Contaminants Present in Organic Waste: Framework

Prepared for Ministry for the Environment

DRAFT

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Report for Ministry for the Environment

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1.0 Audience and the Purpose of the Report

1.1 Introduction

The Ministry for the Environment (MfE) commissioned Eunomia Research & Consulting, Whetū Consulting Group, and Massey University, to examine issues of contaminants in organic waste. The project aims to understand and address the challenges posed by contaminants in our organic waste material streams in order to mitigate risks to soil, human and animal health and expand end markets for processed organic waste. The project outputs will build on existing knowledge and standards and provide clear action recommendations for addressing the contaminants challenge.

The report is one of a series in the project's three phases:

Phase 1: Review of Regulations and Guidelines

- Establish framework (this report)
- Review of NZ standards regulations and guidelines
- Review of international practice
- Gap analysis

Phase 2: Engagement and End Markets

- Develop stakeholder engagement plan
- Tangata whenua engagement
- Industry engagement
- Analysis and reporting

Phase 3: Recommendations

- Draft recommendations
- Review by Tangata whenua and industry
- Final recommendations

1.2 Contextual Framework

This report sets out a high-level approach for what the work is trying to achieve. In this initial piece of work, we aim to articulate, at a high level, what the objectives should be and what they mean in the context of organic waste contamination. This will set the objective against which the adequacy of current standards and regulations can be assessed and set the compass for what future measures should aim to deliver.

In simple terms, if the objective is to enable organic waste recovery at the lowest cost, and simply avoid the worst impacts of contamination, this will deliver a very different set of outcomes than if the objective is to achieve zero contamination to land and full circularity of organics.

2.0 Scope

2.1 What the framework covers

The work covers the full value chain for organic wastes, including end users of processed organic waste products (compost, digestate and other soil amendment products, energy etc), processors of organic waste, waste generators (domestic and commercial), waste management service providers, regulators and certifying agencies. It also includes dedicated Māori engagement to understand and reflect te ao Māori perspectives on these issues as we seek to transition towards a circular economy.

2.2 Te Ao Māori

In the context of this project the contribution of Māori extends beyond acknowledging and incorporating Māori perspectives. Concerning the whenua, mātauranga Māori has specific insights that it is anticipated will be able to practically shape and direct the nature of the solutions that are forged. The te ao Māori input is expanded in the "Māori Perspectives Approach report[1].

3.0 Basis for Framework: NZ Waste Strategy

For the purposes of establishing a conceptual framework for this project we have taken as our starting point the New Zealand Waste Strategy[2]. Central to the waste strategy is the concept of the circular economy enriched by te ao Māori.

3.1 Vision and Principles

The vision of the waste strategy is:

> *By 2050, Aotearoa New Zealand is a low-emissions, low-waste society, built upon a circular economy.*

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[1] Whetū Consultancy (2023), *Māori Perspectives Approach*, Prepared for Ministry for the Environment for the Options for Contaminants in Organic Waste Project August 2023

[2] Ministry for the Environment. 2023. *Te rautaki para | Waste strategy.* Wellington: Ministry for the Environment.

We cherish our inseparable connection with the natural environment and look after the planet's finite resources with care and responsibility.

The vision is supported by a number of guiding principles. Relevant ones in this context include the following:

- Enable people, businesses, organisations and sectors to do the right thing, by improving systems, services and information.
- Shift the responsibility and cost of minimising and managing waste to industries and consumers, and away from communities, nature and future generations.
- Create accountability, by having transparent data and reporting and clear regulated obligations.
- Rethink and redesign products, to avoid using materials unnecessarily, design out waste and pollution, and make it easy to reuse and recycle products.
- Recognise the unique perspectives, needs and approaches facing different local communities, businesses, hapū, iwi and whānau.
- Consider how the social situation of individuals, whānau, iwi and communities, and their locations – rural and urban, national or international – affect their perspectives.
- Recognise the connections between waste and other environmental, social and economic issues, including climate change and biodiversity.

Source: Ministry for the Environment. 2023. *Te rautaki para | Waste strategy.* Wellington: Ministry for the Environment

3.2 Phased Approach

The strategy divides its approach into three phases:

1. **Embedding circular thinking into systems.** By 2030, our enabling systems are working well, and behaviour is changing.
2. **Expanding to make circular normal.** By 2040, circular management of materials is normal, expected and well supported.
3. **Helping others do the same.** By 2050, New Zealand has a low emission, low-waste circular economy and is helping other countries make the change

This phased approach is potentially a useful model to consider how contamination could be progressively addressed. For example:

1. In the first phase measures could be focused on addressing key waste streams and key contaminants and building a framework for managing contamination across the value chain.
2. In the second phase the focus could be on implementing the framework, expanding the range of contaminants addressed, and addressing the production

and use of key types of contaminants.

3. In the third phase the focus could be on achieving a fully circular bioeconomy, where no harmful contaminants enter the system, and all biological materials are able to be put to their highest value use.

This type of phased approach helps clarify the purpose of the current work within a larger framework. In other words, the current project would focus on addressing the first stage, while forming a steppingstone to a more holistic management approach.

