)[3] is the principal standards development organisation.

Depending on their intended use, standards can be of several types:

- **Specifications**: these set prescriptive requirements for items, materials, components, systems, or services by **defining the technical and performance criteria** that must be met. For example, **EN 13432**[4] is the European standard that specifies the requirements that must be met through laboratory testing for packaging to be recoverable through industrial composting and biodegradation. Specification standards prescribe the **test methods** that must be used and the **pass/fail criteria** against which **conformance assessment** must be measured.
- **Test methods**: These are **detailed protocols/methods for laboratory testing** and aim to ensure that test results obtained by different laboratories can be compared and clearly interpreted on the basis that the tests have been conducted in exactly the same way regardless of the testing location. Different test methods are used to test different aspects of performance of compostable items. The test method sets out the procedure the laboratory follows but does not include pass/fail criteria.
- **Vocabulary**: A vocabulary is a list of definitions and terminology created to standardise language use in a particular field or discipline. For example, ISO 59004:2024[5] provides a vocabulary for the **circular economy**.
- **Guides**: These offer optional guidance that reflects the most common perspectives and approaches among experts in a certain field.

[3] CEN standards have the prefix EN placed before its unique number.
[4] EN 13432:2000 Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging. [Currently under review]
[5] ISO 59004:2024(en) Circular economy — Vocabulary, principles and guidance for implementation.

It is important to remember that standards are not the same as laws. Unlike governmental regulations, which are legally binding, standards are voluntary. They are often used by companies to support legal compliance and to direct the design, manufacturing, assessment and procurement processes; they are regularly incorporated into legislative texts to give technical nuances.

1.1.2 EUROPEAN STANDARD EN 13432

EN 13432:2000 "Requirements for packaging recoverable through composting and biodegradation", is an EU harmonised specification standard for compostable and biodegradable packaging. It sets out the test methods and pass/fail criteria to evaluate if packaging can be suitable for bio-waste recycling in industrial composting systems. It focuses on ensuring that materials designated for industrial composting are suitable for this method of bio-waste recycling, do not negatively affect the composting process, and result in compost that aligns with broader quality regulations such as the EU Fertilising Products Regulation (see Chapter 3).

EN 13432 was developed to provide a clear framework for evaluating the suitability of packaging for industrial composting. The standard sets several criteria that **packaging items, packaging materials** (i.e. source materials from which the item is manufactured) and **packaging components** (i.e. individual parts of the final item that serve a specific function, such as structure, protection or containment)[6] must meet to be considered industrially compostable. CEN is currently revising EN 13432 in order to reflect developments in bio-waste recycling methods and quality criteria. Until the revised standard is published, the original 2000 version remains in effect.

EN 13432 currently specifies the following:

- **Characterisation**: Initial analytical testing to ensure that packaging, packaging materials or packaging components will cause no negative effects on the composting process. This testing enables checks that 11 potentially toxic elements (described in the standard as 'heavy metals and other toxic and hazardous substances') do not exceed specified limit levels.
- **Disintegration testing**: The standard specifies that the item should physically break down into sufficiently small particles over a maximum of 12 weeks in composting conditions in either a controlled pilot-scale test or in a full-scale treatment facility. In order to pass the disintegration test, the amount of the tested item retained on a sieve with 2 mm holes must not exceed 10% of the item's original dry weight, by a maximum of 12 weeks. The item should physically break down into pieces that are visually indistinguishable from the rest of the compost, leaving no visible fragments that significantly reduce the aesthetic properties of the compost.

[6] It is important to note that whenever packaging is made up of a number of different components, individually these components must meet the criteria set in EN 13432 for the finished item to be classed as compostable.

- **Biodegradability testing**: This involves testing the item in a laboratory environment for the conversion of organic carbon into carbon dioxide within a six-month timeframe under controlled composting conditions at a temperature of 58°C. [7] In analogy to natural biopolymers, a biodegradable polymer is converted under aerobic conditions by microorganisms into biomass, water, CO_2 and energy (emitted); The proportion of carbon stored in the biomass cannot be recorded by this type of test, hence the measured CO_2 value as indicator of biodegradability cannot be 100%.
- **Compost quality assessment**: The standard specifies that the item must not have an adverse effect on compost quality. It specifies a number of physical-chemical parameters that need to be determined, as well as ecotoxicological tests and an associated ecotoxicity pass/fail criterion to ensure that the compost does not have toxic effects on plants.

When a packaging item meets all the criteria specified in EN 13432, it claims to be suitable for industrial composting. However, as claims of conformity by manufacturers and suppliers are potentially subject to misrepresentation or false claims, certification by a third-party independent **certification body** is strongly encouraged.

EN 14995:2006[8] is identical to EN 13432 (requirements for packaging recoverable through composting and biodegradation) with regards to compostability criteria and specified test methods; the only difference relates to its scope, which covers non-packaging plastics.

1.1.3 CERTIFICATION

Certification is a formal procedure in which an **independent third-party organisation** (a **certification** body)[9] assesses and confirms that a product complies with the defined requirements of a particular standard, such as EN 13432. It involves a **conformity assessment**, where the certification body evaluates whether the item complies with the relevant standard through audits, inspections, testing or assessments.

In the case of compostable items, certification provides **objective and impartial assurance** to interested parties (customers, regulators and suppliers) that the **certified item** fulfils the defined criteria specified in EN 13432.

Upon successful evaluation, the certification body issues a **certificate** that documents the scope and validity of the certification and may also approve the use of its certification mark (a special type of logo)

[7] ISO 14855-1:2012 Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions — Method by analysis of evolved carbon dioxide.
[8] EN 14995:2006 Plastics - Evaluation of compostability - Test scheme and specifications.
[9] Certification bodies should also be **accredited** by an authoritative accreditation body, which assesses whether the certification body meets strict requirements for competence, impartiality, and performance. Accreditation provides third-party assurance that the certification body operates according to standards such as ISO/IEC 17065 (for product, processes and service certification).

to help consumer and industry recognise the product specification and select the appropriate end of life treatment route.

Certification is specific to **individual compostable items**. It is voluntary, but can be required or referenced in contracts, regulations or market requirements to demonstrate compliance and build consumer trust.

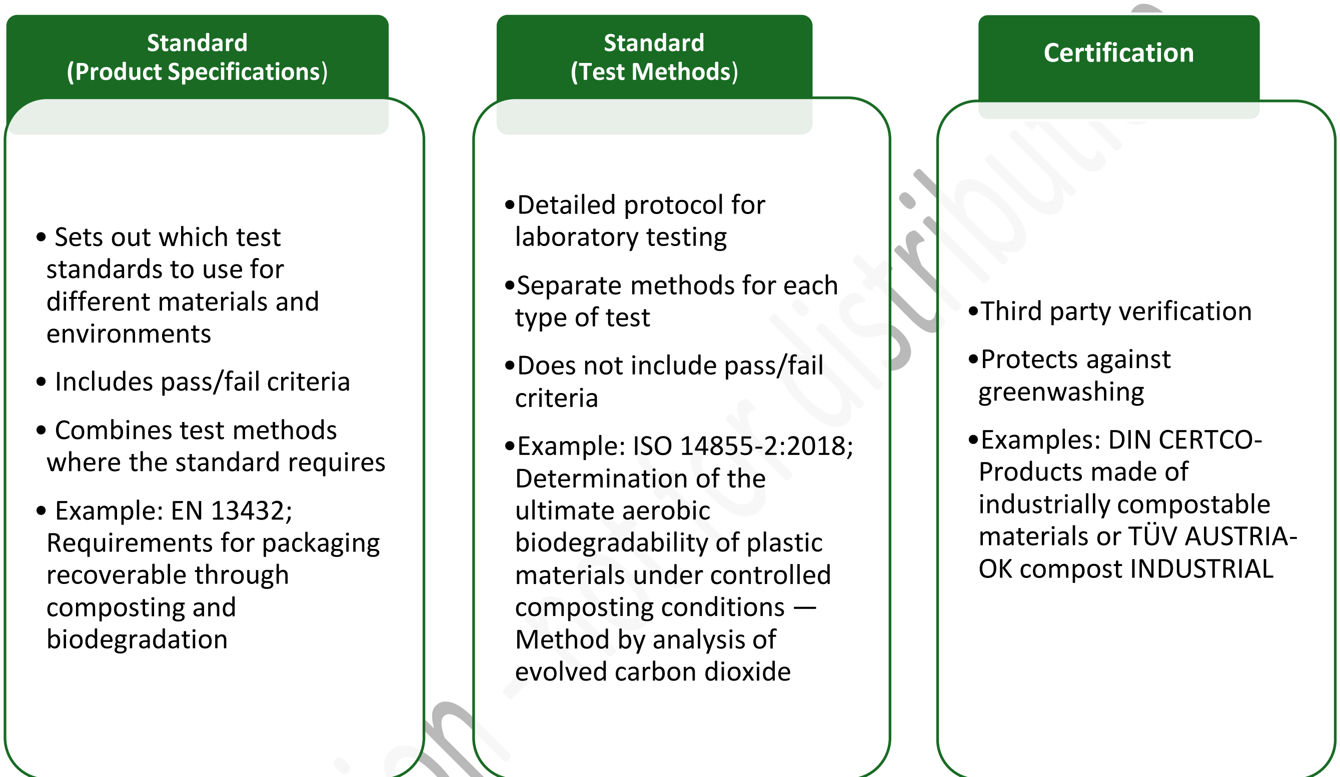


Figure 1. Overview of standards and certification

2 CHAPTER 2: COMPOSTING PROCESSES

2.1 BIO-WASTE RECYCLING OPTIONS

Across Europe, there are currently two main approaches used to recycle bio-waste: namely, **composting** and **anaerobic digestion** (AD).

- **Composting**, is an aerobic process where naturally occurring aerobic micro-organisms (bacteria and fungi) decompose organic material in the *presence* of oxygen, converting it into a stable organic output (compost), carbon dioxide and water. There are two main scales of composting:
    - **Industrial composting (IC)** which is carried out on a large-scale, treating thousands of tonnes of bio-waste every year, and
    - **Home composting (HC)** which, as the name suggests, is generally carried out by individual residents in their gardens, vegetable patches or allotments. It involves small volumes of bio-waste and is carried out at lower temperatures than industrial composting, so it therefore takes much longer to produce compost.
    - **Community composting (cc),** describes local schemes that process quantities of biowaste, often for entire neighbourhoods or small municipalities. These can vary in size, the way that they operate and the equipment used. Bio-waste can be collected from local householders or these schemes can accept deliveries from residents. The management of the composting process is undertaken by the community composting group and the resulting compost is often returned to the local community, either for free or with a small charge.
- **Anaerobic digestion** is a process where naturally occurring anaerobic micro-organisms (bacteria) decompose organic material in the *absence* of oxygen, converting it into **digestate** and **biogas**. The anaerobic digestion treatment timescales are typically shorter than composting ones and AD is now starting to be used as a first step in combined systems where it is followed by a post composting (aerobic) phase.

In Europe, composting is the dominant method, accounting for approximately 59% of the total bio-waste processed, while anaerobic digestion is used for about 41% (see Figures 2 and 3).

