A Practitioner's Guide to Preventing and Managing Contaminants in Organic Waste Recycling

ISWA
International Solid Waste Association

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Definitions

Organic waste

This guide defines organic waste as food scraps (and other organic kitchen waste) from households, restaurants, caterers and retail premises, biodegradable garden and park waste (leaves, grass, brush), food waste and comparable waste from food processing plants. The definition does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood; it also excludes those by-products of food production that never become waste.

The term 'bio-waste' is not used, as this definition primarily focusses on the European context.

Within the context of this document, organic waste is assumed to be sorted by generators (e.g., householders, commercial entities, etc.), collected separately from residual waste by waste hauliers and intended for recycling by means of composting, anaerobic digestion or both treatment techniques combined.

Organics recycling through biological treatment

This guide considers the following types of biological treatment of separately collected organic waste:

Composting –	the aerobic biological degradation of solid organic wastes under controlled conditions resulting in the production of "compost"; and
Anaerobic digestion –	the anaerobic biological degradation of organic wastes under controlled conditions resulting in the production of "biogas" and "digestate".

As some organic recycling facilities first treat incoming organic waste in an anaerobic digestion process, then stabilise the resultant digestate through composting, this approach is defined in this report as "combined anaerobic digestion and composting".

This document does not consider mechanical biological treatment (MBT) amongst the biological treatment options that may be used to recycle organic wastes. MBT is a type of process applied to mixed municipal solid waste (MSW), involving an initial sorting step to separate the organic fraction from more bulky, inorganic materials such as plastics, metals and glass. The (mechanically) separated organic fraction, which remains contaminated with a number of physical contraries (e.g., plastics) and inorganic and organic chemicals (e.g., heavy metals and persistent organic pollutants, respectively) then undergoes a form of biological treatment (such as composting or anaerobic digestion) to stabilise it. The stabilised organic fraction can be then landfilled to reduce greenhouse gas emissions or incinerated in a waste-to-energy plant.

Contaminant

An undesirable item, substance or biological material in organic waste and/or its recycled product that has the potential to adversely affect the recycling process and/or the recycled end product(s).

Hazard

Something that has the potential to cause harm. In the context of this report, it is a contaminant (physical, chemical or biological).

Risk

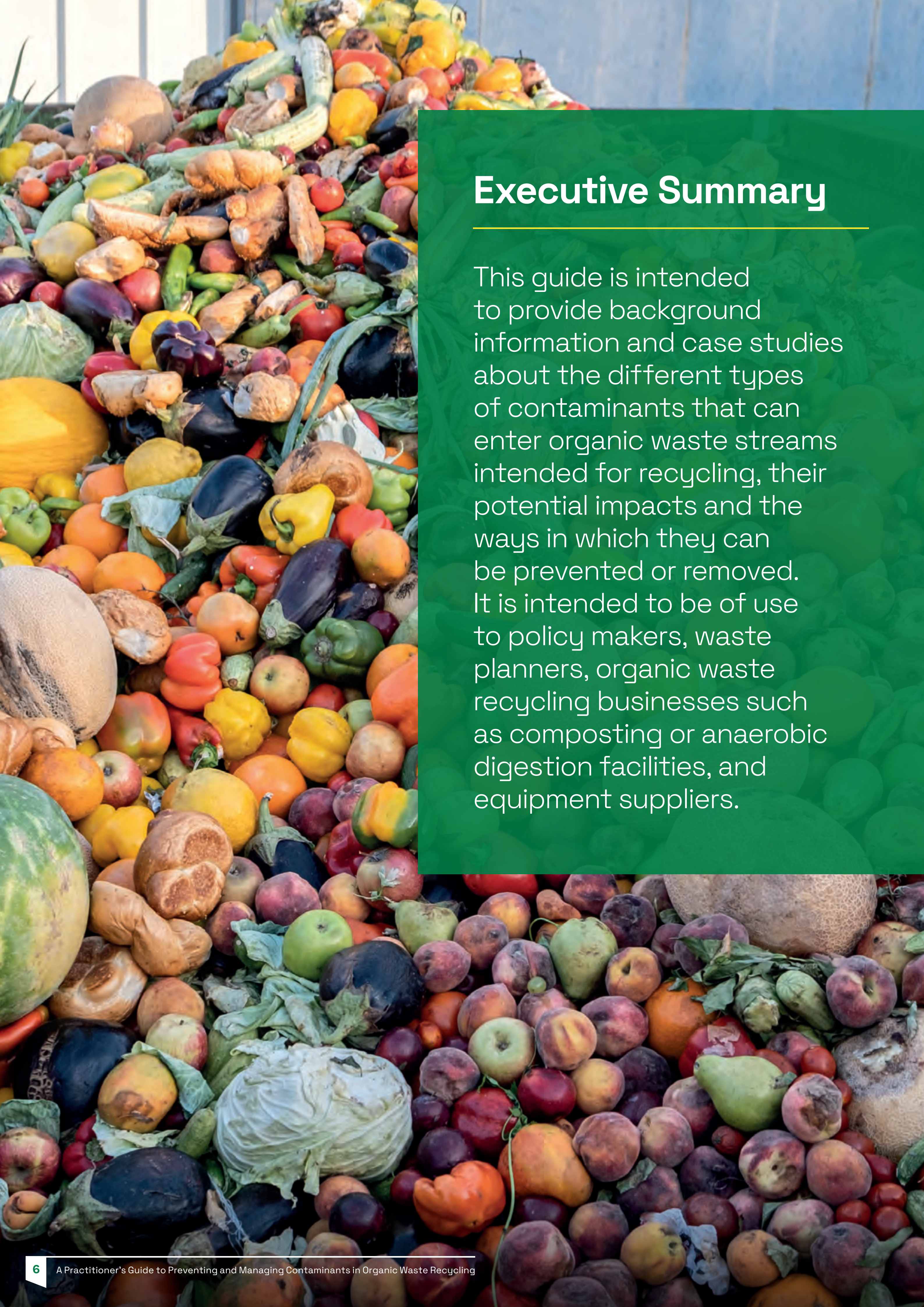
The probability that someone or something may be harmed by a hazard and how serious that harm may be.

Abbreviations

AD	Anaerobic digestion
dm	Dry matter
EPR	Extended Producer Responsibility
EU	European Union
EUR	Euro
fm	Fresh matter
HACCP	Hazard Analysis and Critical Control Point
HoReCa	Hotels, Restaurants and Canteens
ISWA	International Solid Waste Association
m	million
mm	millimetre
MBT	Mechanic and biological treatment
MSW	Municipal solid waste
PFAS	Per- and polyfluoroalkyl substances
POP	Persistent organic pollutant
SUP	Single-use plastic
t	tonnes or metric tonnes; US tons have been converted into metric tonnes
USD	US Dollar
WEEE	Waste Electrical and Electronic Equipment

Decimals are separated by points (full stops) "." and markers for thousands with a comma ",".
For example, $25,000.50 is twenty-five thousand dollars and fifty cents.

Where reference has been made to selected countries, these have been denoted using their two-letter country code defined by ISO 3166-1.



Executive Summary

This guide is intended to provide background information and case studies about the different types of contaminants that can enter organic waste streams intended for recycling, their potential impacts and the ways in which they can be prevented or removed. It is intended to be of use to policy makers, waste planners, organic waste recycling businesses such as composting or anaerobic digestion facilities, and equipment suppliers.

Contaminant definition and types

The document starts by providing a practical definition of the term "contaminant" in order to clarify its meaning and to prevent confusion, as different nouns (having subtly different meanings) are sometimes used by waste and recycling professionals.

Definition of a contaminant

An undesirable item, chemical substance or biological material in organic waste and/or its recycled product that has the potential to adversely affect the recycling process and/or the recycled end product(s) (i.e., compost or anaerobic digestate).

In general, there are three different types of contaminants:

- **Physical –** these are generally large, visible items such as plastics, metal items, glass and stones.
- **Chemical –** these are organic and inorganic chemicals derived from natural and man-made sources. Examples include pesticides, persistent organic pollutants and heavy metals.
- **Biological –** these occur naturally and are often intrinsic parts of some organic wastes. They include, for example bacterial and fungal pathogens, weeds seeds, plant propagules and toxins.

Types of contaminants

PHYSICAL

CHEMICAL

BIOLOGICAL

Contaminant impacts

Overall, contaminants in separately collected organic waste have potential to cause harm, including:

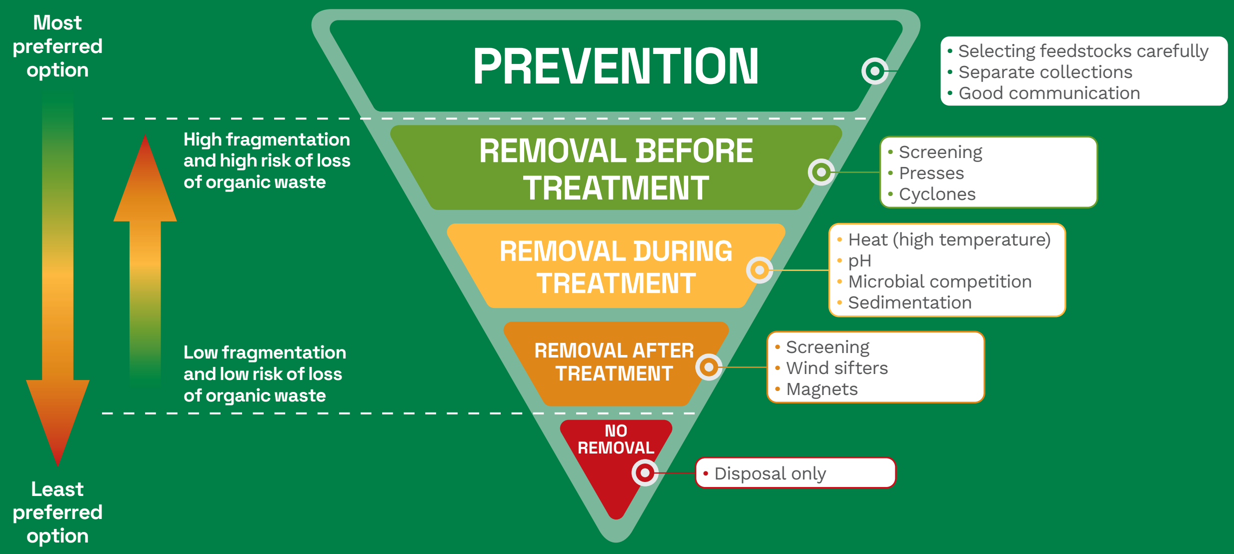
- **Recycling equipment –** where they can damage or impede machinery.
- **People and the environment –** where they can hurt recycling operatives, end users or ecosystems where products are used.
- **Profitability –** due to damage of equipment, removal and disposal costs.
- **Product quality –** due to consumer aversion and regulatory constraints.

The negative impacts of contaminants in organic waste recycling

Contaminant management and costs

This guide presents for the first time a preferred hierarchy for practitioners to follow, in which prevention is the most preferred option, and no removal the least preferred option. The hierarchy has been developed with the aim of maximising the quality of the recycling process and reducing losses due to contamination.

The contaminant management hierarchy



Examples cited in the document suggest that every one tonne of contamination removed from organic waste and disposed of costs the operator between EUR 180-230 (USD 200-260). This is a burden which is largely a result of society's widespread use of plastic products.

Contaminant prevention

The three main factors influencing the behaviour of waste producers (e.g., households) and thus the levels of contamination, relate to the ways in which organic wastes are collected as follows:

- **The type of collection scheme –** such as a kerbside (door-to-door) or bring scheme.
- **The type of tools provided to waste producers –** such as dedicated caddies and compostable liners.
- **The frequency and quality of information and awareness raising –** in order to educate and facilitate behavioural change.

Contaminant removal

Physical contaminants are generally removed from organic waste by exploiting differences in physical properties. Examples include screening, centrifugal separation and simple handpicking of large visible contaminants.

Some organic chemical contaminants can be destroyed during the process through biodegradative processes. However, some may only partially decompose, or may persist throughout the process. Certain recalcitrant chemicals that persist for long periods of time in the environment and are resistant to composting and anaerobic digestion are of particular concern.

Inorganic chemicals cannot be destroyed, although the compounds that they form may change. Binding of metals to solid particles and solubility differences can affect the ways in which they behave and are diluted during the recycling process.

Most biological materials are decomposed during composting and anaerobic digestion processes (having a pasteurisation step), which is why process monitoring and minimum temperature-time phases are important management steps at all facilities.

Practical examples

Practical examples of technology configurations at operational composting and anaerobic digestion plants are provided in the appendix, alongside key data summarising removal efficiencies.

Conclusions

Whilst many contaminant removal processes are largely effective, they are never 100% efficient; due in part to the ‘sticky’ properties of water, common in organic wastes. Water helps organic materials adhere to physical contaminants, with plastic films being particularly problematic. Removing plastic contaminants at the start of the recycling process, can result in a significant loss of organic waste (the so-called “dragging effect”) as well as fragmentation of the plastic, resulting in smaller pieces that subsequently become harder to remove. On the other hand, leaving plastic in the process can cause operational difficulties, concerns by regulators and disintegration of the plastic due to exposure to high temperatures, leading to further fragmentation. An imperfect balance thus needs to be found by operators.