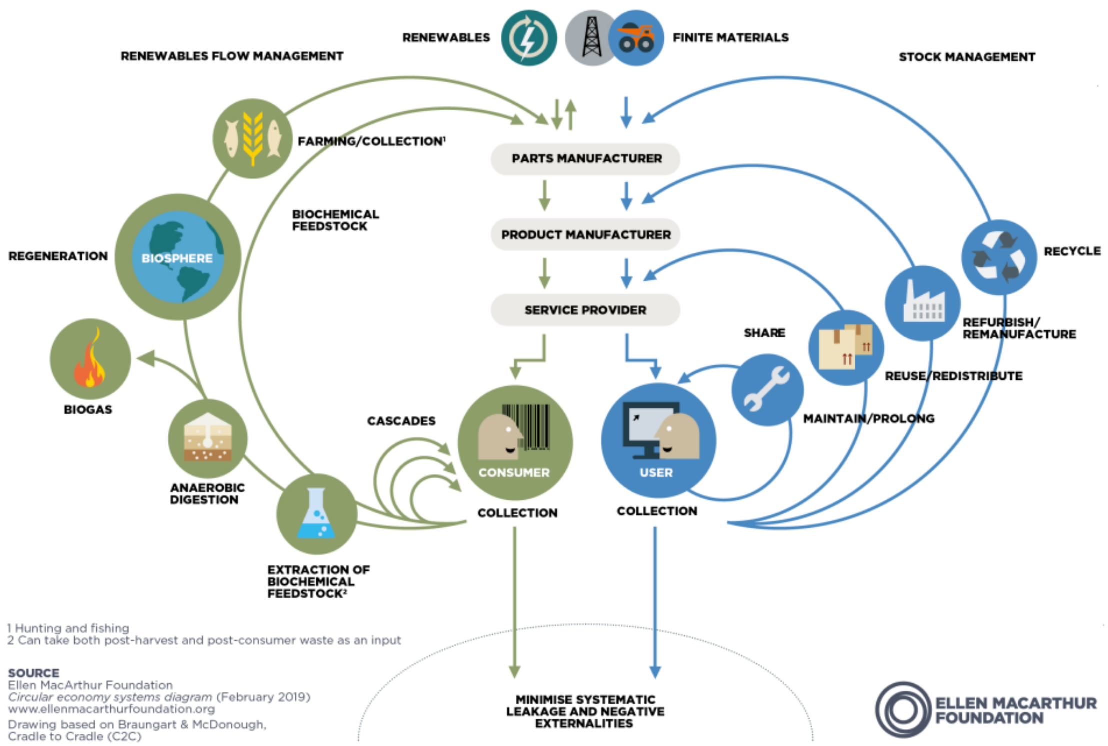
3.3 Circular Economy

The Ministry for the Environment describes the circular economy as follows:

> *In a circular economy, we design out waste and pollution, keep resources in use for as long as possible, then recover and regenerate products and materials at the end of their lifecycle. Protecting and regenerating natural systems is key to a circular economy, as is delivering equitable and inclusive outcomes.*[3]

The Ellen McArthur Foundation is acknowledged as the leading global organisation in articulating and promoting the circular economy. They developed what has come to be referred to as the 'butterfly diagram'. This shows how there are two fundamental types of systems in a circular economy, biological systems and 'technical' systems.

Figure 1: Ellen McArthur Foundation Butterfly Diagram



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[3] https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/circular-economy-and-bioeconomy/

In biological systems materials are harvested and the products and waste products are reabsorbed back into nature where they provide nutrients to contribute to regeneration and create more natural materials.

In technical systems, materials such as metals and plastics are circulated as long as possible and are eventually recycled back into materials and products. This is illustrated in the diagram above.

3.4 Circular Bioeconomy

Bioeconomy describes the parts of the economy that use renewable biological resources to produce food, products and energy.[4]

For a circular bioeconomy to function effectively the renewable biological resources have to recirculate in a manner that provides nutrients and valuable organic matter. If this material is contaminated it will not be able to effectively perform this function. Contaminated waste material will cease to provide value back into the system and will either have to be disposed of or cycled back into lower value uses where the contamination poses less of a threat to people and ecosystems.

Contamination can take place at any point in the material or product life cycle. The linear economic system does not separate biological and technical systems and there are almost unlimited opportunities for materials to cross from one system, where they may be beneficial or benign into another system where they become a contaminant and are potentially harmful. An illustration of this is plastic. In use, and while it remains within technical systems (e.g. recycling, manufacture), plastic is a useful and valuable material, but when it enters biological systems, it is creating significant issues such as plastic and microplastic pollution and as a matrix for chemicals and substances which can have negative health impacts.

A key principle for the circular bioeconomy therefore is that natural products and materials should not be irrevocably mixed with technical materials (such as plastics, chemicals, and non-biodegradable substances). Adherence to this principle would go some way to avoiding some of the key issues in relation to contamination in organic wastes.

It is worth noting however that not all contamination is non-biological. Biological contaminants in organic waste streams can include pathogens, and materials that are not able to be managed within a particular process - such as flax or cabbage tree leave in most commercial composting processes or wood fibres in anaerobic digestion.

[4] https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/circular-economy-and-bioeconomy/

4.0 Organic Waste Contaminants System Components

4.1 Defining Contamination

There is not a singular widely used and accepted definition of contamination in New Zealand. Our review of legislation (refer separate report[5]) reveals that the existing legislation and regulation all use differing definitions.

For the purposes of this project, we intend to identify a definition which can be applied consistently within this work. This will not address the wider question of establishing a common definition or set of definitions across legislation, regulation, guidelines, standards and strategies. Recommendations on standardising definitions is a potential output from this project.

The Natural and Built Environments Bill (S7) defines contamination as follows:

contaminant *includes any substance (including gases, odorous compounds, liquids, solids, and micro-organisms) or energy (excluding noise) or heat that either by itself or in combination with the same, similar, or other substances, energy, or heat, —*

> *(a) when discharged into water, changes or is likely to change the physical, chemical, or biological condition of the water; or*
>
> *(b)when discharged onto or into land or into air, changes or is likely to change the physical, chemical, or biological condition of the land or air onto or into which it is discharged.*

This definition does not make any distinction between a beneficial change and an adverse one. It simply identifies that a contaminant is something that is not a natural or expected part of the ecosystem into which it is discharged. For example, application of fertiliser or soil amendment under this definition would be considered a contaminant even though the effect is to improve the health of the soil. The definition of contaminated land however does take harm into account:

contaminated *land means land where a contaminant is present—*

> *(a) in any physical state in, on, or under the land; and*
>
> *(b) in concentrations that—*
>
> > *(i) exceed an environmental limit; or*
> >
> > *(ii) pose an unacceptable risk to human health or the environment*

[5] Eunomia (2023) Contaminants Present in Organic Waste: Review of New Zealand Regulations and Guidelines. Report for Ministry for the Environment

This introduces the concept that a contaminant has to exceed an environmental or human health threshold.

This in turn raises the issue of what acceptable limits or thresholds might be? The limits or thresholds will vary depending on the receiving environment, and/or the risk of the contaminants spreading to more sensitive receptors from the receiving environment.