Figure 2.Number of composting & AD facilities processing bio-waste in the EU27 in 2019-20

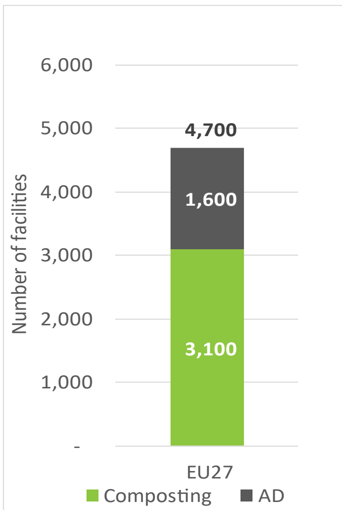
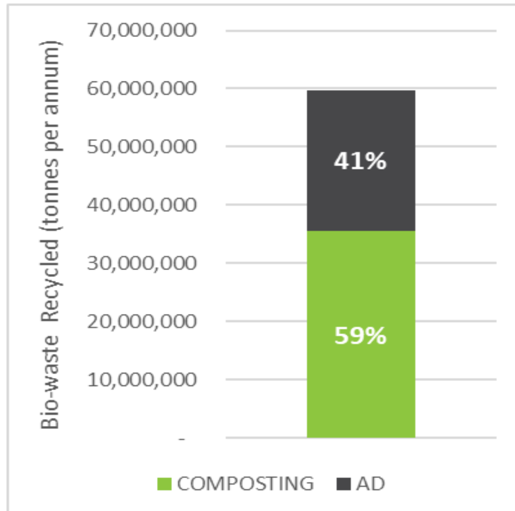


Figure 3. Amount of bio-waste recycled in composting & AD facilities in the EU27 in 2019-20



Source: ECN Data Report (2022) [Overview of Bio-waste Collection, Treatment & Markets Across Europe]

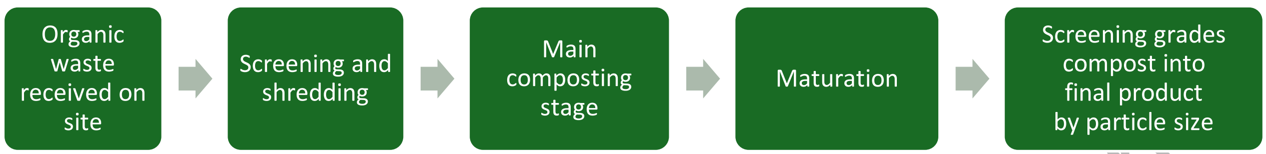
Please note this document focusses on composting and additional information about anaerobic digestion is detailed in the appendix.

2.2 THE COMPOSTING PROCESS

The composting process as shown in Figure 4 typically begins when **bio-waste**, such as food waste, garden waste and compostable items are delivered to the site. In some locations, these may be collected together or separately, and the facilities may take a mixture of all or only one type of waste. These materials are then subjected to any pre-treatments the facility may use such as **shredding**; a critical step that reduces particle size, enhancing the surface area and microbial accessibility. The shredded material is subsequently placed in **composting piles** or **vessels** (which vary in design depending on the method) where active composting takes place.

Following the composting phase, the material is **screened** to remove non-compostable contaminants and to separate fine compost from larger pieces. The final stage, known as **curing** or **maturation**, allows the compost to mature, stabilising its nutrient content and reducing phytotoxic compounds. The outcome is a nutrient and organic matter-rich compost suitable for agricultural, horticultural and soft landscaping applications, contributing to soil health and sustainability.

Figure 4.Typical industrial composting process



The process is managed in aerated environments to optimise microbial activity and ensure efficient decomposition. The aim is to produce stable compost that enhances soil health.

2.3 COMPOSTING METHODS

Composting is a broad term that encompasses various methods including windrow (WC), in-vessel (IVC) and aerated static pile (ASP) composting. As composting requires careful monitoring of oxygen levels, temperature and moisture to maintain optimal conditions for microbial activity and efficient breakdown of organic matter, each of these methods differ in terms of process efficiency, control and suitability for various bio-waste streams.

Generally, composting facilities treating food waste must use closed composting reactors (IVC) or closed areas that cannot be by-passed (e.g. ASP), to ensure that all material is treated according to defined time-temperature standards. This is because food waste is subject to the EU's Animal By-Products Regulation, where it is called 'catering waste'.[10] Grass, plant and other garden clippings (e.g. garden and park waste) are suitable for open-air composting methods. In addition, periodic turning or equivalent mixing measures are required to guarantee that the entire mass of material is exposed to the same process conditions, as specified in EU Regulation 2019/1009 on EU fertilising products.

The three main composting methods are summarised below.

2.3.1 WINDROW COMPOSTING

Windrow composting is the most common method used in Europe[11], whereby, organic materials are placed in long rows (windrows) and are often turned regularly using self-propelled or tractor pulled windrow turners, or tractors with front-mounted wide buckets. This maintains aeration and moisture balance. Windrow composting is simple, cost-effective and suitable for large-scale operations, but it requires some manual labour to operate machinery and considerable land. The process needs to be well managed to provide efficient composting performance and avoid odour issues.

[10] Regulation (EC) No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption, as amended.
[11] ECN Status Report 2019 Overview of Bio-waste Collection, Treatment & Markets Across Europe.

2.3.2 TUNNEL SYSTEM COMPOSTING

A tunnel system is a specific type of windrow composting that typically involves composting bio-waste in covered tunnels or channels. These systems provide controlled environments for composting, including regulated aeration, temperature and moisture levels. They are designed to optimise the composting process and are often used in larger-scale operations to manage various types of bio-waste efficiently.

2.3.3 AERATED STATIC PILE COMPOSTING

Aerated static pile (ASP) composting is a method where organic material is composted in a stationary pile with forced aeration, typically without disturbing the compost. This is implemented using a network of perforated pipes and fans that supply air to the pile to maintain aerobic conditions without the need for turning.

ASP composting can improve decomposition rates and temperature control, enhancing the efficiency and speed of composting compared to windrows. Moreover, the static nature of the pile reduces the need for turning and the labour necessary and consequently, requires less land than windrows.[12] Other forms of ASP used are Extended Aerated Static Pile (EASP); a process extended over a larger area and time frame than typical ASP methods and Covered Aerated Static Pile; composting that imitates EASP but uses a gas-permeable cover to control environmental variables such as moisture and temperature.

2.3.4 IN-VESSEL COMPOSTING

In-vessel composting (IVC) offers a high level of process control (temperature, moisture and aeration) through decomposition of bio-waste in a closed, controlled environment. IVC can also process large amounts of bio-waste in smaller areas of land than windrow methods and can accommodate a wide range of bio-wastes (e.g., meat, animal manure, biosolids and food waste)[13].

IVC systems use containers, drums, silos or other structures that can enclose bio-wastes. This facilitates the composting process and aims to optimise the control of key parameters for microbial activity.

[12] EPA. Types of Composting and Understanding the Process. Available at: Types of Composting and Understanding the Process | Sustainable Management of Food | US EPA.

[13] EPA. Types of Composting and Understanding the Process. Available at: Types of Composting and Understanding the Process | Sustainable Management of Food | US EPA.

2.4 COMPOSTING PARAMETERS

Within all composting methods certain key operating parameters must be considered. These include, amongst others, the aeration and turning frequency of the compost, temperature ranges, moisture content and time across the different composting phases.

Compost quality is usually determined by its maturity, stability, nutrient content and contaminant levels; with compost being divided into different grades based on these factors. Various market types, including agriculture, landscaping and horticulture have different quality requirements and individual composting facilities will use processes that produce the grade necessary for their market. This is explored more in Chapter 3.

2.4.1 OXYGEN

Oxygen is an essential component in the composting process as it supports aerobic microbial activity, which is essential for the breakdown of organic matter. In aerobic composting, micro-organisms require oxygen to decompose the organic material, producing compost, carbon dioxide, water and heat in the process.

Maintaining adequate oxygen levels (typically above 10-15%) prevents the compost from becoming anaerobic, which can lead to the production of unpleasant odours and the generation of hydrogen sulphide, nitrous oxide and methane, a potent greenhouse gas.[14] [15]

2.4.2 VOLUME, SHAPE AND POROSITY

The size and porosity of the compost pile play a large role in composting by impacting the way gases and water vapour move through the pile, as well as affecting its temperature. The particle size also affects the surface area on which micro-organisms feed, the homogeneity of the mixture and its ability to generate and lose heat.[16]

Heat retention, is also affected by the composting pile's surface area to volume ratio (SA:V), which, in turn, is determined by its volume and shape. Small piles have greater SA:V ratios than large piles, meaning they lose heat more quickly.[17] This, in turn, affects the temperature of the composting material; hence the rate of composting.[18]

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[14] Epstein, Eliot (2011). *Industrial Composting: Environmental Engineering and Facilities Management.* Florida: CRC Press.
[15] Bernal, M.P., Alburquerque, J.A. and Moral, R. (2009) Composting of animal manures and chemical criteria for compost maturity assessment. A Review, *Bioresource Technology*, 100(22), pp. 5444–5453. doi:10.1016/j.biortech.2008.11.027.
[16] EPA. Approaches to Composting. Available at: Approaches to Composting | US EPA.
[17] Ayilara, M. *et al.* (2020). Waste management through composting: Challenges and potentials. *Sustainability*, 12(11), p. 4456. doi:10.3390/su12114456.
[18] Malwana, C *et al*. (2013). Determination of optimal pile dimensions during Thermophillic Windrow composting of municipal solid waste (MSW) in Sri Lanka. *International Journal of Bioscience, Biochemistry and Bioinformatics*, pp. 552–556. doi:10.7763/ijbbb.2013.v3.274.

Small piles can therefore lead to extended composting times if they are unable to retain sufficient heat, which is why industry generally uses larger piles having lower SA:V ratios. Large piles, however, can result in compaction, reducing the porosity of the material and the ability of gases to permeate within the composting mass.[19]

Moisture levels are also directly affected by windrow size and its SA:V ratio. Small windrows tend to lose water more easily and quickly than larger ones, where moisture retention is easier. Since this parameter is essential for biological activity, heat generation (and thus the material's temperature) will be directly influenced by the moisture levels at every stage of the process.

Ideally, across all composting methods, the piles need to be large enough to retain enough heat and maintain temperatures but small enough to allow oxygen and other gases to permeate into the windrow's core. This can be achieved by keeping the height of piles between 1 to 3.5 m and having a width of between 2 to 8 m, depending on the type of composting in use.[20 21]

2.4.3 AERATION AND TURNING FREQUENCY

Aeration is a fundamental parameter in industrial composting as it ensures the provision of oxygen necessary for aerobic micro-organisms to thrive. Proper aeration facilitates the maintenance of aerobic conditions, preventing the development of anaerobic zones that can produce unpleasant odours and slow down the composting process.

Aeration is achieved through the mechanical turning of compost piles or the use of forced aeration systems. In windrow composting, turning frequency is critical and typically involves turning the compost pile at least every 2 to 15 days during the active composting phase (usually the first six weeks)[22 23]. This is to ensure uniform aeration, release of stale gases and even temperature distribution. In-vessel composting systems often utilise automated aeration, where oxygen levels are closely monitored and adjusted. The frequency and method of aeration significantly influence the decomposition rate, temperature control, and overall efficiency of the composting process, making it a vital aspect of industrial composting management.