ISWA’s Working Group on the Biological Treatment of Waste therefore calls for further research and development to improve the methods and efficiencies of removing unwanted contaminants from organic waste, compost and anaerobic digestate. With the mainstay of contaminant removal techniques having been developed for other purposes, such as the minerals and mining sectors, there is urgent need for improved equipment and the development of new techniques specifically focussed on the organics recycling sector taking into account the high moisture levels of waste inputs.

Improvements and innovation are thus essential, not only to improve operational efficiencies, but also to prevent contaminants accumulating in soil. The anticipated global uplift in organic waste recycling needed to reduce fugitive methane emissions from dumpsites, coupled with the use of compost and digestate to ameliorate arable soils and recycle plant nutrients, highlights the urgency of the task at hand.

ISWA’S call to action

ISWA’s mission to promote the transition to a circular economy depends on quality recycling. The circular economy of organic waste starts with the soils responsible for producing agricultural goods that sustain our cities and culminates with these same soils becoming the ultimate recipients of high-quality compost or digestate. As contaminants threatens to impair recycling processes and reduce product quality, it is essential that they be prevented and removed effectively. In order to address this, ISWA therefore calls on:

- Manufacturers selling equipment to the organics recycling industry to invest in research and development to improve contaminant removal techniques, whilst minimising the concomitant loss of organic matter (the “dragging effect”).
- Managers of composting and anaerobic digestion plants to maximise the quality of their final products. Facilities should, where possible, ensure that contracts with waste producers include a clause setting a maximum contamination level. They should also specify a variable gate fee depending upon the level of contamination in the load received at the facility.
- Municipal solid waste collection companies and waste hauliers to prioritise collection schemes for organic waste that enables the identification of contaminated loads and to feed this back to individual waste producers.
- Local decision makers and city managers to invest in regular information campaigns aimed at raising citizens’ awareness of the importance of maximising the quality of organic waste for recycling.

Rotterdam, October 2023

1 Introduction

Approximately one billion tonnes of municipal organic waste is generated globally each year, with only a small fraction of this currently being recycled into compost or anaerobic digestate (Ricci-Jürgensen, Gilbert and Ramola, 2020).

Recycling organic waste using biological treatment methods, such as industrial composting and anaerobic digestion, helps to alleviate pressures on land management, encourage sustainable farming practices, generate renewable energy and reduce fugitive emissions of methane gas from dumpsites and landfills. Collectively these factors are helping to drive the expansion of effective recycling strategies for organic waste across all continents.

Amidst this enthusiasm, however, contamination jeopardises the integrity and effectiveness of both treatment processes and use of final products (i.e., compost or digestate). With threats to soil health and productivity, water quality and human health being felt keenly across all continents, contaminated organic waste, compost and anaerobic digestate represents a significant environmental and financial burden. The effects of large, visible contaminants, such as metals and glass, have afflicted the composting sector for decades; hence, strategies have been put in place to limit and control the harm they may cause.

Contaminants, of course, mainly reflect society's consumption of goods which has experienced monumental growth over the past fifty years. Separate food waste collections inevitably become contaminated with materials that reflect the type and diversity of food packaging options available on supermarket shelves today. As the vast majority of these are flexible or semi-rigid plastics, they present new challenges for collectors and recyclers of organic waste streams, as their adherence to high moisture food waste makes effective separation particularly problematic. Anaerobic digestion, a sector that has witnessed significant expansion over the last two decades, has been particularly hard hit by plastic contamination due to the processes' more complex and costly equipment, which may become entwined or blocked with plastic film.

Across the waste management industry, physical contamination removal techniques have mainly been developed from simpler tried-and-tested methods used in the minerals and mining sectors. Based on size/density differentiation or magnetic properties, they work well for dry recyclables such as drinks cans and plastic bottles. However, organic waste differs from these in one very important way: its high moisture content. Water, due to its high surface tension, causes items to stick together, making the effective separation of contaminants from wet organic waste difficult. This is a notable problem with plastic films (e.g., carrier bags) and food waste, where the high surface area of the film adheres to large quantities of food waste, resulting in process losses of organics and contaminant disposal challenges.

The purpose of this report is to shed light on the various sources, types and consequences of contamination, aiming to raise awareness and promote strategies for prevention and mitigation. It is split into the following sections:

Chapter 2:

Contaminants

- Definition and classification
- An overview of the types, sources and impacts contaminants may have

Chapter 3:

Managing contaminants

- The contamination hierarchy
- Removal costs, health & safety

Chapter 4:

Preventing contaminants

- Collection schemes and public awareness
- Product bans and differential gate fees

Chapter 5:

Removing contaminants

- Physical, chemical and biological

Chapter 6:

Conclusions

- **ISWA's** recommendations

Appendix:

Managing contaminants in practice

- Examples at composting, wet and dry anaerobic digestion plants

Whilst some of the chapters contain technical descriptions, the overall aim of this guide is to assist waste practitioners plan and manage effective organic waste recycling programmes, minimise contamination and maximise the value of compost and anaerobic digestate. It is also intended to be of use to policy makers, waste planners, organic waste recycling businesses and equipment suppliers.

2 Contaminants

2.1 Defining contaminants

Globally, there is no unified definition of a "contaminant" in organic wastes, compost and anaerobic digestate. Furthermore, a number of different terms are also used including "impurities" or "contraries", some of which refer only to physical contaminants such as plastics, whilst others refer to chemicals and pathogens.

Where there is a legal basis, most contaminants are referenced in legislative instruments covering the outputs/products of a recycling process, such as compost and anaerobic digestate quality standards. Waste inputs into a recycling process are often referenced through "input specifications", some of which form industry standards, whilst others are mandated by environment regulators. These tend to be enshrined in contracts between waste recyclers and waste suppliers.

In principle, physical contaminants in organic wastes do not undergo biodegradation during composting or anaerobic digestion, or, where they do biodegrade, they do so at a much slower rate than the organic waste. Contaminants therefore end up in the final product, negatively affecting its quality and limiting the ways it can be used. Physical contaminants may also interfere with equipment, especially those involved in mechanical activities, and can impair recycling and cause wear of equipment.

A working definition of a contaminant is suggested in Box 1.

Box 1: Definition of a contaminant

An undesirable item, chemical substance or biological material in organic waste and/or its recycled product that has the potential to adversely affect the recycling process and/or the recycled end product(s) (i.e., compost or anaerobic digestate). The term "contamination" means the introduction or occurrence of a contaminant in organic waste, compost or digestate.

Contaminants may be introduced into organic waste streams at different points during its journey from generation through recycling to final product (Figure 1).

Figure 1: Ways in which contaminants can enter organic wastes

Intrinsic = inside the waste	
Bacteria/plant toxins	Some PTEs
Accompany the waste as part of its origin	
Food packaging (food waste)	Plant pots, stones (garden waste)
Extrinsic = introduced from external sources	
Plastic bags (for collection)	Household items

Note: PTE = Potentially Toxic Element

2.2 Types of contaminants

Contaminants can be broadly classified into three main categories based on their properties: physical, chemical and biological.

This functional categorisation enables recyclers to consider their source and determine the necessary steps to remove or reduce their concentration. It is important to note that there is often an overlap between these categories. For instance, plastic, while technically an organic chemical compound (or a group of compounds depending on its formulation), is typically classified as a physical contaminant because its removal from compost is based on considerations of size and density.

Figure 2: The three main types of contaminants

> It is important to note that there is often an overlap between the three categories: Physical, Chemical and Biological.

2.3 Physical contaminants

Physical contaminants are generally large, visible items such as plastics, metals, glass and stones.

The relative composition of different contaminants may vary significantly, depending on a number of factors such as the type of organic waste, the collection scheme, the tools used for separate collection and the awareness of the waste generators committed to sorting organic waste.

With regard to the separate collection of food waste, the Italian Composting and Biogas Association (CIC) found that plastic film represented between 60% and 75% by mass of all items detected (CIC, 2019). Examples of different contamination levels are shown in Figure 3.

Figure 3: Examples of organic waste with different levels of contamination

Source: Agència de Residus de Catalunya, ES

> The Italian Composting and Biogas Association (CIC) found that plastic film represented between 60% and 75% by mass of all items detected (CIC, 2019).

Table 1: Main types of physical contaminants

Category	Characteristics
Flexible and semi-flexible plastics	Lightweight packaging, malleable plastics, plastic films, bags, polystyrene, film plastics
Composites	Composite of different materials (e.g., beverage cartons, multi-layer packaging)
Hard plastics	Non-deformable or hardly deformable (brittle) plastics (e.g., yoghurt pots, fruit bowls, plant pots, plastic bottles, barrels)
Metals	Cans, tins, aluminium foil, bottle-crown caps, cutlery, aluminium lids (e.g., of yoghurt)
Paper and card	Paper, cardboard, cardboard packaging (e.g., newspapers, paper packaging and bags, cardboard handling packaging)
Glass	Disposable glass, bottles, porcelain
Coarse	Oversized interfering materials (e.g., pallets, baskets, roots, meat hooks)
Spinning	Long, possibly stretchable or even knotty disruptive materials that can wrap around moving or rotating parts (nets, tapes, unrolled plastics, ropes, animal skins)
Sand	Finest mineral components, cat litter
Grit	Stones, gravel, glass fragments, bones, eggshells, small metal parts, shells
Mixture	Mixed packaging from the above categories (e.g., glass & wooden lid & metal), seasonal items (e.g., Christmas calendars)
Missorted	Misplaced items, including clothing, decorative items, washing and cosmetic products, WEEE

Generally, within the perimeter of a municipality or a city, organic wastes can be sourced from a number of different entities such as households and schools (municipal sources), commercial retailers and producers such as markets, supermarkets and the so-called hotel, restaurant and catering (HoReCa) sector (Table 2 and Figure 4). In addition, organic wastes are also produced by large generators such as industrial facilities preparing or transforming food and food-commodities, and finally by the agricultural sector.

Table 2: Examples of different sources of organic waste

Type of waste producer	Municipal - Households		Municipal – public gardens and greens	Municipal - Markets
Type of organic waste produced	Food waste Garden waste	Garden waste	Garden waste	Vegetables Fruit Flowers Baked produce Meat
Packaged	Yes & No	No	No	Yes & No
Type of waste producer	**Commercial - Retail**	**HoReCa**	**Industrial**	**Agricultural**
Type of organic waste produced	Food waste	Food waste	Food waste Organic sludges	Vegetables Fruit Crop residues Manures
Packaged	Yes	No	Yes & No	No

Independent of the type of waste producer, there are two main sources of physical contamination:

- Misplaced items (‘misthrows’) that end up in organic wastes either by error, poor segregation practices or as the result of unplanned events.
- Packaging that accompanies food waste.

Figure 4: Example of different types of organic waste feedstocks

Generally, organic waste collected at households and commercial activities has the greatest variability in the type and number of contaminants, being affected by a number of factors such as the type of collection scheme set up by a municipality, the tools available to households and commercial activities to help them sort their organic waste (especially food waste) and public awareness initiatives in place.

Globally a significant challenge for the recycling sector is caused by packaged food items delivered for recycling due to exceeded expiry dates, failure of the cold-chain, or following a change in the type of products offered to customers.

2.4 Chemical contaminants

Chemical contaminants include both organic and inorganic chemicals derived from natural and man-made sources.

Examples of chemical contaminants include pesticides and persistent organic pollutants, as well as heavy metals that occur naturally but can be concentrated in man-made products such as batteries and waste electrical and electronic equipment (WEEE).

Table 3: Main types of chemical contaminants

Category	Source(s)	Organic waste streams affected
Pesticides (including herbicides and insecticides)	Man-made and applied in certain circumstances	Garden and landscaping green waste Agricultural waste
Persistent organic pollutants	Man-made products e.g., WEEE Pesticides	Food waste Green waste Agricultural waste
Dioxins & furans	By-product of low temperature combustion	
Heavy metals	Soil if underlying bedrock contains high levels Personal care products (e.g., zinc) Livestock feed (e.g., copper) Man-made products (e.g., batteries) Treated wood	Green waste Manures and slurries
Pharmaceuticals	Veterinary care and medicines	Manures and slurries
Microplastics – these may adsorb hydrophobic organic molecules such as pesticides and POPs	Disintegrating flexible/semi-rigid plastic items, or wear and tear of rigid plastic items	Garden and landscaping green waste Agricultural waste Food waste

Note to table: as this report does not include sewage sludge/biosolids, the chemical contaminants that may be present in these wastes are not included in the table.

2.5 Biological contaminants

These occur naturally and are often intrinsic parts of some organic wastes.

Biological contaminants include, for example bacterial and fungal pathogens, weeds seeds and propagules, plant toxins and genetic material that may confer resistance to some antimicrobial pharmaceuticals (Table 4).