Chapman (2007) a paper now cited by 265 other authors, makes a distinction between contamination and pollution. Chapman (2007) states the following:

> "*Contamination is simply the presence of a substance where it should not be or at concentrations above background. Pollution is contamination that results in or can result in adverse biological effects to communities. All pollutants are contaminants, but not all contaminants are pollutants*''.[6]

In other words, contamination is not necessarily a problem and does not always require remedial action: contamination can be geogenic (i.e., arise from natural processes or sources). However, pollution is always bad. The risk associated with contaminants must be assessed and the risk associated with pollutants must be managed/mitigated.

Under this definition any contaminant that exceeds a threshold where it can cause harm is a pollutant. Contaminants therefore need to be managed before they become pollutants.

For the purposes of this work, we therefore propose to use the following definitions:[7]

> **Contaminant** means:
>
> *any substance (including gases, odorous compounds, liquids, solids, and micro-organisms) or energy (excluding noise) or heat that is present in the environment or a specific substance under investigation at a level above what is expected or normal for that environment or substance.*
>
> **Pollutant** means:
>
> *A contaminant in the environment or a substance under investigation that causes, or is likely to cause, harm to resident biological communities (which can be microorganisms, plants, animals or people).*

The benefit of this definition of contaminant is that it allows consideration of contaminants through the system before they cause adverse effects. This is important as adverse effects are not necessarily known until the interaction with the receiving

[6] https://www.sciencedirect.com/science/article/pii/S016041200600136X?via%3Dihub

[7] Based on: Chapman, P. (2007) Determining when contamination is pollution – Weight of evidence determinations for sediments and effluents. *Environment International*, 33: 494-501. doi:10.1016/j.envint.2006.09.001

environment has occurred. Contaminants may cause issues in some receiving environments but not in others.

4.2 Waste Streams

The Ministry for the Environment indicated that the focus of the work should be broadly on sources of household, business, commercial and industrial organic waste that:

- is often/predominantly being disposed to some class of landfill (forestry slash for instance is not typically disposed to landfill); and
- has potential valuable end uses and markets in a processed form.

While the actual feedstocks and sources that may be covered by the study and its recommendations are likely to vary, for the purposes of this work we have assumed the following waste streams will be the key focus:

Food wastes:

- Household food scraps
- Commercial catering wastes (cafe, restaurant, institutional wastes etc.)
- Food manufacturing wastes (e.g. bakery, dairy etc.)

Paper and cardboard

- Incidental paper and card from households
- Shredded paper or card used as mulches or additives to organic processes

Garden and green wastes

- Household garden wastes
- Ashes
- Charcoal
- Landscaping
- Sports fields and parks
- Bark, woodchip and sawdust

Carcasses, sludges, and manures

- Food processing wastes (e.g., meat and seafood processing, packhouse, etc.)
- Farm/production wastes (chicken and piggery wastes, dairy shed effluent, manures)

Waste Water Treatment Plant effluent

- Digestate
- Biosolids

For the purposes of clarity, the following organic waste streams are excluded from the study:

- Forestry slash
- Dead stock
- Biologically hazardous material
- Non-organic soil amendments and fertilisers

4.3 Organic Waste Products

The variety of feedstocks noted above could be managed through a range of processes to produce a number of different products. These could include the following:

- Compost
- Vermicast
- Digestate (liquid and solid)
- Biosolids
- Biochar
- Soil amendments (e.g. gypsum, mulches)
- Fish food
- Stock food

4.4 Key Contaminants and Pathways in a Linear System

If contaminants are defined as above, the range of contaminants is potentially vast. Key contaminants that could potentially result in pollution are noted at a high level below. A more detailed list is provided in Appendix A.1.0.

It should also be noted that plastics present a complex picture in terms of their potential risks as contaminants. They can present risks as physical contaminants, microplastics, and nanoplastics, and due to the large number of types of plastics, the wide range of additives, and their ability to act as vectors for chemicals they absorb, the level of risk can vary. Refer to Appendix A.2.0 for further detail on issue of plastics as contaminants.

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

Table 1: Key Physical Contaminants and Sources

Contaminant	Source Material	Key Feedstocks Affected[8]
Plastics & Petrochemicals		
Plastics as a physical contaminant	Lightweight packaging, malleable plastics, plastic films, bags, polystyrene, film plastics	Garden and landscaping green waste, agricultural waste, food waste
Microplastics, and nano plastics	Lightweight packaging, malleable plastics, plastic films, bags, polystyrene, film plastics	Garden and landscaping green waste, agricultural waste, food waste
Other Physical contaminants		
Metal as a physical contaminant	Metal	Food waste, garden waste
Glass	Glass	Food waste, garden waste
Stones		Garden and landscaping green waste
Non --compostable green waste		
Fibrous material - can't be shredded or slow to decompose	Flax	Garden and landscaping green waste
Fibrous material - can't be shredded or slow to decompose	Cabbage tree	Garden and landscaping green waste
Fibrous material - can't be shredded or slow to decompose	Bamboo	Garden and landscaping green waste
Fibrous material - can't be shredded or slow to decompose	Palm fronds	Garden and landscaping green waste

[8] Based on ISWA (2023) A Practitioner's Guide to Preventing and Managing Contaminants in Organic Waste Recycling

Table 2: Key Chemical Contaminants and Sources

Contaminant	Source Material	Key Feedstocks Affected[9]
Plastics & Petrochemicals		
Motor oil	Motor oil	Food waste, garden waste
Aromatics - benzene, toluene etc.	Petrol residues	Food waste, garden waste
Heavy metals		
Arsenic	Biosolids, multiple sources	Green waste, manures and slurries
Cadmium	Biosolids, additives, soil, multiple sources	Green waste, manures and slurries
Chromium	Biosolids, Ash, multiple sources	Green waste, manures and slurries
Copper	Biosolids, Ash, multiple sources	Green waste, manures and slurries
Lead	Biosolids, Ash, multiple sources	Green waste, manures and slurries
Mercury	Biosolids, multiple sources	Green waste, manures and slurries
Nickel	Biosolids, multiple sources	Green waste, manures and slurries
Zinc	Biosolids, multiple sources	Green waste, manures and slurries
Boron	Ash, multiple sources	Green waste, manures and slurries
Silver	Biosolids, multiple sources	Green waste, manures and