An optimal combination of windrow diameter, material blend, moisture, gas exchange and use of a compost turner, allows for compostable materials and items similar to bio-waste to also be transformed biologically into a stabilised compost, within a short period of 6 - 8 weeks.[24]

[19] ECS (2022). Aerated Static Pile vs. In-Vessel vs. Turned Pile Composting. Available at: Forced Aeration Composting – Engineered Compost Systems.
[20] UrthPact (2020). Industrial Composting: What Is It and How Does It Work? Available at: Industrial Composting: What Is It and How Does It Work? (urthpact.com)
[21] Greenprint (2023). Different Types of Industrial Composting. Available at: Different Types of Industrial Composting - Greenprint (greenprintproducts.com).
[22] Lebensministerium.at (2009). The State of the Art of Composting: A guide to good practice.
[23] US Composting Council (2022). Model Compost Rule Template Version 2.0.
[24] European Bioplastics (2015). EN 13432 Certified Bioplastics Performance in Industrial Composting.

2.4.4 pH LEVELS

The initial stages of composting typically produce acidic conditions (pH 5.5-6.5) due to the production of organic acids. By the stage of well-progressed decomposition, the pH has usually stabilised around neutral (pH 7.0) or alkaline (up to pH 8.5), influenced by the production of ammonia release during protein degradation[25]. pH is not a key factor for composting since most materials fall within this range.

2.4.5 MOISTURE CONTENT

Moisture content is another decisive parameter in industrial composting, directly affecting microbial activity and the composting process's efficiency. Ideal moisture levels range between 40% and 60%[26], with too little moisture inhibiting microbial activity and too much causing anaerobic conditions. During the initial stages, moisture is necessary to support the high metabolic rates of micro-organisms.

Maintaining adequate moisture levels ensures that the compost material remains porous, allowing for proper air flow and preventing the pile from becoming compacted. Industrial composting operations often monitor and adjust moisture levels through watering and by balancing dry and wet feedstocks. Effective moisture management promotes optimal microbial activity, aids in temperature regulation, and ensures the production of high-quality compost with desirable physical and chemical properties.

2.4.6 TEMPERATURE AND TIME

In industrial composting, the decomposing material is exposed to different temperatures. The temperature of the composting material initially rises rapidly during the initial phase as microbes begin breaking down easily degradable materials. This is termed the **mesophilic** phase, as micro-organisms that thrive at **moderate temperatures** (20–45°C) dominate. The process then enters the **thermophilic** phase, where temperatures typically reach and are maintained between **50°C and 70°C** for several days to weeks. During this phase, micro-organisms that prefer high temperatures dominate.

The time range across the mesophilic and thermophilic stages is critical for ensuring thorough decomposition (see *Figure 5* below). Temperature gives an indication of biological activity and is equally important to ensure adequate pathogen and weed seed destruction which is usually achieved when surpassing 55 °C for a sufficient period of time.[27] [28] The process typically lasts several weeks. Once decomposition slows and temperatures drop below 45 °C mesophilic microbes return, stabilising the compost throughout the maturation phase. The duration and management of these phases are pivotal to producing high-quality compost, free of harmful micro-organisms and suitable for use.

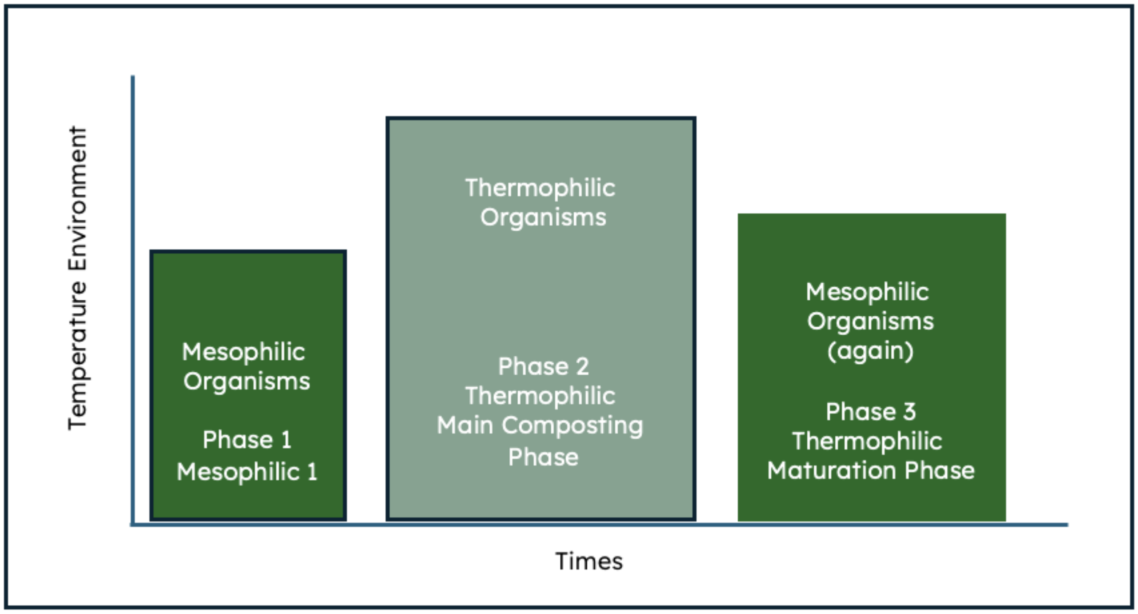
[25] Bernal, M.P, et al. (2009). Composting of animal manures and chemical criteria. A review. *Bioresource Technology: 100(22).* Doi: https://doi.org/10.1016/j.biortech.2008.11.027

[26] Amuah, E.E.Y., *et al.* (2022). A review of the principles of composting: understanding the processes, methods, merits, and demerits. *Org. Agr.* 12, 547–562. https://doi.org/10.1007/s13165-022-00408-z

[27] SUEZ in the UK. Composting. Available at: Composting - SUEZ in UK (Accessed: September 2024).

[28] Barthod, J., *et al* (2018). Composting with additives to improve organic amendments. A review. *Agron. Sustain. Dev.* 38(17). https://doi.org/10.1007/s13593-018-0491-9

Figure 5. Temperature and microbial phases of composting



Source: Adapted from Composting Consortium, Centre for Circular Economy, Closed-loop Partners[29]

2.4.7 FEEDSTOCK MIXING RATIOS

The proportion of carbon to nitrogen by weight in the composting materials is an important consideration in all composting systems and is referred to as the **carbon-to-nitrogen ratio (C:N)**. It is important in industrial composting, ideally ranging from 25:1 to 40:1[30], in the incoming feedstock mix. This ratio optimises microbial activity, as carbon provides energy, and nitrogen is necessary for protein synthesis and growth. Green wastes, that are high-carbon materials such as wood chips, dry leaves, cardboard, and straw, are blended with nitrogen-rich materials like food, manure, fresh grass clippings or green leaves to achieve this balance.

Composting facilities often pre-process materials through shredding or grinding to increase uniformity, which helps maintain the correct C:N. Regular monitoring of the compost's chemical composition allows for adjustments to the mix, ensuring the ratio remains within the optimal range. An excess of carbon slows the process due to nitrogen deficiency, while excess nitrogen can lead to ammonia emissions and odours. Maintaining the proper C:N supports efficient microbial decomposition and enhances aeration and moisture content, resulting in a more effective composting process.

[29] Closed Loop Partners (2024). Breaking It Down: The realities of compostable packaging disintegration in composting systems.
[30] Amuah, E.E.Y., *et al.* (2022). A review of the principles of composting: understanding the processes, methods, merits, and demerits. *Org. Agr.* 12, 547–562. https://doi.org/10.1007/s13165-022-00408-z

3 CHAPTER 3: COMPOST QUALITY

The regulatory environment for industrial composting in Europe is characterised by a comprehensive set of standards and regulations aimed at ensuring compost products' quality, safety and environmental sustainability which often includes minimum quality criteria.[31] This chapter explores compost quality criteria, and the regulatory landscape which industrial composters must navigate, focusing on the EU Fertilising Products Regulation (EU FPR), and the individual standards within European countries.

3.1 EU FERTILISING PRODUCTS REGULATION

The EU Fertilising Products Regulation (EU FPR) [32] is a significant regulatory framework for fertilising products, including compost, marketed within the European Union. The EU FPR aims to harmonise the market across EU member states, facilitating the free movement of these products within the internal market. The Regulation covers a broad range of products, including bio stimulants, soil improvers, and fertilisers derived from organic and secondary raw materials. Composts and digestates can qualify as relevant product types or be part of such products, provided they meet the relevant criteria, including minimum quality criteria.

It is worth noting that EU Member States may still place compost on their national markets that does not comply with the EU Fertilising Products Regulation 2019/1009, as long as it is not marketed as an "EU fertilising product" with the CE marking. In these circumstances, member states are allowed to use their own national standards as an alternative to EU FPR requirements, which has led to the wide range of variation between composting operations and parameters across Europe.

3.1.1 KEY REQUIREMENTS

Under the EU FPR, products that consist of, or include compost, must meet the following criteria:

- **Organic Content**: Compost must contain material solely of biological origin. The Regulation sets different minimum organic carbon content (on a percentage by mass basis) in each of the **Product Function Categories**[33]:
    - organic fertiliser (in solid and liquid forms);
    - organo-mineral fertiliser (in solid and liquid forms);
    - organic soil improver (in effect, in solid form).

[31] ECN (2014). ECN-QAS Manual. Available at: ECN-QAS Manual - European Compost Network

[32] Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003.

[33] A **Product Function Category** (PFC) in Regulation (EU) 2019/1009 defines the intended function and use of an EU fertilising product, such as fertiliser, soil improver, plant bio-stimulant, or growing medium, and determines the specific safety and quality requirements it must meet.

Under the Regulation, compost can be used as a solid organic fertiliser, an organic soil improver, as part of a solid organo-mineral fertiliser or as part of a growing medium, where it meets **Component Material Category**[34] criteria applicable to compost and the final product meets its relevant Product Function Category criteria.

- **Nutrient Content**: Compost must provide essential nutrients such as nitrogen, phosphorus and potassium, and should meet minimal concentrations to be an effective product.
- **Stability and Maturity**: The bio-waste from which the compost is made must have undergone sufficient decomposition that any intermediate, natural break-down substances in it are unlikely to harm plants. The Regulation specifies minimum **stability/maturity** levels for compost (see Section 3.1.4).
- **Contaminant Limits**: The Regulation sets strict limits on contaminants, including heavy metals, pathogens, and physical impurities such as plastic, metal and glass.
- **Labelling and Traceability**: Detailed labelling requirements ensure transparency and traceability, providing end-users with critical information about the product's composition and use.

The EU FPR also sets **End-of-Waste** (EoW) criteria for waste-derived compost, meaning that when the compost meets the specified criteria, it is no longer classified as waste but as a marketable product that can be used outside of waste regulatory controls. [57]

ORGANIC CONTENT

The organic content of compost (the amount of organic matter present) is essential for its role as a soil improver. When used as an organic fertiliser, the organic matter must include the primary constituent organic carbon, and at least minimum-specified concentrations of nutrients for plant growth. In general, **organic matter** content can be tested using a range of laboratory test methodologies, one of which determines its **organic carbon** content.

The EU FPR states that for solid organic fertiliser (compost can be used as this product type if it meets the corresponding criteria), its organic carbon content must be at least 15%, by mass (i.e. the 'percentage of the mass of the entire EU fertilising product in the form in which it is made available on the market').[35] It also states that organic soil improver products must contain at least 7.5% organic carbon as too must solid organo-mineral fertilisers.