Table 4: Main types of chemical contaminants

Category	Source(s)	Organic waste streams affected
Pathogens (viruses, bacteria and fungi)	The type and infectivity of a pathogen depends on its source: Plant pathogens (e.g., fungi and viruses) would be derived from plant waste Bacterial pathogens (e.g., *Salmonella* spp. and *Escherichia coli*) are prevalent in animal faeces	Food waste Green waste Agricultural waste Manures and slurries Slaughterhouse waste/animal by-products*
Parasites	Animal material	Manures and slurries Slaughterhouse waste*
Plant toxins (e.g., toxoids, cyanogenic glycosides)	Certain plants e.g., yew trees, cherry laurel	Green waste
Weeds (seeds and propagules)	Plant material that includes weeds	Green waste Agricultural waste Manures and slurries
Invasive species (e.g., seeds, bulbs, corms, tubers)	Non-native plants (e.g., Japanese Knotweed in the UK)	Green waste from domestic gardens, landscaping waste or conservation clearance
Insects and pests	Eggs laid in organic waste	Food waste Green waste Agricultural waste Manures and slurries Slaughterhouse waste/animal by-products*
Genetic material conferring anti-microbial resistance or genetically modified organisms	GMO Crops Animals and humans treated with antibiotics	Food waste Green waste Agricultural waste Manures and slurries Slaughterhouse waste/animal by-products* Sewage sludge

***Restrictions are in place in some countries or regions that restrict composting/anaerobic digestion of certain animal by-products for biosecurity reasons.**

2.6 Impacts

Contaminants can have wide ranging impacts over the short, medium and long term, with some being significant enough to close recycling operations or result in prosecution by regulatory authorities.

The impacts caused by contaminants include the following aspects that reinforce each other (Figure 5).

Process impairment

Physical contaminants are particularly problematic in recycling systems that rely on the mechanical movement of wastes, including impellers and pumps in wet anaerobic digestion (AD) plants, and shredders and screens. Plastic bags are notorious for wrapping around equipment and impeding mixing, whilst stones and large items can cause undue wear and tear and damage equipment.

Safety

Some items can present safety hazards to operators working at composting and AD plants. For example, golf balls and pieces of metal can be ejected at high speeds and over long distances from hammer mill shredders, whilst ordnance/munitions and cannisters of compressed gas have been known to cause explosions, resulting in significant infrastructure damage.

Shards of glass not only devalue a product, but they can hurt people and animals, whilst plastic fragments in compost and digestate can build up in soil and disintegrate into smaller microplastics (see Box 2).

Profitability

Removing contaminants, replacing or repairing damaged/worn equipment and disposal of removed contaminants are all costly. Not only does this have a direct impact on business profits, but it also reduces process efficiency, increases processing times and affects recycling rates.

Product quality

Instead of being a product that can be marketed and sold, contaminated compost and digestate hold very little, if any, value. In many countries there are regulatory limit levels on contaminants, restricting application to low grade areas such as landfill daily cover; practices that often entail cost rather than being revenue generating. Quality assurance schemes and standards are established in many countries, setting limit levels for contaminants such as PTEs, plastics and human pathogen indicators. Examples of standards are shown in Table 5.

Figure 5: The negative impacts of contaminants in organic waste

Table 5: Example compost quality standards including limits for physical, chemical and biological contaminants for different world regions

	European Union	Australia	US (New York)	Uruguay
Physical impurities (plastic, glass, metal) g/kg (dm)	d>2 mm, limit=0.5%	d>2 mm, limit=0.5%	d<25.4 mm, limit=2%	d>2 mm, limit=1%
Plastics only g/kg (dm)	d>2 mm, limit=0.3%	d>5 mm, limit=5%	-	d>2 mm, limit=1%
Cu mg/kg (dm)	<300	>150	<1500	≤100
Zn mg/kg (dm)	<800	<300	<2500	≤200
Ni mg/kg (dm)	<50	<60	<200	≤20
Other Heavy Metals or PTEs	Limit values included	Limit values included	Limit values included	Limit values included
Salmonella	Absent	Absent	To be analysed	Absent
Escherichia coli	<1000 CFU/g	<1000 MPN/g	-	-
Fecal coliforms	-	<100 MPN/g	To be analysed	<1000 MPN/g
References	(European Union, 2019)	(Standards Australia, 2012)	(New York State, undated)	(DGSA, 2018)

Note to table: d = diameter; dm = dry matter; g = gram; MPN = Most Probable Number; CFU = Colony Forming Unit

Importantly, the adverse impact contaminants may have on the environment is increasingly of concern. A great deal of media attention has been made of plastics in marine ecosystems, although arguably, the potential harm they exert on terrestrial environments is at least as great. In recent years, hazards of concern include microplastics and per- and polyfluoroalkyl substances (PFAS); see text Box 2 and Box 3. Although these are societal problems, their potential presence in compost and digestate needs to be taken seriously.

Box 2: Microplastics

These are particles of plastic that are less than 5 mm in size and are formed from a wide range of plastic products, with car tyres and synthetic textiles being the two largest sources. Once in the environment they fragment even further, becoming smaller and smaller, eventually becoming nanoplastics (< 1 µm).

Due to their very small size these plastics are of concern, as there is evidence that they can be eaten by animals and become concentrated as they pass up the food chain. Humans are known to ingest microplastics when eating shellfish and sardines. There is also evidence that some chemicals and pathogenic micro-organisms can bind onto microplastics, so the effects these plastics exert are not solely physical as chemical and biological effects are known to occur.

To date, most research into microplastics has centred on rivers and oceans, whilst our understanding of their behaviour and the risks they present in soil is less well known. Ongoing research shows that soils are affected by microplastic contamination due to air drift and agricultural activity, with a wide range of contamination ranging from a few particles per kg up to thousands of particles per kg.

(Brandes, Henseler and Kreins, 2019)

Box 3: PFAS

These are per- and polyfluoroalkyl substances and are widely used in a range of products, such as waterproof textiles, fire extinguishing foam, non-stick pans and food service packaging. As a group of chemicals, they are stable and repel both water and lipids (fats, oils and grease). For this reason, they are used to treat paper and fibre-based food packaging in order to prevent it from becoming soggy and losing its form and function.

Whilst their stability means they function very well for their intended purpose, the fact that they are resistant to degradation also means they accumulate in the environment, leading to them being dubbed ‘forever chemicals’. Furthermore, there is evidence that some PFAS compounds can be harmful to humans, leading to increased scrutiny by regulators.

PFAS have long been associated with biosolids (sewage sludge) and landfill leachate, although compost and digestate are now being scrutinised as more food waste is diverted to these processes for recycling.

(Pinkerton, 2020)

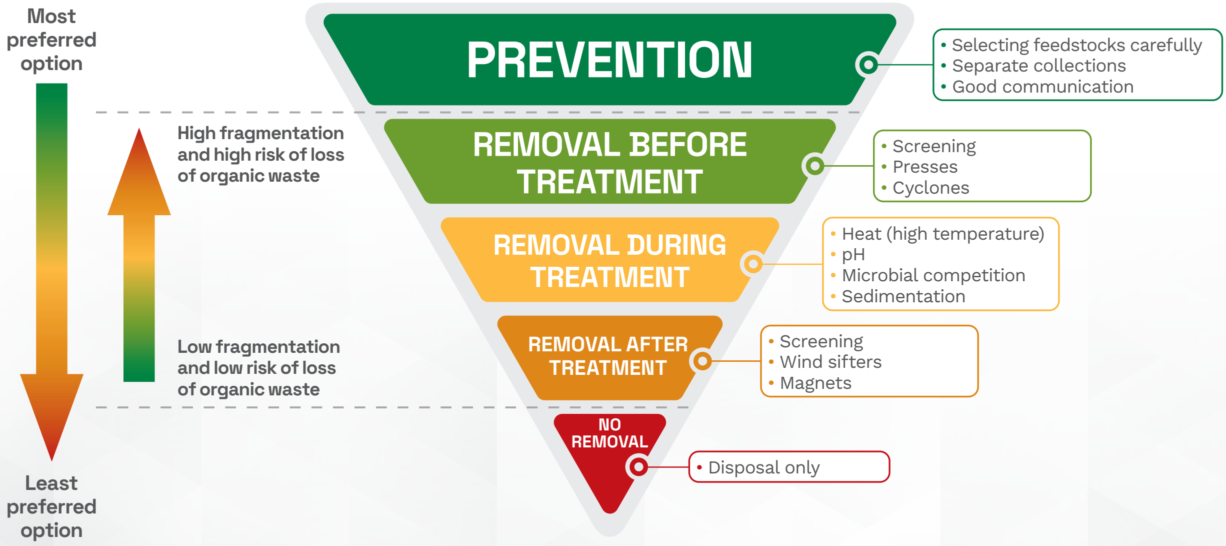
3 Managing contaminants

3.1 Contamination hierarchy

The Dutch philosopher Erasmus is attributed as the source of the saying “prevention is better than cure”.

This principle is as relevant to contaminants in organic waste streams as it is in other areas of waste recycling and can be summarised as a hierarchy of management options (Figure 6).

Figure 6: The contaminant management hierarchy



Looking at the supply chain starting from waste generators through to recycling facilities, it is preferable to remove contaminants as soon as possible for a number of reasons. Firstly, the mechanical nature of composting and AD processes means that as materials are moved and mixed, shear forces help to break up the composting mass. These forces also act on contaminants, causing single plastic bags or glass jam jars, for example, to be reduced to many smaller-sized fragments. This not only means that they are harder to remove (as one large item is easier to remove than many smaller items), but they also become dispersed within the organic matrix. Secondly, some contaminants may begin to partially disintegrate/biodegrade during the recycling process, potentially transforming a relatively benign contaminant into one that presents a much greater potential for harm.

Unfortunately, most organic wastes have a high-water content. Water is a polar solvent that has the ability to stick to itself (cohesion), but also to stick to other objects (adhesion). This property of water means that organic waste also sticks to physical contaminants, especially light plastics such as polyethylene film. This makes them harder to remove at the beginning of the process when there is a high moisture content, compared to the end of the process when moisture levels are generally lower. Removing plastic contaminants at the start of the recycling process, can therefore result in a significant loss of organic waste (the so-called “dragging effect”) as well as fragmentation of the plastic, resulting in smaller pieces that subsequently become harder to remove. On the other hand, leaving plastic in the process can cause operational difficulties, concerns by regulators and disintegration of the plastic due to exposure to high temperatures, leading to further fragmentation. An imperfect balance thus needs to be found by operators. There is no easy answer to this problem at present, but it is one that warrants further research and development given the scale of the challenges.

Box 4: HACCP

Hazard Analysis and Critical Control Point (HACCP) is a system used by organic recyclers for the identification, evaluation and control of hazards that are significant for the production of compost/digestate so that they can be used without harm. It is a concept that was originally developed by NASA in the 1960s to ensure food was safe for its astronauts to eat, and is now widely used in the food and pharmaceutical industries.

Fundamentally, HACCP is about the prevention of harm, rather than relying on extensive testing of an end product for the presence and level of a hazard or hazards. The process involves seven sequential activities:

1. **Conduct a hazard analysis**
2. **Identify all Critical Control Points (CCPs)**
3. **Set Critical Limits (CLs)**
4. **Establish a system to monitor and control critical limits**
5. **Describe corrective actions in the event of a failure**
6. **Establish systems to verify the HACCP system is working**
7. **Establish documentation for all procedures and records**

A hazard is something that has the potential to cause harm. In the context of this report, it is a contaminant (physical, chemical or biological).

A Critical Control Point (CCP) is the last step at which a control can be applied and is essential to prevent or eliminate a hazard or reduce it to an acceptable level.

A Critical Limit (CL) is the criterion that separates acceptable from unacceptable concentrations or levels. When considering critical limits in compost/digestate, these are usually defined in quality standards (see Table 5).

HACCP planning is required by law in the European Union (European Union, 2009) whenever animal by-products (including food waste) are treated through AD and composting in order to ensure that potential microbial pathogens are destroyed or reduced to acceptably low levels (sanitisation). In this instance the control measure involves processing the animal by-products at high temperatures for minimum periods of time (time-temperature profiles) (European Compost Network, 2017).

In principle, control measures can be implemented at different stages at composting and AD plants. However, in practice it is nearly always preferable to remove contaminants from organic wastes as soon as possible (i.e., during the input stage) as shown in Figure 6.
This is important as:

- Some contaminants may be localised to particular areas within incoming waste. Materials handling and processing have potential to disperse these contaminants throughout the waste, potentially devaluing the entire batch of product.
- Plastics and glass may break up into many smaller fragments, making subsequent removal far more difficult to achieve. This is especially problematic when these small fragments become dispersed.

3.2 Removal costs

Once mixed with organic wastes, it is costly to remove contaminants. By how much, depends very much on the type of waste, the type of contamination (e.g., whether physical or chemical), the processes employed (including capital infrastructure) and the intended use of the end product.

Information is limited about the costs for removing contaminants mixed with organic waste.

One study of a low-tech, passively aerated windrow composting facility in Malawi suggested that the labour associated with removing plastics amounted to just over 12% of active labour time (Yesaya, Mpanang'ombe and Tilley, 2021). As this facility composted discarded vegetables collected as mixed waste from two vegetable markets, initiating a separate collection scheme would therefore reduce labour costs and increase profitability.

A survey in Italy by the Italian Composting and Biogas Association concluded that the extraction and disposal of all physical contaminants during the recycling of food and garden by means of composting and/or anaerobic digestion in Italy would costs the sector some EUR 52 million; this is equal to about EUR 227/tonne of contaminant and excludes the losses from selling lower quality compost and reduced biogas production (CIC, 2017).

Another study in the UK used data from an operator of a wet anaerobic digestion facility, where it was estimated that each tonne of removed mixed contaminants (mainly plastics bags) would cost GBP 156/tonne (EUR 157; USD 207), including haulage and disposal (REA, 2020).