[9] Based on ISWA (2023) A Practitioner's Guide to Preventing and Managing Contaminants in Organic Waste Recycling

Contaminant	Source Material	Key Feedstocks Affected[9]
		slurries
POPs		
Hexabromodiphenyl ether (hexaBDE)	Industrial chemical, used in additive flame retardants	Food waste, green waste, agricultural waste
heptabromdiphenyl ether (heptaBDE)	Industrial chemical, used in additive flame retardants	Food waste, green waste, agricultural waste
Lindane	Insecticide	Green waste, agricultural waste
PCBs	Caulk, paint, glues, plastics, fluorescent lighting ballasts, transformers and capacitors	Food waste, green waste, agricultural waste
Chlordane	Insecticide	Agricultural waste
Dioxin	Pesticides and legacy chemicals in soils	Agricultural waste
PFAS, phthalates, and bisphenols etc.	Plastic, paper packaging, compostable packaging	Food waste, green waste, agricultural waste
DDT	Disease control	Agricultural waste
Pharmaceutical compounds & metabolites		
Human medicines	Medicine	Manures and slurries
Animal remedies/hormones	Drenches, veterinary medicines	Manures and slurries
Garden / lawn		
Clopyralid	Grass clippings	Garden and landscaping green waste, agricultural waste
Aminopyralid	Grass clippings	Garden and landscaping green waste, agricultural waste

Contaminant	Source Material	Key Feedstocks Affected[9]
Picloram	Grass clippings	Garden and landscaping green waste, agricultural waste

Table 3: Key Biological Contaminants and Sources

Contaminant	Source Material	Key Feedstocks Affected[10]
Pathogens		
E. coli	Biosolids, food waste	Food waste, green waste, agricultural waste, manures and slurries, slaughterhouse waste/animal by-products*
Salmonella	Biosolids, food waste	Food waste, green waste, agricultural waste, manures and slurries, slaughterhouse waste/animal by-products*
Campylobacter	Biosolids, food waste	Food waste, green waste, agricultural waste, manures and slurries, slaughterhouse waste/animal by-products*
Human adenovirus	Biosolids	Food waste, green waste, agricultural waste, manures and slurries, slaughterhouse waste/animal by-products*
Helminth ova	Biosolids	Food waste, green waste, agricultural waste, manures and slurries, slaughterhouse waste/animal by-products*
Enteric viruses (e.g. Norovirus)	Biosolids	Food waste, green waste

[10] Based on ISWA (2023) A Practitioner's Guide to Preventing and Managing Contaminants in Organic Waste Recycling

Contaminant	Source Material	Key Feedstocks Affected[10]
		Agricultural waste, manures and slurries, slaughterhouse waste/animal by-products*
Bio-aerosols		
Fungi	Decomposing material	Food waste, green waste, agricultural waste
Actinomycetes	Decomposing material	Food waste, green waste
Endotoxin	Decomposing material	Food waste, green waste
Legionella	Decomposing material	Food waste, green waste
Other biological		
Parasites	Animal material	Manures and slurries, slaughterhouse waste
Plant Toxins	Certain plants e.g., (nightshade, tutu karaka oleander, hemlock, foxglove)	Green waste
Invasive species (e.g., seeds, bulbs, corms, tubers)	Certain plants (e.g. wild ginger)	Green waste from domestic gardens, landscaping waste or conservation clearance
Weeds (seeds and propagules)	Plant material that includes weeds	Green waste, agricultural waste, manures and slurries
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

5.0 Organic Waste Value Chain

5.1 Waste Flows

In this section we endeavour to provide some high-level quantification of the material that is potentially involved through different parts of the organics value chain. The data analysed in this section is taken from the Ministry for the Environment's National Waste Infrastructure and Services Stocktake[11]. The data presented was primarily compiled in 2020 and so it is recognised that some of the data, such as that pertaining to kerbside collections will be out of date, in particular in relation to the quantities of kerbside organics being recovered. However, it is still expected to be broadly indicative.

High Level Flows

The data for putrescibles and for green, wood and manure are derived from information gathered in the stocktake. Rendering facilities were not included in the study and so data for rendering plants were calculated based on industry data on the quantity of meat sold and the proportion of the carcass that is utilised.[12] Approximately half of the organic waste disposal is estimated to occur on farms, with a further 546,627 tonnes going to Class 1 disposal[13], and the remainder mainly consisting of timber processing waste going to industrial monofills.[14]

The Sankey diagram below shows the total quantities of organic waste and its estimated management pathways.

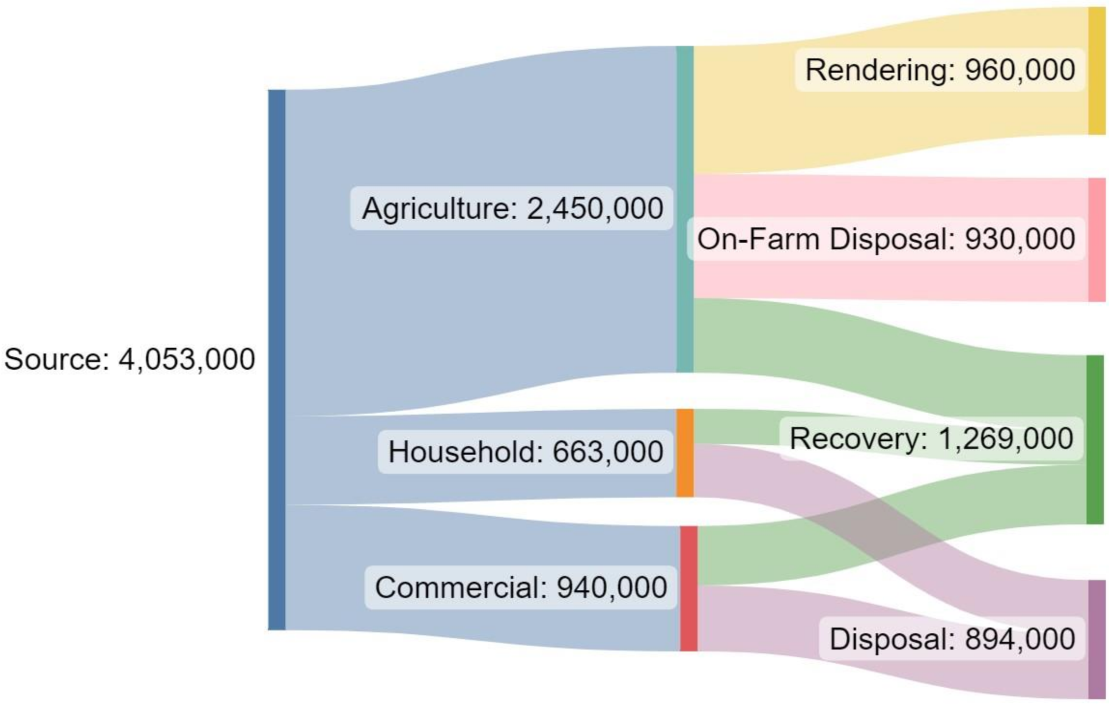
[11] Eunomia (2021) National Waste Infrastructure and Services Stocktake, prepared for the Ministry for the Environment. The Stocktake report should be referred to in regard to caveats on the data, but a key caveat is that the figures represent what was able to be quantified in the study and so will be an under-representation of the quantities as it does not include data from organisations that did not respond, or were not included in the study.