[34] A **Component Material Category (CMC)** specifies the **type and origin of materials** that can be used in EU fertilising products, such as compost, digestate, plant materials, or by-products, and ensures these materials comply with safety and environmental standards

[35] European Union Regulation 2019/1009 on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) no 1107/2009 and repealing Regulation (EC) No 2003/2003. Available at: [Regulation - 2019/1009 - EN - EUR-Lex (europa.eu)]

High organic carbon content indicates that the compost is rich in carbon that has come from plant and/or animal sources, which are beneficial for soil health.[36] Similar requirements for organic carbon content can also be found in national regulations, such as the German RAL-GZ 251, which also emphasises high organic matter content to ensure the quality and efficacy of compost products.[37]

3.1.2 NUTRIENT CONTENT

Composted bio-wastes contain useful amounts of a wide range of primary, secondary and tertiary (also known as trace) nutrients that support the growth and health of plants. Nitrogen (N), phosphorus (P), and potassium (K) are the primary nutrients, essential for plant growth. The nutrient content of compost enhances soil fertility, and it provides a slow-release source of nutrients, reducing the need for chemical fertilisers. In addition to fertilising properties, compost acts as a soil improver by adding organic matter which improves soil structure.

During composting, some of the total organic nitrogen in bio-waste is mineralised into inorganic forms, namely: ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-)[38]. Microbes convert the organically bound nitrogen they can access into ammonium-nitrogen, then into nitrite-nitrogen and then into nitrate-nitrogen. This means nitrogen concentrations are observed in matured compost, in different 'total' and inorganic (water-soluble) forms and can be used as a proxy for compost quality.

Compost's C:N ratio (total carbon to total nitrogen ratio) is a very commonly used quality proxy and its NH_4:NO_3 (ammonium-nitrogen to nitrate-nitrogen ratio) also provides useful information.[39] Compost is commonly used as a soil improver and has some track record of use as, some or all, of, the bulky substrate in growing media. EN 13654-1:2001[40] sets out test methods for determining the ammonium-N, nitrate-N, nitrite-N and organic N content of soil improvers and growing media.

Some European regulations require compost to contain adequate amounts of nutrients, and their availability to plants is often assessed through various analytical test methods. The EU FPR's requirements applicable to solid organic fertilisers set minimum concentrations for total nitrogen, total phosphorus pentoxide and total potash, and requires that the sum of these is at least 4% by mass in compost (on a fresh matter basis).[41]

36 Azim, K., *et al.* (2018). Composting parameters and compost quality: a literature review. *Org.Agr.*8, pp.141-158. https://doi.org/10.1007/s13165-017-0180-z
37 Siebert, Stefanie (2007). Compost from Biodegradable Waste – Status and Results of Quality Assurance in Germany.
38 Azim, K., *et al.* (2018). Composting parameters and compost quality: a literature review. *Org.Agr.*8, pp.141-158. https://doi.org/10.1007/s13165-017-0180-z
39 Chen, J. *et al.* (2024). The optimal ammonium-nitrate ratio for various crops: A meta-analysis. *Field Crops Research*, 307, p. 109240. doi:10.1016/j.fcr.2023.109240.
40 EN 13654-1:2001 Soil improvers and growing media - Determination of nitrogen - Part 1: Modified Kjeldahl method
41 European Union Regulation 2019/1009 on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) no 1107/2009 and repealing Regulation (EC) No 2003/2003.

Organic soil improvers can have beneficial effects even if their concentrations of total nitrogen, total phosphorus pentoxide and total potash are low, e.g. benefits due to their organic matter content and their range of nutrients needed by plants. Consequently, the EU FPR does not set minimum concentrations for nutrients in organic soil improvers.

3.1.3 STABILITY AND MATURITY

Stability and **maturity**[42] refer to the specific state of organic matter decomposition during composting and its readiness for use as a product[43]. Mature compost is that which has completed its maturation phase, whereby the bio-waste from which it is made has sufficiently decomposed and the compost is free from phytotoxic substances, does not emit unpleasant odours, and does not reheat.

The EU FPR requires compost to meet at least one of two stability criteria:

Oxygen uptake rate

The oxygen uptake rate measures the rate at which composting micro-organisms consume oxygen for respiration and can be tested according to EN 16087-1:2020[44]. It can be measured using respiration activity indices (DRI, AT4 or others), which quantify the amount of oxygen consumed by micro-organisms over a defined period of time. The EU FPR sets a maximum respiration rate of 25 mmol O_2/kg organic matter/h.

Self-heating

This uses the Rottegrad test, which assesses the compost's ability to self-heat under standardised conditions in an insulated vessel over a set period of time, as measured by temperature increases relative to ambient. The Rottegrad is a unit-less scale ranging from I (fresh, unstable) to V (fully mature and stable).

The EU FPR specifies that compost must reach at least Rottegrad III to be classified as stable. The standards EN 16087-2:2011 and DIN V 11539 are published methodologies for carrying out self-heating tests.[45] [46]

[42] The terms stability and maturity are sometimes used interchangeably, although there are technical differences between the two: **Compost stability** refers to the degree to which compost resists further biological decomposition, indicating low microbial activity and minimal release of gases or heat. **Compost maturity** describes the extent to which compost has fully decomposed and is free from phytotoxic compounds, making it safe and beneficial for plant growth.
[43] US Composting Council (2022). Model Compost Rule Template Version 2.0.
[44] **EN 16087-1:2020** Soil improvers and growing media - Determination of the aerobic biological activity - Part 1: Oxygen uptake rate (OUR).
[45] **EN 16087-2:2011** Soil improvers and growing media - Determination of the aerobic biological activity - Part 2: Self heating test for compost.
[46] DIN (2007). Compost – Determination of the degree of rotting in a self-heating test. Available at: DIN V 11539 - Compost - Determination of the degree of rotting in a self-heating test | GlobalSpec

3.1.4 CONTAMINANT TYPES AND LIMITS

Contaminant limits are important to ensure that compost is safe for users and the environment as high levels of contaminants can pose risks to human health, soil ecology, and plant growth. Contaminants are generally categorised into three types: physical, chemical and biological.

Physical Contaminants

Physical contaminants (also known as impurities) are non-compostable materials that are not intended to be part of compost and can adversely affect its quality and usability. These are often described as 'macroscopic impurities' which are materials such as glass, metal and non-compostable plastics that were in the incoming waste and were not removed during waste pre-treatment at the composting site or during the composting process.

Physical contaminants appear often due to poor segregation practices or non-compostable packaging that accompanies food waste being put into the composting stream. Composters aim to remove physical contaminants as best as possible during waste pre-treatment and, secondarily, in the compost screening phase through sieving the compost to a suitable particle size range.[47] [48] Any compostable item that does not adequately **disintegrate** by the end of the composting process is also counted as a physical contaminant[49].

The EU FPR sets a compost quality criterion of no more than 3 g/kg in compost (on a dry matter basis) of macroscopic impurities sized ‘above 2 mm’, reducing to 2.5 g/kg by the 16 July 2026.

The EU FPR does not limit stones in compost and national standards for composts differ on whether stones are included in their macroscopic impurities limit. In some cases, a separate limit is set.

Chemical Contaminants

Chemical contaminants include a range of substances that can be toxic to plants, animals and humans. These can be persistent in the environment and adversely affect soil health. They include potentially toxic elements (PTEs) such as cadmium (Cd), hexavalent chromium (Cr VI) and mercury (Hg), and some substances, such as biuret.

[47] European Commission (2013). End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate).
[48] Lebensministerium.at (2009). The State of the Art of Composting: A guide to good practice.
[49] Applies to an item or any piece / fragment sized 2 mm or larger, in any dimension.

The EU FPR limits for PTEs, PAH and substances applicable to organic fertilisers are listed in Table 1.

Table 1: EU FPR limit levels of potentially toxic elements and PAH allowed in organic fertilisers

Element or substance	Maximum concentration
Cadmium (Cd)	1.5 mg/kg dry matter
Hexavalent chromium (Cr VI)	2 mg/kg dry matter
Mercury (Hg)	1 mg/kg dry matter
Nickel (Ni)	50 mg/kg dry matter
Lead (Pb)	120 mg/kg dry matter
Inorganic arsenic (As)	40 mg/kg dry matter
Copper (Cu)	300 mg/kg dry matter
Zinc (Zn)	800 mg/kg dry matter
Biuret ($C_2H_5N_3O_2$)	Must not be present
Total of 16 named types of polyaromatic hydrocarbon (PAH_{16})	< 6 mg/kg dry matter

The Standard EN 13650:2001 sets the methodology for determining the content of potentially toxic elements in compost.[50]

Biological Contaminants

Biological contaminants include pathogenic micro-organisms (e.g. viruses and bacteria), parasites, plant toxins and weed seeds.[51] They occur naturally in some bio-wastes and are usually eradicated in composting processes by the high temperatures reached in the thermophilic phase and the activity of composting microbes. Temperatures are usually monitored closely by composting facility operators to ensure compost has reached the required temperature for a sufficient length of time.

Considering pathogens, most national standards, including the EU FPR, require the following:

- *Salmonella* spp should be absent in at least 5 samples of 25 g of 'fresh matter', and
- *Escherichia coli* should not exceed 1,000 colony forming units (CFU) in 1g or 1 ml of 'fresh matter' in at least 5 samples.

[50] EN 13650:2001 Soil improvers and growing media - Extraction of aqua regia soluble elements
[51] International Solid Waste Association (2023). A Practitioner's Guide to Preventing and Managing Contaminants in Organic Waste Recycling.

- Furthermore, there are lab testing standards found to examine specific biological contaminants in compost samples such as weed seeds (EN/TS 16201[52]), *Salmonellae* CEN/TR 15215-3[53]), and *Escherichia coli* (ISO 16649-2[54]).

3.1.5 OTHER COMPOST CHARACTERISTICS

Other compost characteristics that may be tested are its pH level and how plants respond to it. Common acceptable ranges of pH are usually between 6.5 and 8.5. While the EU FPR requires the pH of organic soil improvers and growing media to be tested and declared, it does not require any product or material in the product to undergo plant response testing.

Some national standards require, or recommend, these tests; for example, BSI PAS 100[55] in the UK sets plant response pass/fail criteria and recommends that compost pH levels are tested and declared. It should be noted that different plant species prefer different pH levels, and the rate of compost use, how it is used (e.g. surface-applied or incorporated), soil type and stage of plant development when compost is added are factors relevant to planning its use.

3.1.6 TRACEABILITY AND LABELLING

Traceability and labelling are essential for providing consumers with information about the compost's composition, origin and usage instructions. This transparency ensures that users can make informed decisions and use compost products safely and effectively.

To maintain traceability, industrial composters implement robust quality management systems that track the composting process from feedstock receipt to product. This includes recording feedstock sources, composting batch numbers, process management and processing conditions, compost sampling and test results, and storage then dispatch of compost batches.

This traceability ensures accountability and facilitates compliance with regulations.[56] Production, quality control, compost sampling and testing, labelling plus waste and compost traceability documentation is often audited by organisations offering compliance schemes across Europe.

The EU FPR specifies that compost must be labelled with details such as nutrient content, contaminant levels and appropriate usage guidelines.

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[52] CEN/TS 16201:2013 Sludge, treated bio-waste and soil - Determination of viable plant seeds and propagules

[53] CEN/TR 15215-3:2006 Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and bio-wastes - Part 3: Presence/absence method by liquid enrichment in peptone-novobiocin medium followed by Rapport-Vassiliadis

[54] ISO 16649-2:2001 Microbiology of food and animal feeding stuffs — Horizontal method for the enumeration of beta-glucuronidase-positive *Escherichia coli.* Part 2: Colony-count technique at 44 degrees C using 5-bromo-4-chloro-3-indolyl beta-D-glucuronide.