3.3 Health and safety

All contaminants are hazards, meaning they have potential to cause harm, whether that be to humans, animals, plants, ecosystems or equipment.

Whilst environmental harm is usually controlled through environmental legislation, harm to workers falls under health and safety legislation. It is therefore important to risk assess all on-site activities and introduce control measures to reduce the risk of harm to operatives. This is particularly important in the removal of physical contaminants by hand (hand picking) and could, for example, include the use of personal protective equipment.

Further information on health and safety at composting sites can be found in (Rynk et al., 2022).

4 Preventing contamination

4.1 Collection schemes

Once contaminants are inside organic waste it is technically difficult to sort them out during the biological recycling process; prevention should therefore be the general approach to limit these substances in the recycling process leading to the production of compost or digestate.

When collecting organic waste separately there are three main factors that influence the behaviour of waste producers and thus the levels of contamination, namely: the type of collection scheme, the collection tools used, and the information provided to waste producers (Figure 7).

Figure 7: Factors influencing contamination levels

Type of collection scheme

- Pick-up (also called kerbside or door-to-door schemes) perform better than bring schemes (e.g. roadside container or underground schemes).

Type of collection tools

- The use of certified compostable plastic or paper liners perform better than conventional polyethylene plastic liners.

Public awareness initiatives

- Communication campaigns and awareness initiatives improve understanding and behaviour of waste producers in sorting organic wastes correctly.

The type of collection scheme

The type of collection scheme affects the behaviour of waste producers and the types of waste they discard. When set up correctly, organic wastes can be checked prior to collection and the waste producer made to take responsibility for sorting their waste correctly. This is well documented in technical guidance and practical experiences with food waste collection schemes; these are summarised in Box 5.

Usually local decision-makers choose to collect organic waste with schemes similar to those in use for other MSW streams; hence if they opt to use bring schemes it is advisable that they provide lockable bins, providing residents with access through a user-specific identification system. This was the experience of the city of Viana do Castelo in Portugal[1], which limited the level of contamination in collected food waste to less than 5% by mass.

Box 5: Examples of the effectiveness of pick-up collection schemes

CATALONIA, SPAIN: The handbook on separate collection published by the Catalan waste agency (Agencia de Residuos de Cataluña, 2018) in Spain showed that pick-up schemes for food waste resulted in 57% less contamination when compared with bring schemes.

ITALY: The Italian Composting and Biogas Association (Ricci and Centemero, 2014) reported that pick-up (or door-to-door) schemes reduced contaminants by 50% when compared to bring schemes, thus keeping the contaminants delivered with food waste below 4% on average.

PARMA, ITALY: In 2014, the district city changed the collection scheme for kitchen waste from households by stopping the bring scheme using road containers and adopting a door-to-door scheme using 20 litre caddies and wheeled bins; compostable plastic liners were introduced for sorting kitchen waste and distributed by the waste company to all households regularly (Ricci-Juergensen and Folli, 2016). A comparison of the two schemes led to a significant reduction in contaminants (from 8.3% to 3.3%) as well as doubling the quantity of waste sorted, reaching about 100 kg per capita per year.

ROMANIA: Compositional data for separately collected organics in different towns (Salacea, Valea and Beius) showed that contaminants were between 27-35% in weight with road container collections, whilst in towns with pick-up schemes, the level of contamination dropped to 4-5% in weight (A Bihor & E Bihor, personal communication, 2022).

Due to its greater volume and lower density, collection systems for garden waste (consisting of pruning, tree trimmings, grass clippings etc.) necessarily differ from those of food waste. The use of open, unguarded containers should be avoided in order to prevent fly-tipping and the disposal of bulky waste items (such as damaged lawnmowers). Supervised drop-off points are preferable, such as municipal collection centres, temporarily manned collection points or a scheduled specific door-to-door scheme. These all provide opportunities for operatives to check the quality of the waste prior to collection.

[1] Azevedo S., Implementation of a PAYT selective collection system for Organic Fraction of MSW and promotion of domestic composting, 2022, personal communication.

The type of collection tools

The collection of food waste from households and commercial activities often requires producers to use certified compostable bags to prevent leachate and keep collection receptacles clean. In some countries householders are required to sort food waste using bags made of paper or compostable plastics (see Box 6) together with vented kitchen caddies. This "vented system" is commonly used in parts of Austria, Catalonia (Spain), Denmark, France, Italy, Norway, Switzerland and the UK (ECN, 2019), as it helps to reduce the moisture content in food waste by between 7 to 10% before collection (Caimi, Ricci-Jürgensen and Favoino, 2006).

Box 6: Compostable plastics

A bag or packaging can be labelled as compostable if it complies with a recognised technical standard such as the European standards EN 13432 (for packaging), the American ASTM D6400-21 or the Australian AS4736-2006; these standards guarantee disintegration and biodegradability of the product in a certain time under optimal, professional composting conditions and the absence of adverse biological effects of the compost produced. These standards do not apply to facilities relying solely on anaerobic digestion to recycle organic waste.

Certification of a product to a published standard may only be carried out by an accredited certification body should a manufacturer wish to claim conformance. Within Europe there are two main certification bodies certifying compostable products (DIN CERTCO and TÜV AUSTRIA), with the Italian Composting and Biogas Association (CIC) and the Renewable Energy Assurance Ltd (REAL) in the UK running smaller schemes. The Biodegradable Products Institute (BPI) operates in the USA and Canada, the Australasian Bioplastics Association (ABA) operates in Australia and New Zealand, whilst the Japan BioPlastics Association (JBPA) focusses on Japan, China and Korea.

Examples of the adoption of compostable caddy liners combined with public awareness initiatives are detailed in Box 7. Other local authorities such as the New York City Department of Sanitation encourage the use of paper bags and compostable bags as preferential to plastics to sort food waste, even where there are no binding requirements.

When it comes to garden waste the use of large paper bags is preferable to plastic bags, thus preventing plastics getting into organic waste recycling facilities.

Box 7: Collection schemes using compostable caddy liners

SLIGO, IRELAND: The provision to householders of compostable liners together with vented kitchen caddies coupled with a public awareness initiative, reduced the level of contaminants from 18% to 3% by weight and doubled participation by households (Sligo County Council *et al*., 2019).

KASSEL, GERMANY: This showed that the distribution of compostable plastic bags to households resulted in a drop of contaminants by 56%, whilst also increasing by 23% the share of organic waste collected (Gröll *et al*., 2015).

13 CITIES & MUNICIPALITIES, GERMANY: A study showed that in areas with the recommendation to use compostable plastic bags, kitchen waste resulted in a contamination level of just 2.5% by mass, while contamination rose to 3.8% by mass in the cities/municipalities where no compostable plastic bags were allowed (Kern, Siepenkothen and Turk, 2018).

BRATISLAVA, SLOVAKIA: A start-up initiative to collect household kitchen waste in high-rise built up areas showed that a door-to-door collection combined with the distribution of compostable plastic liners and vented caddies led to levels of contamination below 2.6% by mass (Zenzo, personal communication, 2022).

Quality inspections during collection

Implementing quality inspections during the collection service can serve as a crucial tool in preventing the entry of physical contaminants into organic recycling facilities. This is particularly significant in areas where pick-up schemes are employed, as a well-trained collection crew can visually inspect individual household buckets and bins. They can refuse to empty receptacles that fail to meet the quality standards specified by the local operator. By adopting this approach, the collection of food waste with contamination levels below 3% can be achieved and below 1% in particularly favourable situations, provided there are motivated crews and areas with predominantly single households.

In the case of larger bins and containers located in densely populated areas, detection devices installed on collection vehicles can be utilized. These devices range from induction technologies, which assess the presence of metals only, to camera inspections during tipping that employ artificial intelligence to recognize the contents (although they are unable to sort out contaminants before collection). Whilst the latter solution is currently under development (INFA, 2023), initial results look promising.

Both approaches, whether labour-intensive or technology-driven, prove effective in avoiding the collection of contaminated bins. Moreover, they provide households with valuable feedback by affixing stickers to the bins, indicating incorrect sorting of organic waste (Figure 8).

Figure 8: Examples of stickers showing non-compliances in the separate collection of kitchen waste

> By carrying out quality inspections during the collection of food waste, contamination levels below 3% can be achieved and below 1% in particularly favourable situations.

Collecting packaged food waste from large producers

Packaged, expired food products collected from food, beverage, or feed production companies for organic recycling present significant technical issues for waste managers, as all conventional plastic packaging needs to be removed before treatment.

It is therefore advisable to require waste producers and dedicated collection services to deliver food waste generated at industrial and commercial units already de-packaged; moreover, maximum acceptable contamination levels should also be established to facilitate acceptance at the gate of recycling facilities[2] (Bundesumweltministeriums, 2012). Compared to other organic waste streams, packaged food waste is expected to contain a significant proportion of contaminants, so pre-treatment techniques have to be chosen according to the type of physical contamination and the desired efficiency of separation that can be achieved.

In the case of closed loop collection schemes for catering services, a possible alternative to conventional plastic packaging of food is to require the use of paper or compostable plastic packaging, complying with a standard for compostability described in Box 6. However, using compostable packaging together with food items presents both opportunities and challenges as set out by the European Compost Network (ECN, 2019); hence the effective acceptance of those items at local composting or AD facilities needs to be verified in advance.

[2] **For example, the limit level for plastic fragments larger than 2 mm allowed in feedstocks for composting or anaerobic digestion in Germany is 0.5% (dry mass) for de-packed food-waste (See Box 17: Contaminant limits in Germany).**

Box 8: Food packaging challenges

The packaging materials used for food products must meet a wide range of requirements during the progress of the production process to the end-consumer.

The materials and their requirements can be roughly divided into three categories: sales packaging, outer packaging and transport packaging. Thus, in addition to hygienic aspects, the packaging industry has to take into account food-quality properties, stacking and transport requirements. Transportability of materials also presents challenges including shelf life and the consistency of food. These complex requirements on the material properties of the packaging are also reflected in the processing technology, which is intended to separate the packaging from the food to the highest possible quality.

> Using compostable packaging together with food items presents both opportunities and challenges as set out by the European Compost Network (ECN, 2019).

4.2 Public awareness initiatives

The examples of collection schemes shown in Box 7 were developed in conjunction with efforts in raising the knowledge and understanding of waste producers in how to correctly separate different types of organic feedstocks and compostable waste.

Awareness raising initiatives that led to a reduction in contamination levels prior to collection were more effective than removal during the recycling process; this was summarised as "an ounce of prevention is worth a pound of cure" (Washington Organic Recycling Council, 2017).

Examples include nationwide campaigns such as the "Aktion Biotonne Deutschland", a German campaign by the federal government and national associations promoting the collecting of more kitchen waste with less plastics, the Italian campaign "Di che plastic sei" to show consumers how to distinguish compostable plastic packaging from conventional polymers, and the Washington State (USA) Organics Contamination Initiative focused on preventing contaminants in compost (Figure 9).

Figure 9: Examples of main of awareness initiatives focused on organic waste collection or recycling in DE, IT & USA

Box 9: Awareness raising in Sligo, Ireland

A pilot project was carried out in Sligo, Ireland, with 6,000 households (Sligo County Council *et al.*, 2019). The aim of the project was to see how a range of educational and collection tools, such as the use of Brown Bin Waste Management Advisors and the provision of kitchen caddies to householders, could improve the capture and quality of food waste in the brown bin. The goal was to demonstrate the positive impact relatively low-cost measures could have on the performance of the system.

There were a significant number of households with brown bins in Sligo City and prior to the awareness work their use was very low. A door-to-door education programme, and provision of a kitchen caddy and compostable bags to households resulted in:

- Participation and capture of organic waste at least doubling on average in areas that received awareness information compared with those that did not.
- A reduction in the level of contamination in brown bins from 18% to 1%.

The provision of a door-to-door education programme might not be feasible for some waste collectors. However, the study showed that the provision alone of just a kitchen caddy, compostable bags and information leaflets would result in dramatic increases in the quantity and quality of food waste collected in the brown bins.

Feedback to waste producers can also be achieved by making the produced compost available at the end of a recycling process; this has been achieved successfully by ABITO (C. Mulcahy, personal communication, 2023), a private-funded initiative launched in 2018 in Uruguay to increase and ameliorate separate collection and recycling waste produced from supermarkets, restaurants, shopping centres, private and public offices, schools and universities. ABITO's customers receive a free bag of high quality "BioTerra compost", produced from their organic wastes; this also serves as a marketing action for the composting plant.

Box 10: Awareness raising in Germany

Raising public awareness about organic waste is the subject of the nationwide campaign "#wirfuerbio - Biomüll Kann Mehr" (#wirfuerbio - organic waste can do more) implemented every year by municipal waste management companies.

It aims to educate citizens through a direct approach and cross-media communication, such as repeated broadcasting on several channels. The "Aktion Biotonne Deutschland" (campaign for organic waste bins in Germany) is another nationwide campaign by the federal government and national associations; it promotes more compostable kitchen waste and less plastic in the organic waste bin. Inspections of organic waste containers can complement public relations work, especially in collection districts with repeatedly heavily contaminated organic waste bins. The assessments can be carried out by manual sifting and electronic control and detection systems. Incorrectly filled organic waste containers are disposed of as residual waste at a charge.