[12] https://www.mbie.govt.nz/assets/8fdebf6c7b/investors-guide-to-the-new-zealand-meat-industry-2017.pdf

[13] Waste Not (2020) Update of National Average Waste Composition for Class 1 Landfills, Report to Ministry for the Environment

[14] Sewage sludge (biosolids) going to landfill is classified as 'hazardous and special waste' in composition data and is not included in the above totals. There is in the order of 800-900,000 tonnes of 'hazardous and special waste' sent to Class 1 landfill annually.

Figure 2: High-level Organic Waste Management Pathways



The data indicates there is in the order of 4 million tonnes of organic waste generated annually with over half of this coming from the rural sector, a further quarter from the commercial sector (including sludges) and the remainder from households. Of the waste material generated, over half is recovered, with approximately a quarter estimated to go to rendering or value add from abattoir processes and close to a third going to some form of composting or biological treatment process. The figures however should be treated with some caution, as they represent information that was able to be compiled for the stocktake and do not represent estimates of overall activity. For example, there is no information on the quantity of materials recovered on-farm, and not all recovery operations contacted supplied quantitative information.

Recovered Organic Waste

The material that is designated as 'recovery' in the above diagram is broken down further in the Sankey diagram below. As can be seen the flows are quit complex. Of the approximately 1.3 million tonnes that was identified in the stocktake as being recovered the main feedstocks were wood and timber (primarily bark and sawdust), household and commercial garden waste, commercial sludges, and animal manures.

The timber waste was going primarily to windrow composting and mulches, the garden waste was going to mainly to windrow, aerated windrow and in-vessel composting, while the commercial sludges went primarily to vermicomposting and the animal manures were split between in-vessel and windrow composting.

Approximately two thirds of the outputs from the various organic waste processes went to commercial users – predominantly farms but also some landscaping applications. The remaining third was sold into domestic markets. Based on the information reported, the various processes resulted in an overall net mass loss of approximately 40% (the majority of this would be moisture loss)

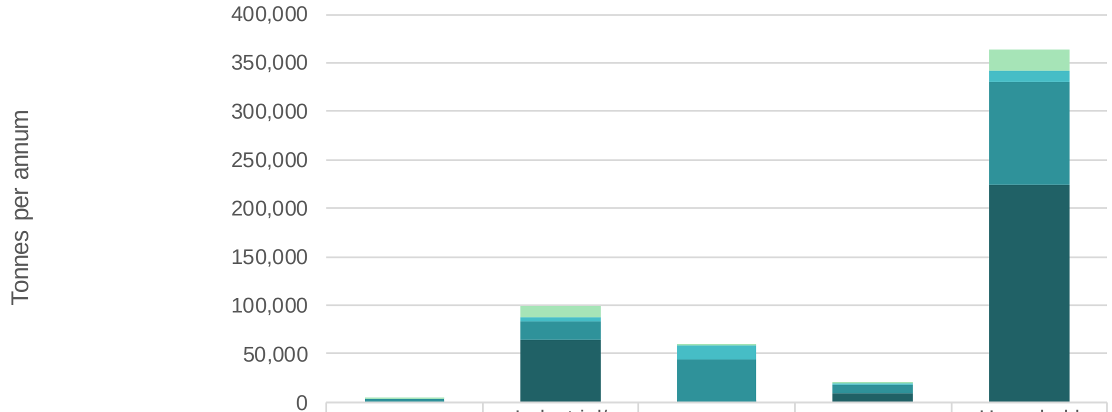
Figure 3: Flow of Recovered Organic Materials

Image redacted due to commercial sensitivity.

Disposal Breakdown

As noted in Figure 2 approximately 900,000 tonnes of organic waste were estimated to be sent to disposal (apart from on-farm disposal). Of this approximately 550,000 tonnes were estimated to be sent to class 1 disposal, and 350,000 tonnes to class 2-5 disposal (refer to Appendix A.3.0 for definition of classes of disposal). The chart below shows a breakdown of types of materials and Activity Source of material send to Class 1 disposal (a similar breakdown of the class 2-5 data is not available)

Figure 4: Composition and Activity Source of Organics to Class 1 Disposal



	Construction & demolition	Industrial/ commercial/ institutional	Landscaping & earthworks	Residential	Household kerbside rubbish
Organics other	83	11,172	184	535	22,151
Non-compostable greenwaste	379	4,759	14,994	1,290	11,837
Compostable greenwaste	2,919	17,975	43,546	9,588	106,532
Kitchen waste	456	65,100	573	8,858	223,696

As can be seen from the above chart the majority of organic waste material being sent to landfill is from household kerbside rubbish sources. About two thirds of this is household food waste and one third garden waste. Commercial and industrial food waste and landscaping garden waste are the other major sources of organics.

In addition to the above there is an estimated 800,000 tonnes of 'special waste'[15] landfilled, a large proportion of which is biosolids, and in the order of 95,000 tonnes of untreated and unpainted timber waste which could potentially be recovered.