[55] BSI PAS 100:2018 Specification for composted materials.

[56] ECN. ECN-QAS. Available at: [ECN-QAS - European Compost Network]()

As an alternative to on-pack labels, labelling can be in the form of document(s) the composter supplies to the compost buyer, which is practical for compost that has not been bagged and can include relevant laboratory test reports. This information helps users apply the compost correctly and ensures it meets their specific needs as well as ensuring compost quality[57].

3.2 COMPOST PRODUCTION AND QUALITY CERTIFICATION SCHEMES

Compost production and quality certification schemes in Europe are important because they ensure that compost products meet consistent safety, environmental and quality standards, in order to protect human health and the environment, and build consumer trust.

The European Compost Network's Quality Assurance Scheme (ECN-QAS)[58] is the sole pan-European compost certification scheme, certifying a number of national quality assurance organisations, such as:

- Kompost & Biogas Verband Österreich (KBVÖ) in Austria;
- Vlaco in Flanders, Belgium;
- Bundesgütegemeinschaft Kompost (BGK) in Germany; and
- Consorzio Italiano Compostatori (CIC) in Italy.

These organisations conduct rigorous certification processes involving regular testing, auditing and monitoring of compost production processes and products to ensure they adhere to established standards, including those specified in the ECN-QAS.

Figure 6. Selected European compost quality logos

Pan-European ECN-QAS

Austria

Flanders, Belgium

Germany

Italy

UK

[57] European Commission (2013). End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate).

[58] ECN. ECN-QAS. Available at: ECN-QAS - European Compost Network

Outside of the EU, the Renewable Energy Assurance Ltd's Compost Certification Scheme in the UK certifies compliance with BSI PAS 100[59] and relevant national end-of-waste criteria set by the environmental regulator.

These certification schemes all licence the use of their certification mark so that producers of certified compost product can demonstrate to consumers that the product has been independently quality assured and meets quality standards. Examples of quality marks are shown in Figure .

[59] BSI PAS 100:2018 Specification for composted materials.

4 FIELD-TESTING GUIDANCE

Standards **EN 13432**[60] and **EN 14995**[61] specify several tests that packaging or products must meet in order to be deemed compostable. Biodegradation, heavy metal concentrations and ecotoxicity can only be tested in a laboratory due to the nature of the test methods and the specific types of equipment needed. However, **field-testing** is a direct way of assessing **disintegration** of compostable products and packaging (**compostable items**) in an operational industrial composting facility, where there will be localised temperature, moisture, aeration and mixing variations. It is an option specified in **EN 13432** and **EN 14995**.

Field-testing can form part of a research trial or can be part of a certification process. It can be applied to items already certified as well as those that are under development. Testing is often undertaken by a site operator, research institute (such as a university) or an ISO 17065[62] accredited certification body (using ISO 17067:2013)[63].

Conducting field-testing trials within different facilities using different industrial composting methods can demonstrate disintegration across the varying operational conditions found in practice.

This chapter describes the key elements needed to conduct a **disintegration study**, incorporating different methods of running field-tests and advising on those deemed to be the most effective. This includes **sample preparation**, **data collection**, **analysis** and **interpretation**.

4.1 FIELD-TESTING OPTIONS

There are two main approaches to field-testing: **bulk dosing** and containing samples inside **mesh bags**. Both methods have advantages and disadvantages, with the choice based on the preference of the facility, the equipment available and the scope of the test.[64.]

4.1.1 BULK DOSING

The bulk dose testing method integrates compostable materials or items directly into the composting process without containment. This method better simulates real-world conditions by allowing the compostable items to interact fully with the composting material and microbial environment.[65]

[60] EN 13432:2000 Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging.
[61] EN 14995:2006 Plastics - Evaluation of compostability - Test scheme and specifications.
[62] ISO/IEC 17065:2012(en). Conformity assessment — Requirements for bodies certifying products, processes and services
[63] ISO/IEC 17067:2013(en). Conformity assessment — Fundamentals of product certification and guidelines for product certification schemes
[64] van der Zee, Maarten, and Molenveld, Karin (2020). The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility. Wageningen University & Research.
[65] Closed Loop Partners (2024). Breaking It Down: The realities of compostable packaging disintegration in composting systems.

Bulk dose testing provides insight into how compostable items behave in a typical composting system, including their impact on overall compost quality and the efficiency of the composting process.

However, retrieving and analysing materials can be more challenging in bulk dose tests, due to the lack of containment and the potential for uneven exposure to composting conditions (e.g. if an item or fragment is at or near the surface of the composting batch for some of the time). Bulk dose testing will also require high sample incorporation rates to make sure significant results in sample retrieval, and assessment against the limit level for plastics in compost set in the EU Fertilising Products Regulation or in national standards or 'end of waste criteria', are possible[66].

4.1.2 MESH BAGS

The mesh bag method involves placing compostable items inside mesh bags, which are then subjected to typical composting conditions. This approach allows for the easy retrieval and examination of the contents after a specified period, facilitating detailed analysis of the disintegration process. The mesh bag method is particularly useful for tracking the breakdown of smaller items and for ensuring that the compostable materials are consistently exposed to similar conditions throughout the test period.[67] Mesh bag sizes can differ depending on the sample size. On average, a mesh bag capacity varies between 20 and 40 litres[68].

The mesh hole sizes of the bags need to be small enough to contain the test samples, but large enough to contain the matrix (rotting) material, water and air. Mesh openings of between 2 to 10 mm are sufficient for many sample sizes[69]. If the test aims to assess disintegration according to EN 13432's threshold of quantifying the total of any sample fragments of 2 mm or larger, then mesh sizes larger than 1 mm should be avoided. On the other hand, small mesh sizes will lead to reduced aeration and hence less aerobic conditions inside the bag compared to conditions outside the bag. Consequently, disintegration may proceed at a slower rate inside the bag than outside.

4.2 FIELD-TEST PREPARATION

When preparing for field-test studies it is important to characterise the type and location of the composting facility where the test will be performed, the methods that will be used to assess compostability and the control measures needed to support interpretation of the outcomes.

[66] The EU Fertilising Products Regulation specifies that the compost shall contain no more than 3 g/kg dry matter of macroscopic impurities above 2 mm, with the limit for plastics >2 mm being reduced to 2.5 g/kg dry matter by July 2026. This means that the maximum concentration of plastics in the incoming wet bio-waste should not exceed 0.09 % (mass/mass) or 0.075 % on a fresh mass basis, respectively. In order to assess plastics levels in the test compost against the EU FPR limits, **dosing rates in excess of 0.1 % on a fresh mass basis would be required**.

[67] Cafiero, L.M. *et al.* (2020). Assessment of disintegration of compostable bioplastic bags by management of electromechanical and Static Home Composters. *Sustainability*, 13(1), p. 263. doi:10.3390/su13010263.

[68] UNI PdR 79/2020 (2020). Test method for the verification of the disintegration of products in industrial composting facilities.

[69] UNI PdR 79/2020 (2020). Test method for the verification of the disintegration of products in industrial composting facilities.

4.2.1 COMPOSTING PLANT

Location and Partnership

An industrial composting operator is an essential partner for field-tests. They will typically provide a suitable space for compost test piles, a replicable process for the facility type (e.g. windrow or aerated static pile), and the process machinery needed (diggers, shredders, etc).

Depending on the preference of the researcher and the facility, the field-tests are often completed in designated piles, but can also be undertaken within existing vessels, piles or rows. The testing pile location needs to be easily accessible and sited in an area where it will meet the specific composting parameters and processes outlined in Chapter 2.

In addition, the facility will need to obtain relevant authorisation from their environmental regulator if the compostable items for testing are not included in the current site permit and/or end of waste rules.

Technical Competency

Test co-ordinators should have a high level of technical competence before running field-tests, and work alongside an experienced composting site manager. This is to ensure that the field-test is set up correctly and that the composting process is managed in line with the site's standard operating procedures throughout the duration of the test.

4.2.2 SAMPLE PREPARATION & INCORPORATION RATES

Format

Items should be tested in the format in which they are usually disposed of by consumers. This includes size, shape and contamination level. For example, teabags should be wet and contain tea leaves, and compostable caddy liner bags should be filled with food waste to reflect their real-world application.

Control Samples

Control materials are often used in field-tests to validate the test results and give facilities a known reference point to evaluate the performance of the test material. A control is a material for which disintegration behaviour in the facility is known and understood from past studies and day to day processing. Common examples are certified compostable packaging, or food samples that disintegrate slowly and remain visible, such as orange peel. In the case of bulk dosing, however, where the latter food examples are not found generally in composting, other control sample types should be considered.

Some non-food examples used by facilities are cellulose film, and single-ply kraft paper.[70] Discussion with the facility operator can help determine the most suitable option to use.

[70] Strand, Chantal and McGill, Emily (2017). Field-testing Protocol for Compostable Packaging. Available at: Field-testing Protocol for Compostable Packaging | BioCycle.

Polylactic Acid (PLA) is not recommended for use as a control as its degradation is more affected by temperature than by microbial activity. Studies on PLA, have found that it often decomposes quicker than bio-waste, deteriorating in as little as 11 days,[71] however, this depends on the material thickness and crystalline content.

Testing samples with these materials helps to determine the efficacy of both research studies and commercial field-testing of disintegration of the sample packaging in question, as shown in Table 2.

Table 2: Interpretation of disintegration results of test sample and control

TEST SAMPLE	CONTROL	INTERPRETATION
✓	✓	Indicates the test samples will successfully disintegrate within the conditions tested[72] The quality of the resulting compost should be tested, and this should be taken as the final result.
✗	✓	It is possible that the test sample is not compatible with the composting process at the test facility. Consider additional testing and/or compare to results from similar field tests.
✗	✗	The process is likely to have fallen outside of the optimum parameters as discussed in Chapter 2. Common reasons for test samples not disintegrating are low moisture content and insufficient time spent in any of the composting phases.

✓ = adequate disintegration of the material at the end of the composting process
✗ = failure to disintegrate at the end of the composting process

Incorporation Rate

The proportion of sample relative to the amount of bio-waste mixture (sample to bio-waste ratios) needs to be considered. This will vary depending on factors such as the sample size, method (mesh bag or bulk dosing) and the type of compostable item being tested. It is, however, important to consider the balance of bio-waste and compostable packaging for maintaining ideal composting parameters.

When using mesh bags, The Consorzio Italiano Compostatori (CIC) suggests a **minimum of 1% sample (by mass) to the mass of bio-waste**.[72] This is ten-fold greater than the minimum of 0.1% required if the plastic limit levels set in the EU Fertilising Products Regulation are to be used as a benchmark.

[71] van der Zee, Maarten, and Molenveld, Karin (2020). The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility. Wageningen University & Research.
[72] UNI PdR 79/2020 (2020). Test method for the verification of the disintegration of products in industrial composting facilities

Incorporation into the Composting System

Testing carried out using the bulk dosing method should incorporate the test items into the composting system at the start of the process (i.e. alongside the incoming bio-waste) and treated in line with the site's standard operating procedures, including any shredding steps. In this way it can be seen how the item will behave throughout the process.

Items tested using the mesh bag method should be incorporated immediately after the shredding stage.