Box 11: International Compost Awareness Week

International Compost Awareness Week (ICAW) is the largest and most comprehensive awareness initiative promoted by a number of compost organisations in many countries, ranging from North America (US Composting Council and Compost Council of Canada) to Europe (ECN European Compost Network) up to Australia (AORA Australian Organics Recycling Association).

It is celebrated each year during the first week of May to raise the awareness of consumers and non-experts about the importance of bringing back organic matter to soil by means of compost and to promote the link between compost, soil health and food production. For details see www.compostfoundation.org/ICAW/ICAW-Home

Box 12: Extended Producer Responsibility for compostable packaging

In Europe, there are Extended Producer Responsibility organisations for packaging in each member state. These organisations collect fees from producers who place compostable materials onto the market. However, the fees are not used for supporting the organic recycling sector, with the exception of one country, Italy.

Biorepack is the Italian EPR scheme collecting the fee for compostable plastic packaging released on the Italian market and collected waste packaging together with food waste; hence the fee is used to support the organics recycling sector in programmes to help remove contamination and also in funding long term programmes of public education of how to collect food waste correctly.
https://eng.biorepack.org/

Discussions are taking place in some EU countries such as Ireland around this topic. In Ireland it has been agreed that compostable materials processed in compost and biogas plants count towards EU Packaging recycling targets.

4.3 Product bans and restrictions

As society's awareness about the accumulation and potential impact of a wide range of consumer products is increasing, bans and restrictions are now starting to come into force.

Many countries are phasing out single use plastic items such as plastic shopping bags, drinking straws and stirrers; items that often end up in organic waste feedstocks and are particularly difficult to remove. However, as the list of "problematic plastic products" (e.g., plastic plant pots) that end up in organic waste streams extends much further than current legislative proposals, more work needs to be done to raise this issue with policy makers. It will therefore be some time before the impact of these bans start to take effect as far as organic waste recycling is concerned.

Box 13: Ban on conventional plastic shopping bags in Italy

Since the 1990s, compostable plastic bags have been used in Italy for collecting bio-waste, so as to ease the sorting of food waste by householders and prevent conventional plastics polymers contaminating organic feedstocks.

After a ban on conventional plastic shopping bags was brought into effect in 2011[3], the total amount of single use shopping bags reduced by 57% between 2010/2022, additionally, phasing out the use of conventional polyethylene bags reduced the risk of plastics contaminating collected food waste. Today, eight out of ten shopping bags on the Italian market are certified compostable to the standard, EN 13432 (CEN, 2000).

In addition, cities and local authorities do not need to equip households with compostable liners, since these are largely available on the market and have a second life as caddy liners for separate food waste collections.

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[3] **Since 2011 Italy has banned single-use shopping bags (under 100 µm thickness) and from 2018 also all single use ultra-light plastic bags; paper and compostable plastic bags, certified according to EN 13432, are exempted from the ban.**

Box 14: Ban of certain conventional single-use plastic items in the EU

In the European Union, the proposed update of the Packaging and Packaging Waste Directive released in November 2022 specifically addresses the issue of conventional plastic polymers contaminating feedstocks recycled at compost and anaerobic digestion plants, following incorrect sorting by households and commercial producers[4].

The proposed new legislation aims to reduce contamination of compostable recycling streams by banning from the EU market a selected list of single-use items such as coffee pods, tea bags, fruit stickers and very lightweight plastic carrier bags.

Hence the draft of the proposed updated Directive introduces mandatory compostability for filter coffee pods, sticky labels attached to fruit and vegetables and very lightweight plastic carrier bags; the list of packaging items that need to be compostable on the EU market can be amended in the future.

[4] The draft regulation can be downloaded from https://ec.europa.eu/info/law/better-regulation/

Many chemicals are also being restricted or phased out entirely. For facilities accepting garden waste, the issue of herbicide residues has been problematic for some time. Problems experienced with pyralid herbicides in the 1990s are discussed in Box 15, whilst glyphosate (a broad-spectrum herbicide that is potentially linked to cancer in humans and harmful effects on wildlife) is currently banned in some countries and being considered in a number of others.

Box 15: Clopyralid & aminopyralid herbicides – two cautionary tales

In the late 1990s, commercially produced compost in the USA and New Zealand was found to harm tomato plants.

Following extensive laboratory testing and sleuth-like detective work, the problem was found to be caused by the herbicide clopyralid, which survived the composting process and remained active in the finished product. At the time, clopyralid was widely used in lawn care products, especially in the USA. As a result of these issues, the manufacturers withdrew some products, and restricted use of clopyralid-containing preparations. Clopyralid-containing products now contain clear guidance about composting treated plant residues.

Similar problems were experienced in 2008 by a number of British allotment holders, where manures were found to damage their plants. The problem was found to be due to the grass on which grazing animals had fed. This had been treated with products containing the herbicide aminopyralid, which was used to control weeds in pastureland. Unfortunately, the herbicide degraded slowly and passed straight through the animals' gut, remaining active in their manure. Since then, the use of aminopyralid has been restricted and stringent record-keeping procedures implemented.

4.4 Differential gate fees

Gate fees applied at composting and anaerobic digestion facilities usually depend on the type of organic waste accepted, considering the technical efforts needed to treat specific types of feedstock.

For example, in Italy or Spain food waste is accepted with a higher gate fee compared to garden waste, considering that the former waste stream needs to be added with bulking material made available by the facility. These fees can include a quota based on the level of contaminants detected inside the delivered organic waste.

The monitoring of contamination is promoted actively by a number of compost organisations; the German compost quality organisation has released a set of three different methodologies to assess contamination levels in bio-waste (a mixture of food scraps and garden waste), while the Italian Composting and Anaerobic Digestion Association (CIC) performs up to 1,500 sorting analyses a year on food waste by applying the association's methodology published with the Italian Standardisation Body, UNI (CIC and UNI, 2021).

Box 16: Contamination fees applied at the gate

The Dirt Hugger composting facility in the USA applies a simple but effective contamination fee on top of the gate fee for accepting organic waste (Washington Organic Recycling Council, 2017). Physical contaminants are assessed either by the number of items (picks) or the volume of the materials sorted out manually from the amounts each haulier has delivered.

The contamination fee ranged from USD 25/delivery to USD 200/delivery according to the results of the contamination analysis.

Deliveries with physical impurities exceeding 150 picks or 200 gallons (about 800 litres) are rejected.

As many municipalities rely on private operators to recycle their organic waste, the amount of acceptable contamination should be included in tenders or contracts including the prescription to perform regular waste compositional analyses on organic waste. These details allow the facility to set the gate fee according to the quality of the organic feedstock and reject single deliveries that present excessive contamination.

Box 17: Contaminant input limit requirements in Germany

The German Bio-Waste Ordinance requires recyclers of bio-waste, to adhere to contaminant control values for the input material (Bundesumweltministeriums, 2012).

These control values mainly refer to the total plastic content in the input material. It is a legal requirement that operators determine the contaminant levels in the input material before it enters the first biological treatment step (in the case of AD plants, this is the digester). The limits are set at 0.5% (fresh mass) for plastic >20 mm and 1.0% (fresh mass) for plastic >2 mm for solid bio-waste collected from private households These limits are challenging - especially for slurries - as it is often hard to distinguish impurities e.g., foils, from other materials or organics in the opaque matrix.

5 Removing or eliminating contaminants

5.1 Physical contaminants

Removal techniques exploit differences in physical properties (e.g., structure, size and density) between contaminants and the materials they accompany, allowing for separation at different stages of the recycling process.

The key factor affecting the choice of separation equipment is the moisture content of the organic waste, as water has such a profound effect on the "stickiness" of the waste and how well it adheres to contaminants, especially plastics[5]. Processes therefore differ depending on whether organic wastes are presented in solid or semi-solid/liquid phases (Table 7).

Although separation equipment can be highly effective, they are never one hundred percent efficient; according to CIC, removal rates of conventional plastic in industrial composting facilities in Italy can reach up to 97.8% in standard treatment conditions[6]. This means that a small fraction will inevitably remain unsorted. Multi-stage approaches increase the overall efficiency of the system, although they often come with a hefty price tag.

It is important to bear in mind that removal techniques often cause a reduction in the size of contaminants, making them far more difficult to remove at the end of the process; in general, the smaller the contaminant, the harder it is to remove. One only has to think about a glass bottle being broken into numerous small, sharp pieces, or a plastic carrier bag being ripped into many fragments. These not only present safety risks to operatives and end users, but can also contaminate the end product, hence the environment. An example of removed contaminants is shown in Figure 10.

Depending on the moisture content of the waste and the type of separation process used, removed contaminants can also carry with them some of the organic waste destined for recycling. This not only reduces recycling efficiency, but can also cause problems with their storage, disposal or recycling. Some wet AD processes wash recovered contaminants to re-extract food waste; a case of removing the organics from the contaminants and not vice versa.

Figure 10: Contaminants separated during the pre-treatment of food waste at a facility in Italy

Source: M Ricci, 2017

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[5] Refer to Section 3.1 for an explanation.

[6] Assessment by CIC technical committee in 2021 on the average removal of plastic contaminants in Italian composting and combined AD & composting facilities, unpublished.

Different separation techniques are used when recycling organic waste which depend on a number of factors such as:

- **The physical properties of different organic feedstocks -** garden and park waste have a lower density compared to food waste and are usually subjected to shredding; thus, large contaminants can be removed from garden waste only before performing volume reduction.
- **The type of biological treatment process applied -** composting relies on simpler technologies than anaerobic digestion therefore the equipment is less vulnerable to damage than at AD plants. Wet anaerobic digestion is prone to clogging of tubes and pipelines used to transfer low solids organic wastes from one process step to the next; hence specific contaminant removal is necessary at wet AD plants. There is some more process flexibility for dry batch AD (such as container treatment) or composting, especially those processes that minimise the turning and mixing of compost piles.
- **The type of technical equipment available at a specific facility and the cost of labour -** in low-income countries waste treatment facilities rely on more manual labour compared to high-income countries where compost and AD facilities tend to be more automated; the activity of manual removal of (large) contaminants from organic waste needs to be approached carefully by equipping workers with all necessary personal protective equipment to prevent injuries and health issues.
- **The cost of disposal of the rejects from the organic recycling process -** facilities that are confronted with high gate fees for landfilling or incineration rejects are committed to minimising the amount of rejected materials, by optimising process performance and by relying strongly on management strategies (i.e. to move up the contamination hierarchy explained in Section 3.1).

Examples and applications of separation common pre-treatment and specific techniques are listed in Table 6 and Table 7. A number of techniques removing contaminants from packed food waste are applied after crushing or shredding the input feedstocks.

Table 6: Applicability of pre-treatment and removal techniques to different organic wastes

Removal technique	Green waste	Food waste	Packaged food waste	Compost	Digestate
Manual (hand picking)	✓				
Screening	✓	✓		✓	
Screw separator		✓	✓		
Centrifugal separator		✓	✓		✓
Floating/ sedimentation		✓	✓		
Solubilisation (dissolution)		✓			
Magnetic separation	✓			✓	
Air separator (wind sifter)				✓	
Density separator				✓	

Table 7: Types of separation techniques

Removal technique	Type of organic waste	Physical properties of organic waste	Stage of separation in recycling process
Manual (hand picking)	Green waste	Solid	Input
Screening	Food waste Green waste	Solid	Input
Screening	Compost	Solid	Output
Crushing or shredding (comminution) as a pre-treatment before removal	Packaged food waste	Semi-solid Liquid	Input
Screw separator	(De-packaged) food waste	Semi-solid Liquid	Input
Centrifugal separator	(De-packaged) food waste	Semi-solid Liquid	Input
Centrifugal separator	Digestate	Liquid	Output
Floating/sedimentation	(De-packaged) food waste	Liquid	Input
Magnetic separation	Compost	Solid	Output
Eddy current separation	Compost	Solid	Output
Air separator (wind sifter)	Compost	Solid	Output
Density separator	Compost	Solid	Output

Separation principles	Advantages	Disadvantages
Visual identification by operatives Removal by hand	Removal of large physical contaminants	Labour intensive Limited throughputs Safety and health issues
Separation of contaminants larger than a minimum size (e.g., 80 mm)	Removal of large physical contaminants	Loss of organic waste especially bulky wooden waste Poor separation efficiency when high moisture content
Separation of product smaller than a max size (e.g., 10 mm)	Allows for recirculation of bulking agent	Poor/no separation of small fragments Recirculates plastics with bulking agent
Reduction of average size of organic waste (e.g., 100 mm)	Frees food waste from plastic film and packaging	Fragmentation of plastics Loss of bulk structure of organic waste Partial loss of product
A solid fraction is separated from a pasty sludge	Effective at removing plastic film	Fragmentation of plastics Loss of bulk structure of organic waste
Separation of floating contaminants (plastic films) and sedimentation of stones and glass	Plastic contaminants are removed separately from high density materials such as stones and glass Can partially solubilise compostable plastic caddy liners	Needs moisture adjustment before treatment
Separation of a liquid fraction (liquid digestate) from a solid fraction	Contaminants removed partially from liquid digestate	Contaminants concentrate in solid digestate
Separation of floating contaminants (plastic films) and sedimentation of stones and glass	Plastic contaminants are removed separately from high density materials such as stones and glass. Can partially solubilise compostable plastic caddy liners The pre-treated organic waste can be managed by pipelines	Works best with liquid/semi-solid waste, therefore limited to wet AD processes
Magnetic attraction of metals	Removes ferrous contaminants	Unable to remove aluminium, copper and other metals
Eddy current induced into aluminium	Removes aluminium contaminants	Unable to remove other metals
Aspiration of contaminants with density lower than compost	Removes light density plastic film Improves quality of recirculated bulking agent	Partial loss of product Requires low moisture content
Ballistic removal of contaminants with density higher than compost	Removes high density contaminants (stones, glass)	Requires low moisture content

5.2 Chemical contaminants

Aside from preventative measures and addressing point sources of chemical contaminants, such as batteries and pesticide containers, there are limited practical options available for the removal of chemical contaminants.