Summary

Of the organic waste identified in the stocktake about 60% comes from the primary sector with approximately 40% being managed through on-farm disposal, 40% through rendering, and 20% recovered through off-farm management. As noted, the quantities of primary sector organic waste are likely to be higher than was captured by the stocktake.

From a contaminant perspective on farm material carries a number of risks such as the potential for presence of agricultural chemicals or drenches, pathogens, pests etc.

Commercial sources make up approximately 25% of organic wastes generated, with about half of this going to recovery and half to disposal. It can be easier to manage contaminant risks from commercial sources as they tend to be more homogeneous feedstocks (for example fruit or vegetable processing wastes), and have larger quantities from a single source.

Domestic sources account for the remaining 15% of organic wastes. The stocktake identified that approximately two-thirds of this was going to disposal, with the two

[15] Special waste as defined as "

thirds of this being food waste and about a quarter garden waste. Domestic sources represent relatively high risks in terms of feedstock contamination as it is hard to control inputs from multiple sources.

In terms of what is currently being recovered the largest fractions are wood and timber which largely goes to composting and mulching, commercial sludges, which go to vermicomposting and household garden waste which goes predominantly to composting.

Of waste currently being disposed of special wastes such as biosolids and sludges represent a high proportion, followed by household food and garden wastes. There are also notable quantities of untreated wood waste, and commercial food wastes that could be recovered.

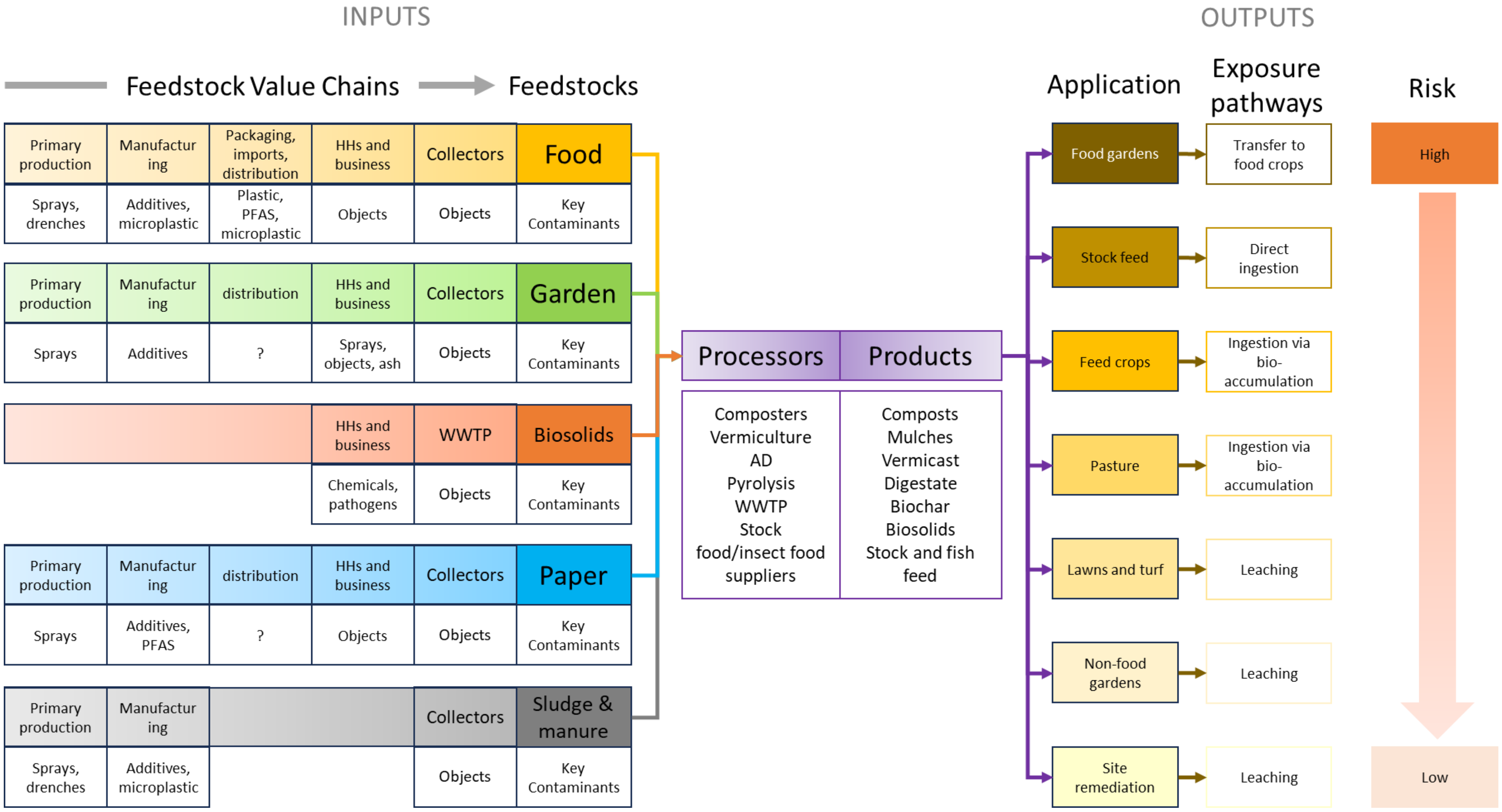
5.2 Value Chain

In order to make sense of the myriad of potential waste streams, materials, contaminants, products, and processors and the way these interact throughout the value chain, we undertook a value chain mapping exercise. A value chain represents all of the steps involved in a product or material life cycle where value is added or subtracted.[16] The high-level outcome of this exercise is shown in the following figure.

Note the flows, contaminants, and exposure pathways shown in this version are highly simplified and intended to be illustrative only. Additional versions of the value chain maps are provided in Appendix A.3.0, and a more detailed version is available as an excel file.

[16] Value Chain: Definition, Model, Analysis, and Example (investopedia.com)

Figure 5: Value Chain Map – Example Contaminants



At the centre of the value chain are the products. The products are the point at which contaminants from the value chain have become aggregated, and the product is what then gets utilised in various potential applications. Each of these different applications represents a potential exposure pathway, which presents a different range and level of risks. This is shown to the right of the diagram.