Contamination Levels

Minimising contamination is particularly important for ensuring compost products comply with compost quality regulations (*see Chapter 3*). Items should not contain any components that will result in visible contamination of the final compost. For example, metal staples on teabags or aluminium films. The impact of product residues should also be considered, for example, detergent residues in packaging can adversely impact the composting process and therefore compostability of the contents of packaging is as important as the packaging itself. Before field-testing, it is best practice that items are first screened for potentially toxic elements to ensure they will do no harm to the compost.

4.3 OPERATING PARAMETERS

The operating parameters during trials should replicate the industry parameters discussed in Chapter 2 (temperature, aeration, moisture content, pile shape, pile turning if applicable and its frequency etc). It is important to examine these parameters during the field-test, to affirm the optimal conditions for composting. Depending on the composting methods used at the facility, the likelihood of variability is inevitable; however, by following the site's standard operating procedures, the parameters should fall within the ranges suggested. However, it is still best practice to check certain parameters over the period of the field test, including:

- **Temperature:** There should be regular daily temperature monitoring following the procedures specific to the facility in which the test is conducted. This should be undertaken at least once daily with one probe every 15 cubic metres, or for smaller masses, at a minimum of three representative points within the material.
- **Moisture levels:** There are differences between European countries on whether moisture monitoring is required or recommended. Such monitoring is beneficial because moisture in composting piles greatly affects outcomes for fibre-based compostable items.[73] Where permits and/or End of Waste rule sets do not already require moisture monitoring and specify associated details, moisture content should be measured whenever the pile is turned, or ideally at least once every two to three weeks for process types which are not turned.[74]
- **Oxygen:** An optional parameter which could be measured during the process.

4.4 PROCESSING CONSTRAINTS

During the field-testing, there are several challenges that can interfere with the investigation and impact the results:

- Contamination by non-compostable materials (such as glass, metals, conventional plastics), which can hinder the composting process and adversely affected the quality of the finished compost. They must therefore be removed from the input material before the test trials.
- Geographical location and seasonality (mainly related to difference in waste composition) were two out of a number of factors that have potential to affect temperature and moisture levels; therefore, they should be taken into consideration when optimising testing parameters.

4.5 SAMPLE COLLECTION, ANALYSIS AND REPORTING

A structured method to monitor disintegration progress is through staggered retrieval of testing samples across the composting timeframe. It is important to include all phases of the composting process when testing, as different types of packaging disintegrate more efficiently at different stages. For example, fibre-based packaging requires, after the thermophilic phase, the mesophilic and maturation phases to disintegrate lignin-rich fibres sufficiently.[73]

4.5.1 SAMPLING POINTS

Choosing exactly when samples can be taken will be dependent on the field test protocol and the composting method, due to the length of time each method takes. As discussed in Chapter 2, there is variation in composting processes across Europe and as such there is a variability in the process timeframes. End points in field tests are set based on a specific timeframe or when a stable and mature compost is produced. The Italian Biogas and Composting Association (CIC) protocol (UNI-PdR-79:2020) follows a 12-week end point, aligned with EN and ISO standards for composability. The ASTM field test methods (D6819 and D6818) instead do not specify a timeframe and set the end point when a stable and mature compost is produced.

To better understand material behaviour during the composting process, recent studies have adopted a dual sampling approach, introducing an intermediate sampling point in addition to the traditional 12-week end point. For instance, the Biodegradable Products Institute (BPI) reviewed around 1,000 field test data points collected across North America and Europe, all involving certified compostable products. This approach enabled the evaluation of material disintegration at different composting stages, offering greater insight into degradation dynamics beyond the final outcome.

[73] Closed Loop Partners (2024). Breaking It Down: The realities of compostable packaging disintegration in composting systems.

These data points were all products certified to ASTM, EN or ISO standards. All products represented in the data (55% compostable plastic, 27% coated paper, 13% uncoated paper, 4% wood, 1% mixed material) passed field-test requirements, with 85% of the samples passing field tests within a 49-day facility timeframe.[74]

Similarly, the Composting Consortium (a project of Closed Loop Partners) implemented two sampling points—one at 47 (±2) days and another at the 12-week mark—across multiple composting facilities in the U.S. This methodology facilitated a comparative analysis of disintegration performance over time, providing a clearer picture of how various materials behave at both early and later stages of the composting process.[75]

4.5.2 SAMPLE PREPARATION AND ANALYSIS

Collected samples first need to be **air dried thoroughly to constant mass** at a temperature of 40 ± 2 °C.

Samples then need to be **sieved to create a number of different fractions** for analysis, as follows:

- Initial screening should be carried out using a **10 mm mesh sieve** to remove oversized fragments of the test item. These fragments should be set aside for disintegration calculation.
- The smaller fragments of the test item that passed through the 10 mm sieve should then be sieved through a secondary **2 mm mesh sieve**.[76] This sieve should collect fragments in the size range ≥ 2 mm to < 10 mm. These fragments should also be kept.
- Fragments smaller than 2 mm should pass through this sieve's mesh and should be discarded.
- Fragments of compost should also be carefully removed. If necessary, the fragments should be washed using distilled water, then dried again to constant mass at 40 ± 2 °C.
- Fragments of **test materials retained on the 2 mm and 10 mm mesh sieves** should then be combined for analysis. This is categorised as **non-disintegrated material**.

There are two methods that can be used to measure the quantity of compostable items greater or equal to 2 mm in size:

Mass

The mass of material is determined using a calibrated top-pan balance, usually measuring to a hundredth of a gram.

The results should be expressed as a **percentage of the initial dry mass of the test item**.

[74] Biodegradable Products Institute (2021). Review of Publicly Available Field-testing Results and Programs.
[75] "Breaking It Down: The Realities of Compostable Packaging Disintegration in Composting Systems" https://www.closedlooppartners.com/research/compostable-packaging-disintegration-at-composting-facilities/
[76] UNI PdR 79/2020 (2020). Test method for the verification of the disintegration of products in industrial composting facilities.

Surface Area

The total surface area of the fragments should be determined in the following way:

- All fragments should be **arranged on a contrasting background** and a digital image taken.
- Specialist software (e.g. open-source ImageJ) should then be used to estimate the **total surface area of the fragments**.

The results should be expressed as a **percentage of the initial surface area of the test item**.

For field-testing, measuring surface area was found to be a more reliable metric for flat samples (i.e. flexible plastic) than measurements based on mass.[77] Detritus sticking to fibrous packaging and absorption of oil from foodstuffs were examples where weighing becomes a challenge. Measuring surface area, nevertheless, requires specialist equipment and weighing can then present itself as a more accessible option.

Both methods are effective. Photographic documentation should be taken as evidence at each stage of screening, and for the different dimensional categories sorted, i.e. <2 mm, 2 - 10 mm and >10 mm.

Compost Quality

The quality of the compost taken from the test samples should also be assessed in line with the requirements specified in EN 13432 and for its environmental and agronomic quality within EU FPR, or relevant national standards / end-of-waste criteria.

4.5.3 FIELD-TEST REPORT

A comprehensive test report should be compiled to ensure transparency and scientific validity; and should include the following:

- **Recorded data** from the testing process
- **Photographic or video evidence** documenting the test setup and progression
- **Detailed descriptions of test materials**, including:
  - Types of samples tested
  - Positive and/or negative controls used
- **Laboratory results**, covering:
  - Compost quality parameters
  - Behaviour and disintegration of the test samples

This documentation should be assembled in accordance with the criteria outlined in this and previous chapters, ensuring the report is robust and verifiable.

[77] Closed Loop Partners (2024). Breaking It Down: The realities of compostable packaging disintegration in composting systems.

5 EXISTING FIELD-TESTING PROTOCOLS

The information and guidance presented to date is partially based on the existing field testing protocols already used in Europe and North America. This chapter will review the key parameters used in the existing protocols as well as showcase the variety of approaches applied as well as the commonalities between the protocols as these have been developed independently based on the national regulations and requirements.

Currently, various field-testing protocols for compostable materials are applied across different countries and are not harmonised across Europe as discussed in the introduction. One of the oldest and most established is the "full-scale" test developed by the **Italian Biogas and Composting Association (CIC)**. This protocol is detailed in UNI-PdR-79:2020 and is an integral part of CIC's certification scheme for compostable products, known as "Compostabile CIC." This scheme ensures that certified items break down effectively under real-world composting conditions.

Similarly, **Cré, the Composting and Anaerobic Digestion Association of Ireland**, has developed its own certification scheme, which includes a dedicated field-testing protocol, to aid acceptance of compostable items at their members' facilities.

Both CIC and Cré protocols have been designed to **evaluate the disintegration of compostable products and packaging under full-scale operational conditions**, closely matching real-world composting environments. Both schemes align with the European harmonised standard EN 13432, which sets the criteria for compostability and biodegradability in industrial composting facilities.

In **North America (United States and Canada)**, multiple field-testing protocols have been used, including the open-source research platform Compostable Field Testing Program (CFTP) and the private certification from the Compost Manufacturing Alliance (CMA). Recently, the Biodegradable Products Institute and CFTP led a 3-year process to develop standardized field test methods at ASTM: ASTM D8619-25 (with "containers" like mesh bags) and ASTM D8618-25 ("dosing" or samples added loose to the pile).

5.1 COMPARISON OF TESTING CRITERIA AND APPROACHES

Each field-test protocol encompasses a range of key aspects, from the preparation of test items to the setup and execution of the field-test, as well as the monitoring and assessment of operating parameters throughout the process. These protocols define specific methodologies for evaluating compostable materials under real-world or controlled composting conditions. Table 3 provides a comparative overview of the main aspects and parameters considered in these different protocols.

It is essential to recognise that these aspects are directly linked to the objectives of each protocol, which may vary significantly or only partially overlap. Some protocols focus primarily on assessing visual contamination, evaluating whether compostable items leave behind noticeable residues in the final compost. Others emphasise quantifying the degree of disintegration within a specified time frame, ensuring that materials break down at an acceptable rate.

Additionally, certain protocols include chemical analyses to examine potential impacts on compost quality, while others prioritise compatibility with different industrial composting processes by simulating actual facility conditions.

These variations highlight the importance of selecting an appropriate field-test protocol based on the intended outcome and regulatory requirements, ensuring that compostable items meet performance expectations in their designated end-of-life environment.

Table 3: Comparison of assessment criteria in different field-testing protocols

Organisation or Field-test name	CIC Test "full scale"	CRE	US
Type of field-test	Mesh bags	Mesh bags	Mesh bags (D8619) and Dosing/loose (D6818)
Type of compostable item	Both paper and bioplastic based, Test used for items to be certified	Must be certified to EN 13432 and certification must apply to the product.	Both paper and bioplastic items that meet ASTM D6400 or equivalent.
Instructions about preparation of samples	Sample sizes reduced to pieces, 10 x 10 cm.	Samples tested whole.	No size reduction of sample. Samples are pre-soaked in water to simulate being food soiled.
Definition of the composition of input mixture of bio-waste (i.e. standard mixture)	Yes	Yes	Yes
Concentration/amount of samples inside composting	Minimum of 1% (fresh mass basis) placed samples in net bags	Samples tested whole in net bag containing 2 kg amount of bio-waste	Max 20% by volume.
Duration of disintegration or endpoint	12 weeks	On completion of batch in accordance with test site standard operating protocol.	No fixed time. Endpoint is when a stable and mature compost has been produced, or the sample disintegrates, whichever is first.
Sample collection FOR the field-test (i.e. who takes sample from the producer of the product to be tested)	Done on site of the applicant by a third-party certification body.	Samples supplied by applicant.	Not restricted.