However, both composting and anaerobic digestion are biologically mediated processes in which a diverse range of micro-organisms are present. These micro-organisms have the capability to reduce levels of certain chemicals or even eliminate them entirely.

Organic chemicals

Composting can effectively break down many organic compounds although certain chemical contaminants may not degrade completely or may require specific conditions for degradation. The breakdown of chemical contaminants during composting can vary depending on factors such as temperature, moisture levels, composting method and the specific contaminants involved. Examples include:

- **Pesticides and herbicides** - Some pesticides and herbicides can undergo degradation during composting. The degree of breakdown depends on the specific compounds and their chemical properties. Some organic pesticides derived from natural sources may decompose more readily compared to synthetic pesticides. Clopyralid and aminopyralid are two examples of herbicides that are resistant to biodegradation (see Box 15).
- **Petroleum-based hydrocarbons** - Composting can facilitate the degradation of certain petroleum-based hydrocarbons, such as diesel fuel or motor oil, especially if the compost pile is actively managed and turned regularly. Micro-organisms involved in the composting process can contribute to the breakdown of these compounds.
- **Food waste contaminants** - Food waste may contain contaminants such as certain heavy metals, food additives or PFAS from packaging (see Box 3). While some of these contaminants may degrade or undergo transformation during composting, others may persist (e.g., PFAS).
- **Pharmaceuticals** - These include hormones (e.g., oestrogen) and antimicrobial agents (e.g., antibiotics) and may be present in animal manures and sewage sludges (biosolids). Composting has been shown to reduce the concentration of different antibiotics and hormones, although drawing general conclusions is difficult due to differing clinical practices in different countries[7].

As anaerobic digestion occurs in the absence of oxygen, microbially mediated biodegradation occurs in different ways to those in composting systems. The specific contaminants that break down during anaerobic digestion depend on various factors, including the composition of the feedstock and the operating conditions. Examples include:

- **Aromatic hydrocarbons**: Some aromatic compounds[8], like benzene, toluene, ethylbenzene, and xylenes (BTEX), have the potential to degrade under anaerobic conditions, although the extent of degradation can vary.
- **Simple chlorinated compounds**: Some chlorinated compounds, such as chloroform and carbon tetrachloride, may undergo partial degradation during anaerobic digestion. However, more complex chlorinated compounds tend to be resistant to degradation.

It is important to note that the breakdown of chemical contaminants during anaerobic digestion can be influenced by factors such as temperature, pH, retention time and the microbial community composition. Additionally, not all contaminants are efficiently degraded in anaerobic digesters, and some may require post-treatment (e.g., composting) to ensure their removal.

Inorganic chemicals

The concentration and distribution of heavy metals, such as lead and mercury, can change during the composting and anaerobic digestion (AD) processes. As waste materials are mixed and moved around, concentrated pockets of heavy metals may be dispersed, resulting in lower overall levels in the final compost or digestate. However, it is important to note that relying solely on this process to mitigate contaminated waste is not recommended over source reduction methods.

During composting, certain heavy metals like mercury, can become volatile under specific conditions. When exposed to high temperatures, these volatile heavy metals can convert into a gaseous form and escape into the atmosphere. However, not all heavy metals exhibit this behaviour, and their potential for volatilization varies.

Compost materials contain organic matter, such as humic and fulvic acids, which have the ability to bind or form complexes with heavy metals. This process, known as adsorption or complexation, can immobilize certain heavy metals, reducing their mobility and availability to living organisms.

Leaching refers to the movement of water through the compost pile, carrying dissolved substances, including heavy metals, away from the compost. The extent of leaching depends on factors such as the composting method, moisture content, and porosity of the compost pile.

In anaerobic digesters, the fate of heavy metals depends on the type of system, whether it is a wet or dry process. In wet AD plants, some heavy metals may dissolve in the liquid phase of the digester. This is more likely to occur for metals that are soluble in water or have a high affinity for organic matter.

Certain heavy metals can also bind to solid particles, such as organic matter or microbial biomass, present in the digester, reducing their concentration in the liquid phase. Moreover, certain micro-organisms involved in AD can accumulate heavy metals to varying extents by incorporating them into their biomass, effectively removing them from the liquid phase.

Similar to composting, during AD some heavy metals like mercury can undergo volatilisation and be released into the gas phase. The fate of these volatile heavy metals depends on subsequent gas treatment processes.

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[7] The type and concentration of pharmaceuticals in organic wastes reflect medical/veterinary licensing of drugs and clinical practice in different countries. As this can vary significantly in different parts of the world, generic conclusions can only be drawn in this publication.

[8] An aromatic compound is a type of organic compound that contains a ring of carbon atoms with alternating single and double bonds. These compounds exhibit a high degree of stability and often have distinct odours or aromas, which is how they acquired the name "aromatic." The most common example of an aromatic compound is benzene, which consists of a ring of six carbon atoms with alternating single and double bonds.

5.3 Biological contaminants

Biological contaminants are either intrinsic to plants or animals that subsequently become organic waste (e.g., plant toxins, weed seeds and weed propagules) or they may be introduced by organisms that live in, on, or reside near them (e.g., rodents that leave their faeces carrying pathogenic micro-organisms, or insects that lay their eggs and can subsequently hatch).

In addition, the survival of genetically modified organisms (GMOs) and micro-organisms that carry anti-microbial resistance (AMR) genes are more recent concerns.

Being of biological origin, these contaminants are generally inactivated, destroyed or decomposed through a number of different mechanisms caused by:

- **High temperatures** – this causes proteins to 'denature' and lose their functional properties and is the reason why we cook foods (think of an egg white turning from a colourless gel into a white solid). This denaturation happens on a micro-scale to most cells exposed to thermophilic composting.
- **Changes in pH** – composting piles often turn acidic (~ pH 5) initially - especially if food waste is present - due to the release of organic acids caused by microbial metabolism. As these acids are then consumed by composting microbes and ammonia starts to be released, the pH then turns alkaline (> pH 8) and can remain so for long periods of time.

By contrast, the pH in anaerobic digesters is generally kept close to neutral (pH 7) in order to maintain a stable microbial population of anaerobic bacteria.

- **Microbial competition/predation** – microbes that evolved to live in specific ecosystems (e.g., mammal intestines) are often unable to survive for significant lengths of time in the hostile environments found in composting and AD systems. This is partly because they are out competed by other microbes who are better adapted to live and source the nutrients they need, or due to predation.
- **Extracellular substances** – some microbes involved in composting (e.g., the group of bacteria called actinomycetes) can secrete anti-microbial substances to provide them with a competitive advantage against neighbouring microbes. These substances therefore kill susceptible microbes.
- **Oxygen levels** – the anaerobic environment in AD systems can be sufficient to kill off microbes that require oxygen for their survival and growth. Conversely, in a composting pile, oxygen levels can vary both temporally (with time) and spatially (with distance), so this can stress microbes that require stable oxygen levels.

On their own, with the possible exception of high temperatures, each of the above factors would be insufficient to eliminate or render a biological contaminant inactive. However, collectively they create a hostile environment for living organisms and plants that have not evolved to survive composting or anaerobic digestion processes.

Pathogens

The elimination of pathogens (human, animal and plant) is called "sanitisation" and is a requirement for organic waste treatment in various countries and regions, where minimum time-temperatures must be reached. These have been based on studies of indicator pathogen species, with risk assessment techniques used to identify acceptable reduction levels. Some of these time-temperature requirements are listed in Table 8 and examples of specific regional legislation for compost are listed in Table 5.

Table 8: Example time-temperature profiles for various types of organic waste treatment

Process	Minimum temperature	Minimum time	Additional requirements
USA PROCESSES TO FURTHER REDUCE PATHOGENS			
Windrow composting of biosolids (sewage sludge)	55 °C	15 days	Minimum of 5 turnings
In-vessel composting of biosolids (sewage sludge)	65 °C	3 days	--
EU FERTILISING PRODUCTS REGULATION			
Composting	55 °C	14 days	--
	60 °C	7 days	--
	65 °C	5 days	--
	70 °C	3 days	--
Anaerobic digestion (mesophilic)	37-40 °C	--	Including a pasteurisation process (70 °C for 1 hour)
		--	Followed by composting at ≥55 °C for ≥14 days
		--	Followed by composting at ≥60 °C for ≥7 days
		--	Followed by composting at ≥65 °C for ≥5 days
		--	Followed by composting at ≥70 °C for ≥3 days
Anaerobic digestion (thermophilic)	55 °C	24 hours	Followed by a hydraulic retention time of ≥20 days
		--	Including a pasteurisation process (70 °C for 1 hour)
		--	Followed by composting at ≥55 °C for ≥14 days
		--	Followed by composting at ≥60 °C for ≥7 days
		--	Followed by composting at ≥65 °C for ≥5 days
		--	Followed by composting at ≥70 °C for ≥3 days
EUROPEAN COMPOST NETWORK QUALITY ASSURANCE SCHEME			
Open windrow composting	55 °C	10 days	Turning/mixing of the material is recommended
	65 °C	3 days	
Enclosed composting	60 °C	3 days	

Due to concerns about the transmission of animal pathogens and prion[9] proteins, the European Union and Australia both place restrictions on the disposal and treatment of animal by-products (European Union, 2009). In the EU, the brain and spinal columns of cattle, sheep and goats must be incinerated and are therefore not allowed to be composted or digested anaerobically. Food waste (called catering waste in the Regulation) can be treated biologically either to the European standard (70 °C for 1 hour with a maximum particle size of 12 mm) or to national rules. Further information can be found in (European Compost Network, 2017).

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[9] These are infectious agents that consist primarily of misfolded proteins. They are responsible for causing a group of neurodegenerative diseases known as transmissible spongiform encephalopathies (TSEs). These diseases affect the brain and nervous system, leading to severe and often fatal neurological symptoms. In animals, well-known prion diseases include bovine spongiform encephalopathy (BSE) in cows (often referred to as 'mad cow disease') and scrapie in sheep.

Weed seeds and propagules

Weeds are generally known for their ability to adapt and survive in diverse and challenging environments. The evolution of weed species that are able to withstand high temperatures means that some are unfortunately able to survive the composting process, especially if thermophilic temperatures are not reached.

Some weed species have evolved seeds with protective coverings, such as hard seed coats or specialized structures, that provide resistance against heat and other harsh conditions. These adaptations allow weed seeds to remain dormant until favourable conditions, including lower temperatures, moisture, or nutrient availability, are present. Furthermore, some weeds, like bindweed and thistle, have underground structures such as rhizomes and tubers that can withstand the heat of composting.

Whilst the types of weeds presenting themselves in green/garden waste depend on the local environment, good site management practices, especially at composting facilities, should minimise their chances of survival. The temperature-time profiles noted in the previous section are normally regarded as being sufficient to ensure their eradication. However, care needs to be exercised during maturation and storage of compost/digestate in order to prevent re-colonisation by wind-blown seeds. Operators also need to exercise care with alien plant species, whose distribution may be unlawful.

Antimicrobial resistance genes

The widespread use of antimicrobial agents (i.e., antibiotics that target bacteria and antifungals that target fungi) in human/veterinary clinical practice and agriculture/horticulture has led to the development of resistant strains of pathogens (both bacterial and fungal). This means that the antimicrobial is no longer effective in killing them and their proliferation is now of global significance. Certain organic waste streams are more likely to harbour resistant micro-organisms, such as animal manures and sewage sludges (biosolids) as noted in Section 5.2. The genes that confer resistance can be passed on to offspring or can be transmitted to other microbes, including those of different species.

There is evidence that composting can reduce antimicrobial resistance (AMR) genes (Esperón *et al.*, 2020); however, the effectiveness of anaerobic digestion appears to be variable and dependent upon the treatment techniques used (Congilosi and Aga, 2021). Post composting of digestate has been found to be effective in reducing AMRs in anaerobic digestate (Congilosi and Aga, 2021; Gurmessa *et al.*, 2021). As this is an area of emerging concern, more research is needed to better understand the risks associated with AMR and process management techniques that will improve their destruction.

Genetically modified organisms

A genetically modified organism (GMO) is an organism whose genetic material has been altered using genetic engineering techniques. These techniques involve the manipulation of an organism's DNA, typically by introducing genes from another organism, to give it specific traits or characteristics. It has been used to modify crops to provide resistance to pests, diseases or environmental conditions, or genes that enhance nutritional content or improve crop yield.
The regulations and acceptance of GMOs vary around the world. Different countries have different approaches and policies regarding the cultivation, importation and labelling of GMOs.