On the left of the diagram the feedstock value chains are represented. In this diagram the value chains are grouped by broad category of organic wastes (food, garden, biosolids, paper, sludges and manures), although in reality each particular feedstock will have its own unique value chain. The feedstock value chains are split by key steps where different actors generate or interact with the feedstock and potentially add contaminants to the material. Underneath each value chain step, example key contaminants that the particular step are likely to add are noted.

When the feedstocks arrive at a processor there is potential for these to be combined to create products (for example composters may combine food and garden waste to create an appropriate carbron:nitrogen ratio for the process). The combinations that take place depend in part on the type of process and the type of product that is aimed to be created.

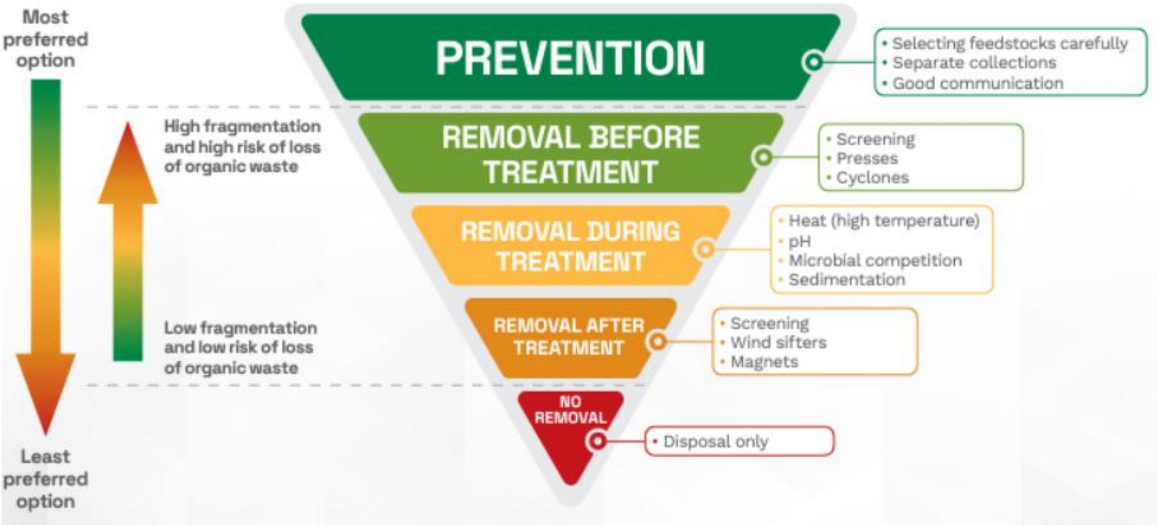
The value chain map helps to reveal where contaminants potentially enter the system, and where products may get applied. This facilitates identification of the parties involved, the potential points for intervention, and the possible types of intervention that might be appropriate at each point.

In the more detailed versions of the value chains the steps are split out in slightly more detail, a fuller range of potential contaminants is noted, and additional layers for actors, interventions, oversight, and certification are added.

5.3 Points of Intervention

A general principle is that it is preferable to address contaminants as early as possible in the value chain. As contaminants move through the value chain, they general become more dispersed and mixed with the target feedstocks. This concept is captured in the contaminant management hierarchy developed by the International Solid Waste Association (ISWA) and shown below:

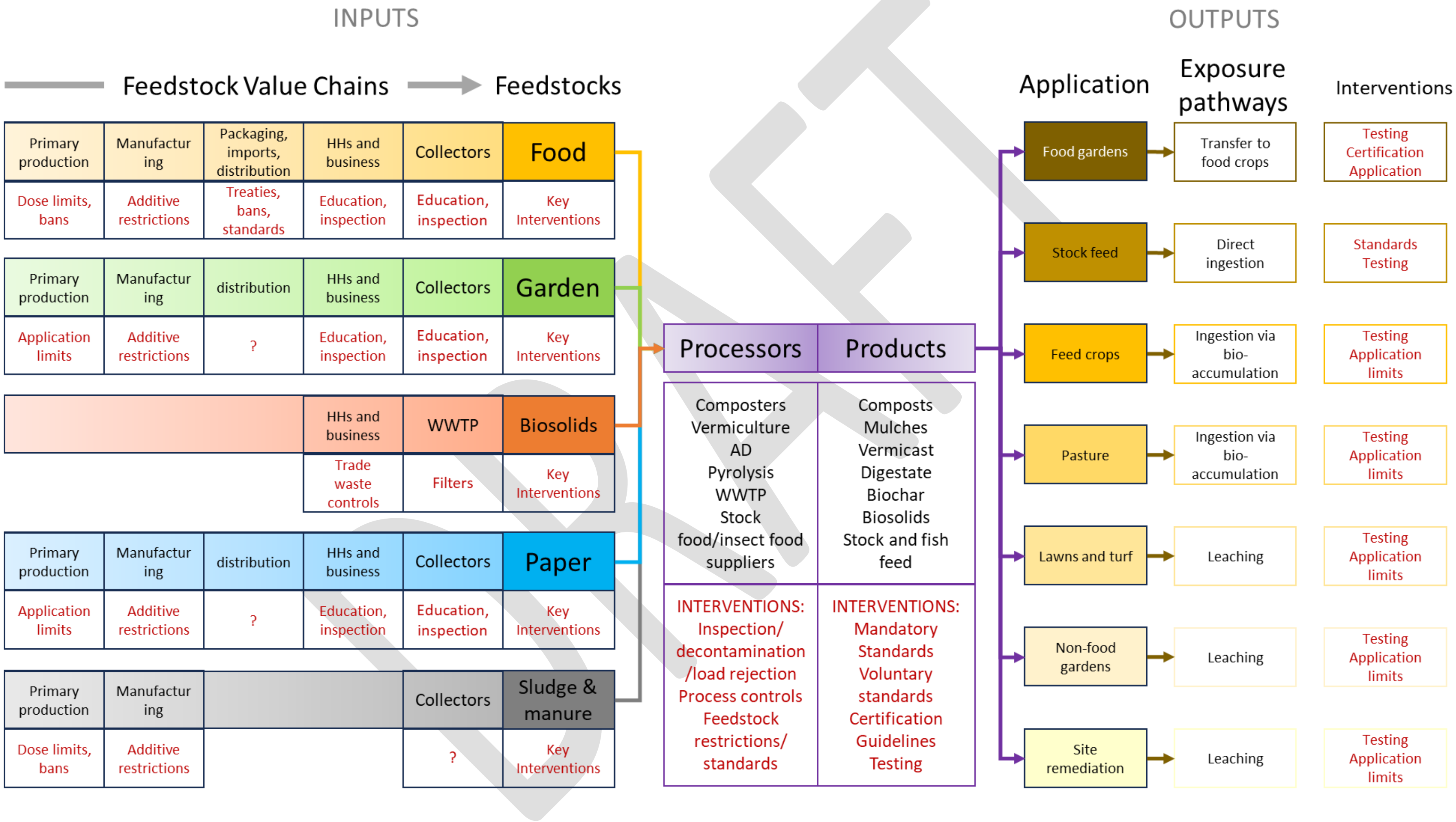
Figure 6: Organic Waste Contaminant Management hierarchy