Organisation or Field-test name	CIC Test "full scale"	CRE	US
Compliance of the compost produced during the test	Yes, defined according to national fertiliser regulations.	Batch meets site license/permit requirements.	Maturity (at end of trial period): ≥80% of control (TMECC 05.05) Stability (at end of trial period) ≤4 mg CO_2-C per g OM per day (ASTM D5975)
Time temperature profile	Min values and frequencies of measurement defined.	Not defined, batch must be run in accordance with site's standard operating protocol.	Values defined, and frequency of measurement, for temperature, moisture, oxygen, C:N, bulk density, and pH.
Reference	UNI PdR 79:2020	N/A	ASTM D8618 and D8619

This comparative overview of existing field-testing protocols used across Europe and North America, illustrating the diverse yet converging methodologies developed to assess the disintegration of compostable materials under industrial composting conditions. While procedural differences exist—such as in test duration, sample preparation, and endpoint determination—all protocols underscore the necessity of evaluating compostable items within operational environments that reflect real-world variability and processing practices.

A fundamental consideration that emerges from this review is the role of compost maturity in enabling full disintegration. Certified compostable items are designed to break down in industrial composting settings that achieve biologically stable and mature compost. Hence facilities operating standard composting cycles that produce stable, mature compost are unlikely to encounter disintegration issues with certified compostable products.

When composting facilities operate under relatively short cycles that yield only partially stabilized material **and produce fresh compost, in accordance with national or regional regulations on soil improvers,** the environmental conditions required for complete disintegration **of compostable items** may not be fully established.

As such, under these constraints, it is not realistic to expect those items to disintegrate completely within ultra-short timeframes. This underscores the importance of aligning product expectations with the actual process capabilities of composting infrastructure. In such cases, facilities may still assess item performance **with field-testing protocols** by applying multiple short-cycle exposures (recirculation), thereby approximating the cumulative conditions of a **longer** composting process.

Harmonising and standardising field-testing methods to take into account of real-world conditions could improve the reliability and interpretation of testing outcomes in real world conditions; meaning that test results obtained in one country could be accepted within another.

APPENDIX

APPENDIX 1: DEFINITIONS

Term	Definition
Aerated Static Pile	A method of composting bio-waste where the material is placed in a large pile and aerated using a system of pipes that blow or draw air through the pile. This method eliminates the need for turning by providing the oxygen necessary for aerobic decomposition through forced air, maintaining optimal conditions for microbial activity and efficient composting.
Anaerobic digestion	Process that breaks down organic matter (e.g. food waste) by microbial activity in the absence of oxygen. It produces biogas which can be treated to produce biomethane or electricity and heat. The resulting material from AD process is the digestate. AD technologies and process management differs, in whether and how they perform the anaerobic process but also how it is to treat digestate before its removal from the facility; Digestate post-treatment examples are: in-situ direct composting; separation into liquid and solids fractions, by composting separated digested solids (with or without adding 'fresh' bio-wastes), or by drying and pelletising separated digested solids. Definition from the current EN 13432, currently undergoing revision.
Bio-based	A material derived from biomass.
Biodegradable	Biodegradable items are made from synthetic or natural origin materials which can be used by microbes as a food source due to their chemical structure. Biodegradable materials can be broken down by extracellular enzymes and/or chemical hydrolysis to yield fragments which can pass the cell walls of microbes and are finally metabolised into CO_2, water, energy and biomass. The classification of an item as biodegradable is only useful if it is combined with a timeframe & environment of biodegradation. As such compostable items can be seen as a sub-set of biodegradable items as they will only biodegrade in a 'composting environment'.
Biodegradable plastics	A plastic that is capable of undergoing biodegradation. The bio-degradability of a plastic is linked to the chemical structure of the polymer chain and does not depend on the origin of the raw materials; hence biodegradable plastics may be derived from either petroleum or biomass precursors.

Term	Definition
Biodegradation	The microbial conversion of the organic constituents of a material or substance to carbon dioxide, new microbial biomass and mineral salts under aerobic conditions, or to carbon dioxide, methane, new microbial biomass and mineral salts, under anaerobic conditions. The rate of biodegradation depends on a variety of factors, such as environmental conditions and the type and properties of a material or substance.
Biogas	Gaseous product of an anaerobic digestion process which consists mainly of methane (CH_4), carbon dioxide (CO_2) and smaller quantities of other gases (e.g. hydrogen sulphide, H_2S). Biogas can be upgraded to produce biomethane or used in a generator to produce electricity and/or heat.
Biomass	Material of biological origin excluding material embedded in geological formations and material transformed into fossilised material. Biomass includes trees, crops, grasses, algae, mycelium and waste of biological origin, e.g. manure.
Bioplastic	A generic term used for plastics that are either a) biobased, b) biodegradable or c) both. Note: Due to the ambiguity of this term, it is not used in this Guideline document.
Bio-waste	Biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing facilities.
Carbon-to-nitrogen ratio (C:N)	The proportion by mass of carbon to nitrogen in 'bio-waste' or 'compost'.
Certification	The provision by an independent body of written assurance (a certificate) that a product, service, or system meets specific requirements (adapted from ISO/IEC 17000:2020)
Certification body	Third-party conformity assessment body operating certification schemes (adapted from ISO/IEC 17000:2020)
Circular Economy	Economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development. Definition from ISO 59004:2024.
Compost	Soil improver obtained by composting of bio-waste (e.g. a mixture of plant waste, kitchen food waste) having a limited mineral content and a significant amount of organic matter. Definition in latest draft (Oct 2024) of EN 13432.

Term	Definition
Compostability	See: 'compostable'
Compostable	A material that undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leave no visible, distinguishable or toxic residue. (ISO 17088: 2021).
Compostable item	Term used to describe compostable packaging and/or a compostable non-packaging product.
Composting	The process of controlled decomposition of biodegradable materials under managed conditions, which are predominantly aerobic, and which allow the development of temperatures suitable for thermophilic bacteria as a result of biologically produced heat. Definition used in the JRC end of waste report 2014.
Conformity assessment	Demonstration that specified requirements in a standard are fulfilled (based on IS0/IEC 17000:2020)
Conventional plastic	Plastic typically derived from fossil-based feedstock sources that is not considered to be biodegradable or compostable over any reasonable timeframe.
Digestate	Solid or liquid by-product of an 'anaerobic digestion' process. Digestate can be used in agriculture as a fertiliser.
Disintegration	The physical breakdown of a material into very small fragments due to physical, chemical, or microbiological processes. (ISO 21067-2:2015)
Ecotoxicity	The harmful effects of a substance or material on the environment and its inhabitants, including plants and animals. It is a measure of the potential or actual impact of a substance on ecological systems and is often used in the assessment and regulation of chemicals and products.
End-of-life	The final stage in the lifecycle of a 'product' or 'material', where it is no longer useful or functional. When a product or material reaches its end of life, it becomes 'waste' or a discarded item. At this stage, it needs to be managed appropriately to minimize negative environmental impacts and promote sustainability.
End-of-waste	The point at which a material that was previously classified as waste has undergone a recovery operation (such as recycling) and meets specific criteria that allow it to cease being legally considered waste and instead be treated as a product or secondary raw material. (Directive 2008/98/EC)

Term	Definition
Field-test (noun) **Field-testing (verb)**	Assessment of the 'disintegration' of a 'compostable item' in an operational composting facility.
Home compostable	Packaging or product that is 'compostable' in a 'home composting' process.
Home composting	A 'composting' process carried out by householders in gardens or community areas. It involves relatively small volumes of bio-waste and is carried out at lower temperatures than industrial composting. The process takes longer than industrial composting to produce 'compost'.
Industrial composting	A 'composting' process that is carried out on a large-scale, treating thousands of tonnes of bio-waste every year and reaching temperatures above 55 °C. It is typically a managed process with defined operational practices (e.g. temperature range, time frame, oxygen supply) for industrial/commercial scale transformation of bio-waste into stable, hygienic 'compost' for use in suitable markets, e.g. agriculture.
Industrially compostable	Capable of being composted in an 'industrial composting' facility. Criteria for industrially compostable packaging are defined in EN 13432 and ISO 18606, while those for industrially compostable plastics (e.g. those in final product formats that are not 'packaging') are defined in EN 14995 and ISO 17088. Materials and products complying with these standards can be certified and subsequently labelled accordingly.
In-vessel composting	'Composting' technology involving the use of a fully enclosed chamber or vessel in which the composting process is controlled by regulating the rate of mechanical aeration with fans. Aeration assists in temperature control and oxygenation of the organic mass. Some countries have in-vessel composting processes that also use at least one outdoor phase of composting.
Landfill	A designated area or site where solid waste is disposed of and buried in the ground.
Main composting stage	Produces a lower quality, fresh compost which is not suitable for all applications. Also known as the thermophilic stage or main rotting stage of a composting process.

Term	Definition
Material	A substance or matter used to create physical objects, products, or structures. Materials can be natural or synthetic, and they can take various forms, including solids, liquids, and gases. They can be raw materials, such as wood, metals, or minerals, or they can be processed materials, such as plastics, ceramics, or composites.
Material recycling	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. The EU waste strategy distinguishes between: 'material reuse without any structural changes in materials; recycling meant as a material recycling, only, and with a reference to structural changes in products; and recovery meant as an energy recovery only. EEA
Maturation stage	Important for producing stable mature compost with a good balance of nutrients. Also known as mesophilic stage or curing stage of a composting process.
Maturity [of compost]	The state at which compost has undergone sufficient decomposition and stabilisation to be safe, stable and beneficial for its intended use, typically determined by a combination of chemical, biological and plant response tests.
Mesophilic	Micro-organisms that grow best at moderate temperatures, typically between 20°C and 45°C.
Non-compostable	Materials that are non-compostable do not degrade in a composting environment. This includes both fossil-based and bio-based materials that are not biodegradable. It also includes biodegradable materials that do not biodegrade in a composting environment.
Open air windrow	A long pile of bio-waste / material types that represent a composting batch, that is exposed to air and sized for regular turning by machinery to aid oxygen supply and diffusion throughout the windrow.
Organic carbon	Carbon atoms that are part of organic compounds—molecules primarily composed of carbon covalently bonded to hydrogen, and often to other elements such as oxygen, nitrogen or sulphur.
Organic matter [in compost]	Organic compounds in compost that are derived from once living plants, animals and micro-organisms. It is usually measured as the organic carbon content multiplied by 1.724.
Organic recycling	See: 'Bio-waste recycling'.
Organic waste	See: 'Bio-waste'.

Term	Definition
Packaging	Products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer.
Screening	The process of separating compost particles by size using mechanical screens or sieves. This can be to remove large, un-decomposed items (such as woody materials or contaminants).
Shredding	The mechanical process of cutting or tearing bio-waste into smaller pieces before composting. This step increases the surface area of the material, making it easier for microorganisms to break it down during the composting process.
Stability [of compost]	The degree to which compost has undergone biological decomposition and reached a state where microbial activity is minimal or significantly reduced.
Standard	A document, established by a consensus of subject matter experts and approved by a recognized body that provides guidance on the design, use or performance of materials, products, processes, services, systems or persons.
Sustainability	A characteristic or state whereby the needs of the present population can be met without compromising the ability of future generations or populations in other locations to meet their needs.
Thermophilic	Micro-organisms that thrive at relatively high temperatures, typically between 45°C and 80°C.
Turning	The mechanical process of regularly agitating, or mixing compost piles to introduce oxygen, distribute moisture, and ensure even decomposition of organic materials. This process helps to maintain aerobic conditions.
Waste	Any substance or object which the holder discards or intends or is required to discard.