As GMOs contain "foreign" genes, some compost markets (especially organic farmers and growers) have expressed concern that this DNA may survive the composting process, then subsequently be transferred to soil micro-organisms. Research carried out in the UK to test whether foreign DNA could survive the composting process (Schwarz-Linek et al., 2007), suggested that it could not be detected following in-vessel composting for more than two days at temperatures greater than 65 °C. Again, this highlights the importance of maintaining appropriate time-temperature profiles.

Plant toxins

Plant toxins, also known as plant secondary metabolites or plant defence compounds, are chemical substances produced by plants that are toxic or harmful to other organisms. These toxins serve as a defence mechanism for plants against herbivores, pathogens and competing plants. They play a crucial role in plant survival and protection.

Plants produce a wide variety of toxins with diverse chemical structures and properties. Some common types of plant toxins include alkaloids, glycosides, terpenoids, phenolics, and lectins. These toxins can be found in various plant parts such as leaves, stems, roots, flowers and fruits.

The production of plant toxins is an evolutionary adaptation that allows plants to deter herbivores from consuming them. Consequently, some farmers operating mixed agricultural systems have expressed concern that compost could potentially harm their grazing livestock. Research carried out in the UK looked at the fate of four plant toxins during composting, summarised in Table 9. The authors concluded that the toxins posed a negligible risk to livestock due to degradation of the toxins before and during composting and dilution within the composting mass.

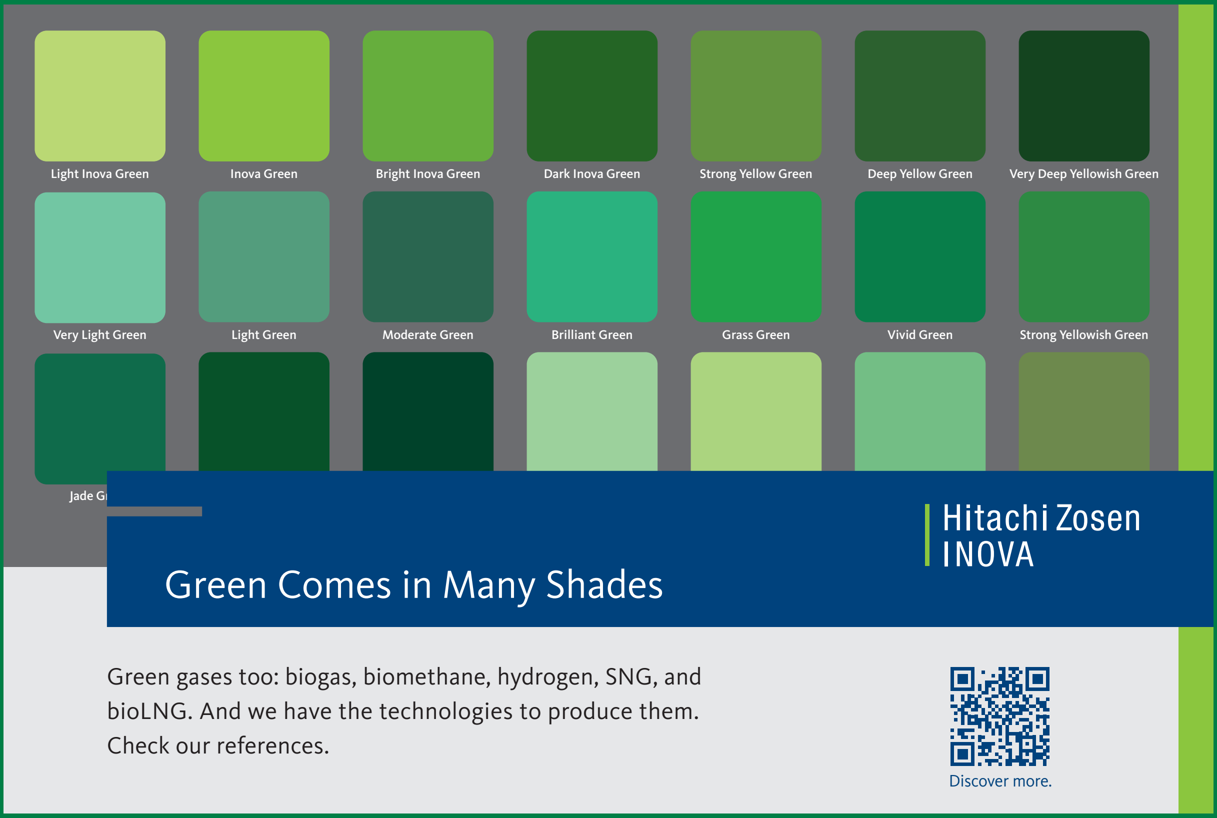
Table 9: Fate of plant toxins during open air windrow composting of garden waste

Toxin	Plant	Time taken for concentration to fall below the limit of detection	Reference
Taxoids (taxines A and B)	Yew *(Taxus baccata)*	65 days	(Michie, Litterick and Crews, 2010)
Coniine	Hemlock *(Conium maculatum)*	Degradation not accelerated by composting cf. control	
Coniceine	Hemlock *(Conium maculatum)*	35 days	
Grayanotoxins	*Rhododendron ponticum*	63 days	(Michie, 2009)

5.4 Practical examples

Some of the ways in which contaminants are removed and managed at organics recycling facilities are detailed in the Appendix. The examples include both composting and anaerobic digestion facilities treating separately collected organic waste.

Although the range of organic waste accepted at each facility varies, it mainly includes organic waste collected at households and green waste arising from private gardens and municipal green areas.



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Green Comes in Many Shades

Green gases too: biogas, biomethane, hydrogen, SNG, and bioLNG. And we have the technologies to produce them. Check our references.

Discover more.

6 Conclusions

This guide has provided background information on the different types of contaminants that can enter organic waste streams intended for recycling, their potential impacts and the ways in which they can be prevented or removed.

Plastics currently make up the majority of physical contaminants found in organic waste, with their removal presenting significant technical challenges in high moisture wastes (such as food) due to the “sticky” properties of water. Consequently, this has a significant impact on organics recycling processes, their profitability and the quality of final products. For example, the cost of removing and disposing of contaminants per tonne is 2-to-4 times higher than the gate fee for organic waste levied by many recycling facilities in the EU.

To address these issues, a contamination hierarchy has been proposed, suggesting that preventing the introduction of contaminants into organic waste streams should be prioritised whenever possible.

This can be achieved through targeted awareness campaigns aimed at waste producers and by implementing bans on certain items, such as fruit stickers.

Where prevention is not possible, removal of contaminants at the start of a recycling process is generally preferable to removal at the end of the process. However, this can result in organic waste losses due to co-removal alongside the contaminant (the so-called “dragging effect”) as well as contaminant fragmentation, resulting in smaller pieces that subsequently become harder to remove. On the other hand, leaving contaminants in the process can cause operational difficulties, concerns by regulators and disintegration of the plastic due to exposure to high temperatures, leading to further fragmentation. An imperfect balance thus needs to be found by operators.

With the mainstay of contaminant removal techniques having been developed for other sectors, such as minerals and mining, there is urgent need for improved equipment and the development of new techniques specifically focussed on the organics recycling sector taking into account the high moisture levels of waste inputs.

ISWA’s Working Group on the Biological Treatment of Waste therefore calls for further research and development to improve the methods and efficiencies of removing unwanted contaminants from organic wastes, compost and anaerobic digestate.

Improvements and innovation are essential, not only to improve operational efficiencies, but also to prevent contaminants accumulating in soil. The anticipated global uplift in organic waste recycling needed to reduce fugitive methane emissions from dumpsites and landfills, coupled with the use of compost and digestate to ameliorate arable soils and recycle plant nutrients, highlights the urgency of the task at hand. Therefore:

- **ISWA** urges **manufacturers selling equipment to the organics recycling industry to invest in research and development to improve techniques for removing contaminants, whilst minimising the concomitant loss of organic matter (the “dragging effect”)**. In particular, the report recommends studying the properties of water that make the effective removal of plastic film particularly challenging.
- **ISWA** calls on **managers of composting and anaerobic digestion plants to prioritise maximizing the quality of their final products**. This entails establishing agreements with local authorities/ municipalities and waste haulers that include financial penalties (e.g., through variable gate fees) for batches of organic waste that do not meet acceptable quality standards and exceed the established threshold values for physical contaminants. This should include setting a maximum level of contaminants in contracts.
- **ISWA** also **encourages municipal solid waste collection companies and hauliers of organic waste to routinely inspect loads and to feedback contamination issues to individual waste producers**. This approach ensures a quality-oriented process, starting from the point of production all the way to the recycling facility.
- **ISWA appeals to local decision makers and city managers to invest in regular information campaigns aimed at raising citizens’ awareness of the importance of maximising the quality of organic waste for recycling.**

The circular economy of organic waste starts with the soils responsible for producing agricultural goods that sustain our cities. It culminates with these same soils becoming the ultimate recipients of high-quality compost or digestate made out of organic waste. To ensure the utmost effectiveness, it is essential to minimise contamination, optimise product quality and enhance the efficiency and economic viability of organic waste recycling processes.

> The circular economy of organic waste starts with the soils responsible for producing agricultural goods that sustain our cities.

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Appendix - Practical examples

The following sections demonstrate the practical management of contaminant removal at organics recycling facilities. They outline the specific steps in which contaminants are eliminated or diverted from the main process flow.

It is important to note that contaminants are typically quantified on a "wet" mass basis, which often overestimates the actual amounts. It would be more accurate to express these quantities based on a "dry" mass basis. Furthermore, the removal of contaminants leads to an increase in rejected materials due to the "dragging effect", which inadvertently removes both contaminants and a portion of the organic waste from the recycling process.

The following examples cover four different organics recycling facilities: a composting plant for food and garden waste, a facility producing biogas by dry anaerobic digestion (AD) and two plants combining both wet AD and composting.

The types of organic waste treated at each facility vary significantly. The composting facility primarily treats food waste, while the range of waste handled at other facilities is broader. These include bio-waste, which is a combination of food residues and garden waste collected from households, as well as packaged food waste from commercial sources such as supermarkets and restaurants. Additionally, the AD facility also processes manure. It is worth noting that garden/green waste is incorporated into the input feedstock of all the facilities under investigation. For each facility a short diagram has been prepared, estimating the contaminant quantity diverted at the different process steps.

Pre-treatment of food waste at a composting facility

The facility accepts food waste collected separately from households and from HoReCa producers; since some municipalities collect food waste using a bring scheme, an intensive pre-treatment process is applied to sort out conventional plastics from the organic waste undergoing composting.

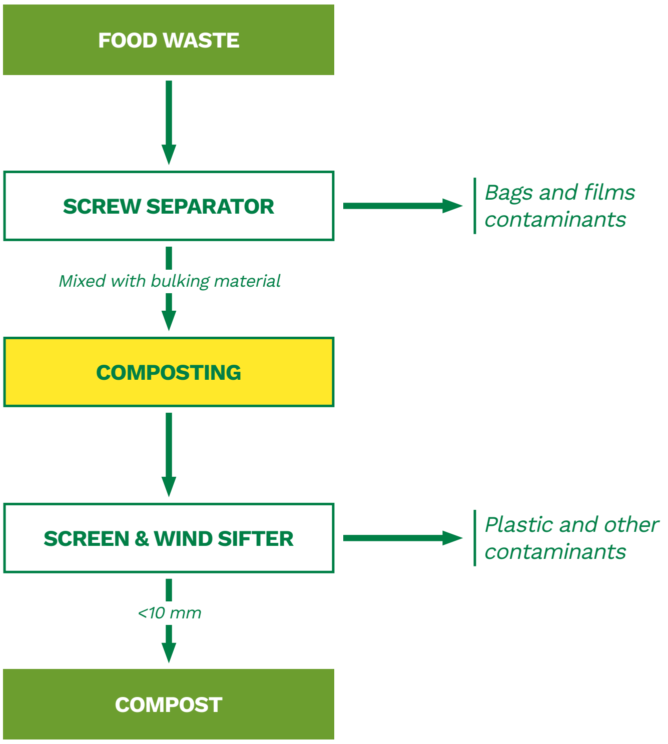
The main process steps are shown below and in Figure A1.

1. The input food waste is pre-treated by means of a screw separator that sorts out plastic liners and part of the organic material, which are both sent for disposal.
2. The pre-treated food waste, which has partially lost its bulk structure, is then mixed with a bulking agent (shredded garden waste and prunings) and sent to an in-vessel composting unit for approximately eight weeks.
3. The fresh compost is then screened to 10 mm so as to sort out plastics and other contaminants and the bulking agent is then recirculated.
4. The fine fraction (compost) is further stored for about one month for final maturation before being sold to farmers.

According to detailed waste composition analysis at the facility, approximately 97% of all plastic contaminants (conventional polymers) are sorted out of the process.

Figure A1: Scheme of contaminants removal at a composting plant

Composting facility – IT – key data	
Input: Food waste	**32,000** tonnes/annum
Contaminants in input	**1,184** tonnes/annum
Contaminants removal (data on plastics) during pre-treatment	**92%**
Contaminants removal (data on plastics) after composting	**5%**



Data source: courtesy of Altereko sas and Biociclo (IT), 2023
Edited by: M. Ricci & J. Gilbert; 2023

Pre-treatment of bio-waste at a dry anaerobic digestion and composting facility

The facility in Sweden accepts bio-waste collected separately from households (mostly in paper bags), green waste, horse manure and packaged food waste from commercial activities.