APPENDIX 2: ANAEROBIC DIGESTION

Although composting remains the dominant method for bio-waste treatment, **anaerobic digestion** (AD) is increasing due to its ability to produce renewable energy in the form of **biogas**. Traction for biogas generation is increasing in Europe due to market incentives for renewable natural gas.[78] Furthermore, the land footprint of anaerobic digestion facilities can be lower than composting and odour exposure can be reduced, providing improved solutions to composting in an urban setting.[79]

Despite this, the fate of compostable items in anaerobic digestion systems is a newer area of study with much ongoing research. The first edition of this Compostable by Design Platform document focuses on industrial composting; however future editions plan to address anaerobic digestion in more detail.

Until relatively recently, AD and composting have been viewed as mutually exclusive processes, sometimes operating in competition with each other. This is now starting to change, with countries such as Italy requiring the pre-treatment of food waste-rich bio-wastes in anaerobic digesters before subsequent composting of solid digestate alongside garden waste. The two systems thus operate in series, forming complementary processes carried out at so-called integrated bio-waste recycling facilities.

Background information has therefore been provided in this appendix for reference purposes.

5.2 OVERVIEW OF ANAEROBIC DIGESTION

Anaerobic digestion involves the degradation of organic matter by micro-organisms in the absence of oxygen and produces biogas (a mixture of methane and carbon dioxide) and **digestate** without significant heat production. Biogas can be utilised in a combined heat and power facility to produce electricity and heat or can be upgraded to bio-methane where it can be injected into the national gas grid or compressed and used to power vehicles.

Anaerobic digestion technologies vary widely and can be categorised based on several criteria. The most relevant for municipal bio-waste treatment facilities are:

- Operating temperature:
  - Mesophilic: operating at 35-40 °C.
  - Thermophilic: operating at 50-55 °C.
- Moisture content:
  - Dry anaerobic digestion, with a moisture content of less than 85%.
  - Wet anaerobic digestion, with a moisture content of more than 85%.

[78] Closed Loop Partners (2024). What Role Can Anaerobic Digestion Pay in Processing Compostable Packaging?
[79] European Bioplastics (2024). Anaerobic Digestion of certified compostable products.

- Operational mode:
    - Continuous Digestion: E.g. food waste is continuously or incrementally added to the reactor.
    - Batch Digestion: e.g. bio-wastes are added to the reactor at the start and the reactor is sealed for the duration of the process.
- Standalone vs integrated systems
    - In standalone facilities the digestate is directly used in agriculture without additional composting
    - In integrated facilities (that have anaerobic digestion and a composting stage), the solid output from anaerobic fermentation (solid digestate) undergoes further aerobic stabilisation (composting) to reduce residual biological activity and achieve complete maturity of the final product (compost).

5.3 BIO-WASTE PRE-TREATMENT METHODS

Different anaerobic digestion technologies need different configurations of the pre-treatment stage in order to properly condition (macerate and remove contaminants) and feed the substrate into the digester. In this respect, the difference between wet and dry AD systems plays a crucial role. The choice between wet and dry anaerobic digestion depends primarily on the characteristics of the bio-waste substrate. Municipal bio-waste consists of green (garden) waste (high structure, high total solids content and fibrous) and food waste (having poor structure, low total solids content (<30%) and high-water content). Food waste can therefore be turned into a pumpable slurry and is better suited to wet AD systems. Structure and total solids content thus determine suitability for either dry or wet anaerobic digestion systems:

- Dry systems are suitable for substrates with higher structure and total solids content.
- Wet systems are suited for substrates with lower total solids content and higher water content.

In municipal bio-waste treatment facilities, pre-treatment typically generates residues of 10+%, with some facilities generating up to 30% of the input feedstock if commercial food waste is collected in combination with household food waste. If low in physical contaminants, these rejects may be suitable for composting due to their predominantly biogenic origin.

With current technology and facility set-ups these physical contaminants are being sorted out as rejects before the organic fraction enters the digestion system, however there are new technologies and approaches emerging to recover compostables for further treatment.

Depending on the content of contaminants in the input material, hand or automated picking was necessary in the past before shredding could continue. Thanks to advances in software technology, in particular artificial intelligence, an automated picking technology comparable to hand picking is now available, which is economically viable and especially useful for continuous operation.

Common combinations of technologies and pre-treatment options for bio-waste are outlined in Table 3.

Table 3: Overview of bio-waste pre-treatment options at different anaerobic digestion processes

Pre-treatment	AD Process Type			Comments
	Wet	Dry Plug Flow	Dry Batch	
Hand picking prior to milling or shredding	⊗	☑	☑	Working hygiene critical. Cost/benefit low for continuous operation.
Automated picking prior or after milling or shredding	⊗	☑	☑	Technological progress has resulted in higher picking efficiency.
Hydropulper	☑	⊗	⊗	
Hammermill + Screen	☑	☑	⊗	Milling increases metal and plastic contamination, strong dependence on hammermill design, speed and feedstock.
Shredder + Star Screen	⊗	☑	⊗	Slow-speed turning shredders should be used. Coarse fraction from the star screen should not be recirculated.
Shredder + Mixing	⊗	⊗	☑	
Magnetic separator[80]	☑	☑	☑	For ferromagnetic contaminants
Eddy current separators[80]	⊗	☑	☑	Non-ferrous metals, not widely used, low cost/benefit ratio
Stone separators[80]	☑	☑	⊗	

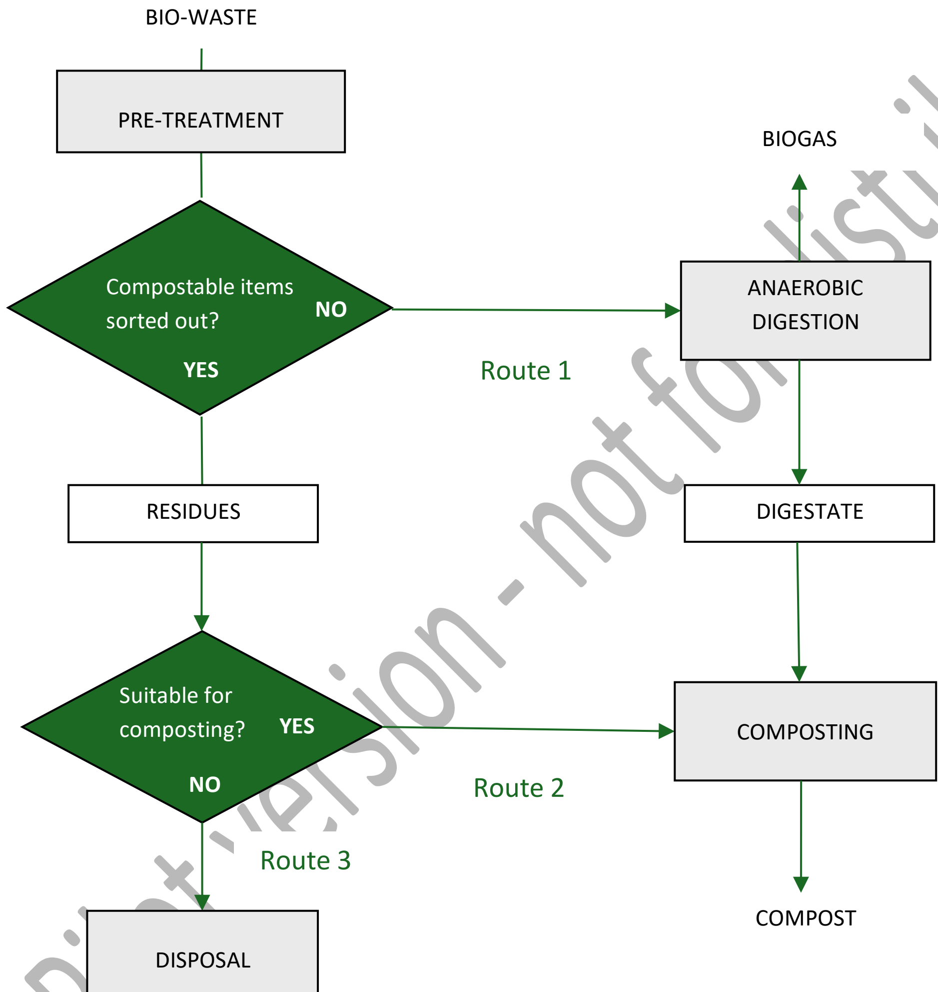
The CbDP innovation work stream is aiming to address these new pre-treatment technologies as well as other innovations in terms of technology, sorting and operation models relevant to the bio-waste recycling of compostable packaging and products.

[80] Grundkurs Ausbildung Betriebspersonal von Kompostier- und Vergärungsanlagen, Kapitel 3 – Verfahrenstechnik; U. Baier; Verein Inspektorat der Kompostier- und Vergärbranche der Schweiz; 2022.

5.4 FATE OF COMPOSTABLE ITEMS IN AD SYSTEMS

Bio-waste going to anaerobic digestion normally requires a pre-treatment step to prepare the input for digestion. This includes size reduction and maceration, mixing and in some cases de-packaging to remove non bio-waste components from the organic fraction.

Figure 5. Routes for compostable items at anerobic digestion facilities



Compostable packaging and products can follow different paths within bio-waste treatment facilities that combine AD with composting, depending on the pre-treatment and AD technologies employed. There are three possible routes as outlined in Figure 7 and the fate of the compostables in each of these routes are described in more detail in Table 4.

Table 4: Potential fate of compostable items in anaerobic digestion facilities

Anaerobic Digestion	Route 1	Route 2	Route 3
Pathway	Compostable items or parts thereof enter the digester with the bio-waste. In integrated facilities, after anaerobic digestion the digestate, including any remaining compostable plastic or fibre, undergoes aerobic stabilisation to produce stable compost.	Compostable items or parts thereof are sorted out during pre-treatment stage and rejoin the process during aerobic composting of the digestate.	Compostable items or parts thereof are sorted out during pre-treatment stage and are sent for disposal due to high contamination from non-compostable materials or the absence of a composting stage on-site for digestate stabilisation.
Impact on compostable items	Maximises energy recovery and material recycling, producing both biogas and compost. Compostable items are also fully included into biological treatment.	Ensures that also compostable items and other biogenic residues are composted to reduce disposal. This route is highly dependent on the pre-treatment technology applied and the range of physical contaminants delivered with the bio-waste.	This route is not optimal, resulting from either contaminated bio-waste or facility design limitations, leading to the disposal of compostable items along with the other physical contaminants and potentially significant amounts of bio-waste that are being dragged out with non-compostable items.

Shifting from Route 3 to Routes 1 or 2 enhances the efficiency of resource use. Low contamination rates by physical contaminants (such as non-compostable plastics, glass, metal) in input bio-waste are essential for this shift, with compostable items playing an important role in minimising contamination and maximising bio-waste exploitation.

It is worth noting that intensive pre-treatment systems are also used in many composting-only facilities. Therefore, the reasoning presented here about different routes for the recycling of compostable items may also be applicable to such situations.