The main processes steps are shown below and in Figure A3.

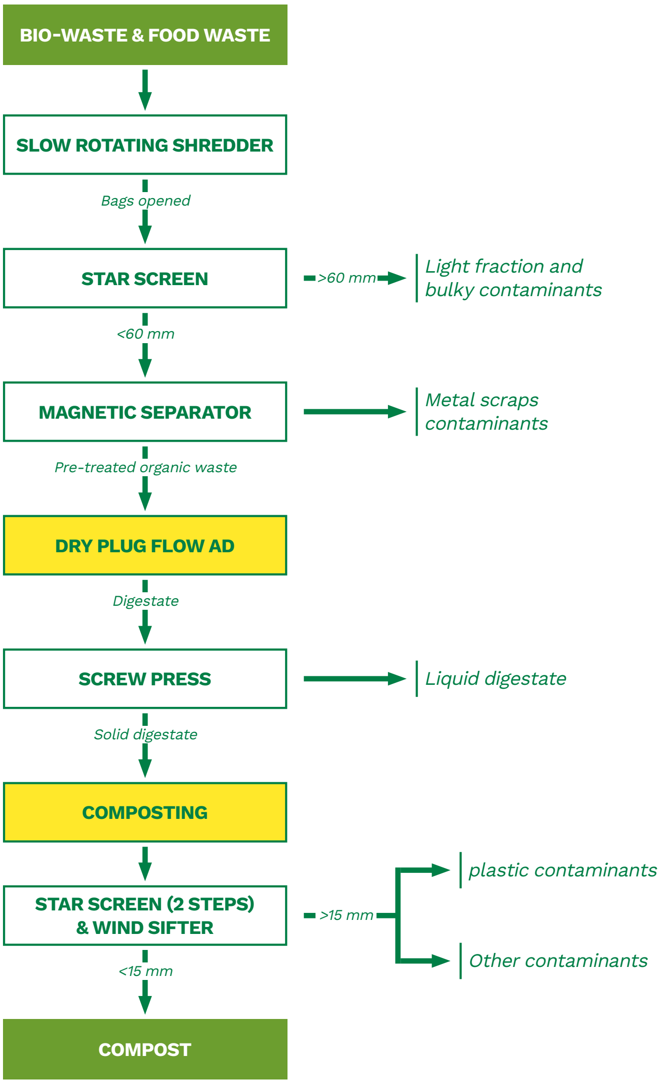
1. The input feedstock is pre-treated by means of a slow rotating shredder to open the bags and limit fragmentation of (plastic) contaminants. The organic waste is then sieved using a star screen to separate all bulky and light fraction above 60 mm. About 90% of metal contaminants are separated by an electromagnetic separator and sent for recycling. Approximately 50% of all contaminants are sorted out by these pre-treatment processes.
2. The pre-treated organic waste is then sent to the dry AD plug-flow process for 2-3 weeks during which there is anaerobic decomposition and related biogas production.
3. After biogas production, the digestate is dewatered by means of a screw press. The liquid is used as an agricultural fertiliser, with a small part being reused for humidification in the AD stage. The solid fraction has the characteristics of raw compost and contains the majority of contaminants.
4. The solid digestate is then mixed with a bulking material and treated for approximately four weeks in an aerated composting tunnel.
5. The compost is then screened into three different fractions and wind sifted, to sort out plastics and other contaminants from the final product (Figure A2). The fine fraction (compost) has a size of less than 15 mm.

Figure A2: Plastic contaminants separated at the facility in Sweden

Source: Hitachi-Zosen

Figure A3: Scheme of contaminants removal at a dry anaerobic digestion plant in Sweden

Dry AD & composting facility - SE – key data	
Input: Bio-waste & food waste	**67,700** tonnes/annum
Contaminants in input	**8,100** tonnes/annum
Contaminants removal during pre-treatment	**50%**
Contaminants removal after composting	**42%**



Data source: courtesy of Hitachi-Zosen, 2022
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Pre-treatment of bio-waste at a wet anaerobic digestion and composting facility

The facility in Italy accepts primarily food waste collected separately from households (mainly in compostable plastic bags), sludges and other organic waste from the food processing sector, and green waste.

Figure A4: An example of food waste collected with significant quantities of contaminants

Source: M. Ricci

The main process steps are shown in Figure A5 and described below:

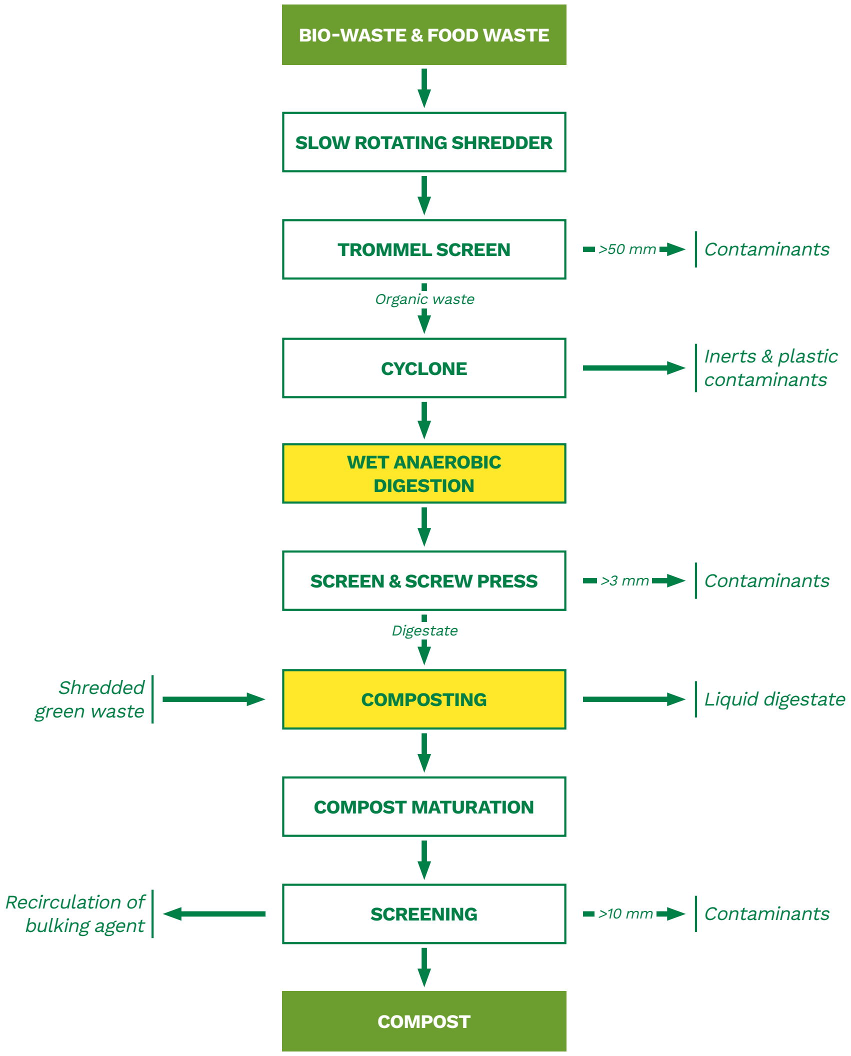
There are various steps to remove physical contaminants during the integrated AD and composting process of organic waste, in order to maximise process yields and minimise contamination of the compost product:

1. The input food waste is pre-treated by means of a slow rotating shredder followed by a trommel screen to separate the fraction above 50 mm, which is then sent for disposal.
2. The organic fraction (< 50 mm) is further cleaned in a cyclone to remove inert and plastic contaminants; approximately 60% of all contaminants are removed by this complex pre-treatment process.
3. The pre-treated organic waste is then mixed with hot water and sent to a wet AD process at 55 °C.
4. After biogas production, the digestate is screened and dewatered by means of a screw press, which also serves to further remove contaminants.
5. The solid digestate is then mixed with shredded green waste with a low content of contaminants not exceeding 1% and the organic waste is composted for approximately four weeks in aerated windrows. The fresh compost is further treated aerobically in static windrows for an additional eight weeks.
6. The mature compost is then screened at 6-10 mm, to remove contaminants from the product.

The biogas produced at the facility is further upgraded to biomethane, while the final compost is produced according to the quality label assigned by the Italian Composting and Biogas Association (CIC).

Figure A5: Scheme of contaminants removal at a wet anaerobic digestion and composting facility in Italy

Wet AD & composting facility – IT – key data	
Input: Food waste and other organic waste	**75,000** tonnes/annum
Contaminants in input food waste and green waste	**8,602** tonnes/annum
Contaminants removal during pre-treatment	**60%**
Contaminants removal after AD	**12%**
Contaminants removal after composting	**27%**



Data source: courtesy of M.Ricci (IT), 2023

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Pre-treatment of bio-waste at a wet anaerobic digestion facility

The facility in Germany accepts commercial food waste, industrial waste and equal amounts of bio-waste collected separately from households alongside green/garden waste.

Figure A6: An example of bio-waste collected from households

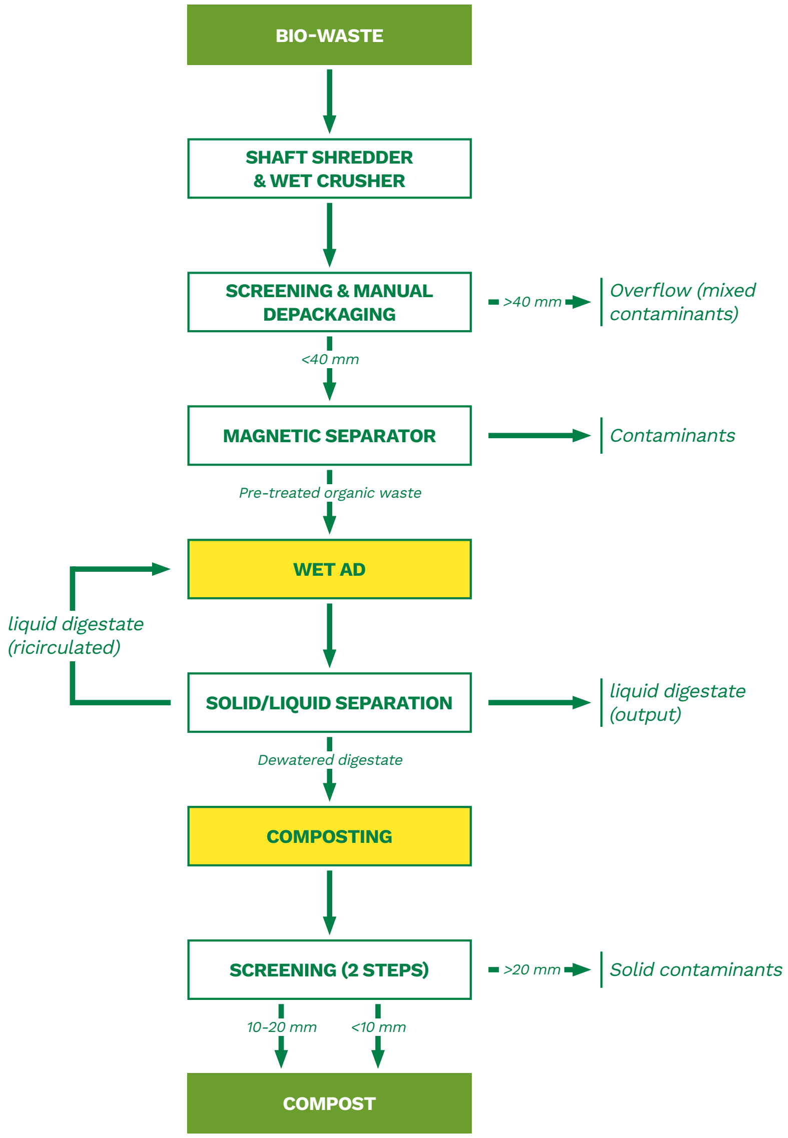
Source: Fachverband Biogas e.V. (German Biogas Association)

The main process steps are shown in Figure A7 and summarised below:

1. The input bio-waste is pre-treated using a crusher and then screened at 40 mm, so that oversized contaminants are removed; the input food waste then undergoes manual de-packaging before undergoing further crushing and screening.
2. The organic fraction (<40 mm) is further cleaned for metals; approximately 85% of all plastic contaminants are sorted out by the pre-treatment steps.
3. The pre-treated organic waste is sent to a wet AD process.
4. After biogas production, the digestate undergoes partial recirculation, while a significant part is being dewatered by means of a screw press and a liquid fraction is partially eliminated.
5. The solid digestate is then mixed with shredded green waste and the organic waste is composted in turned windrows under a roof for at last three months.
6. The bulk compost obtained is then sieved into a fine fraction below 10 mm for use at private horticultural entities, a coarse fraction at 10-20 mm is used in agriculture and an over sized fraction (above 20 mm) with the residual contaminants is sent for disposal. The compost produced has obtained the German compost quality certificate.

Figure A7: Scheme of contaminants removal at a wet anaerobic digestion plant in Germany

Wet anaerobic digestion facility – DE – key data	
Input: Bio-waste & industrial organic waste	**53,000** tonnes/annum
Contaminants (plastics only) in input	**707** tonnes/annum
Contaminants removal during pre-treatment	**85%**
Contaminants removal after composting	**12%**



Data source: courtesy of German Biogas Association, 2023

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