Source: ISWA (2023) A Practitioner's Guide to Preventing and Managing Contaminants in Organic Waste Recycling

The value chain mapping enables potential points of intervention and key types of intervention to be readily identified. This is shown in the version of the value chain map below, which highlights possible key interventions at each point.

Figure 7: Value Chain Map – Example Interventions



5.4 Control Mechanisms

There are a range of control mechanisms which can operate to restrict contamination and avoid or limit harmful outcomes. These can potentially be applied across all parts of the value chain.

System Input Controls

Controls at the system input level are where materials entering the system are restricted. This includes:

- National product or material bans (for example bans on chemicals, plastic microbeads, plastic shopping bags)
- International treaties restricting, the production, sale, or movement of substances or materials (for example Montreal Protocol on ozone depleting substances[17], Basel Convention[18], or the international plastics treaty currently being negotiated[19])
- Food and product safety standards

Feedstock Input Controls

These types of controls involve restricting the types of materials that can be accepted into organic waste management processes. Examples include:

- Education. For example, on what material households can place in their food or garden waste bins.
- Monitoring and compliance. This involves checking material before it is accepted into collection systems, and taking compliance action such as removal of service where contamination persists.
- Regulation for standardisation. For example the kerbside standardisation controls recently introduced by the Ministry for the Environment.
- Consent conditions. Resource consents typically specify the types of materials that are able to be accepted at organic waste processing sites.
- Acceptance criteria (voluntary). This is where individual operators or facilities have their own criteria in respect of the types of materials they accept and/or the level of contamination they will accept into their processes. This can be a relatively strong control as operators want to create a product they can sell and the presence of high levels of contaminants can reduce product value or create reputational damage.

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[17] About Montreal Protocol (unep.org)

[18] Basel Convention Home Page

[19] Towards a global treaty to combat plastic pollution | Ministry for the Environment

Process Controls

Once material has been accepted by an organic waste processor there are a number of controls that can be put in place to help ensure product quality. These include:

- Decontamination. This includes automated processes such as screening, and manual processes such as picking lines to remove physical contaminants.
- Process management. This includes controlling elements of the process such as temperature, residence time, moisture content, aeration, and input blends to ensure the process kills pathogens, seeds, and produces a product that is not phytotoxic (harmful to plants)
- Blending of contaminated material with uncontaminated material to reduce concentrations to acceptable levels.
- Screening. If the finished product contains physical contaminants such as plastics, or large objects these are typically removed by screening before sale.
- Monitoring of processes.
- Testing of material.
- Guidelines. Guidelines provide technical guidance for processes or the application products but do not have any mandatory force.
- Voluntary standards. These are standards such as NZS 4454, BioGro, or Assure Quality, that impose requirements on processes.
- Mandatory Standards. This is where standards have to be met before a product is allowed to be sold, or restrictions on how the product may be applied.
- Certification. This is where independent bodies certify that a product or process meets a particular standard (voluntary or mandatory)
- Market forces. This is where customers demand product that is free of contamination and has no adverse impacts when used.

Output Controls

Output controls involves controls on the quality of product and how it may be applied. This can include.

- Testing of product.
- Guidelines. Guidelines provide technical guidance on the application of products but do not have any mandatory force.
- Voluntary standards. These are standards such as NZS 4454, BioGro, or Assure Quality, that impose requirements on product quality, including contaminant limits.
- Mandatory Standards. This is where standards have to be met before a product is allowed to be sold, or restrictions on how the product may be

applied.

- Certification.
- Market forces. This is where customers demand product that is free of contamination and has no adverse impacts when used.

Social Participation

A further constraint on control is the fact that achieving clean streams of material relies on people to actively participate with perfect knowledge and willing compliance. In other words, people need to not only be willing to make the extra effort to correctly separate materials or keep them separate (whether in a home or work context), they have to be able to correctly identify desired materials from potential contaminants. Indeed, the desire to 'do the right thing' can lead to more contamination - as experienced with 'wishcycling'.[20]

Participation in organic waste value chains will be a subset of the wider willingness of people to engage positively in the circular economy (the 'ambient socialised conditioning for positive eco-participation'). The general willingness to participate is in effect a civic asset which can be invested in and grown. If a perfect circular economy is to be achieved the full and willing participation of everyone through the value chain will be required.

Participation and compliance are factors across all parts of the value chain. For example:

- **System Inputs.** The awareness, compliance, and willingness to avoid the manufacture or import of materials or substances that could be problematic if they enter the organics value chain as contaminants.
- **Process inputs**. The degree to which participants are willing and able to correctly separate out valuable materials from potential contaminants.
- **Processing.** The degree to which organic resource recovery processing sector might participate in and comply with regulations /standards (e.g., NZS4454:2005)/industry accords.
- **Outputs.** The degree to which retailers and consumers might communicate/understand/follow product end-use guidelines/restrictions, or stage interventions designed to manage and mitigate the risk of contamination in a circular bioeconomy.

Boundaries of control

The processes for identifying, understanding, managing and mitigating the potential manifestation of environmental and human harm, fall to regulatory / approvals / standards and monitoring agencies in both the international and NZ domains.

Because a proportion of the materials and products used in NZ are produced offshore, direct oversight and control falls outside of our jurisdiction. There are some controls in terms of import restrictions and product standards, but given the constantly evolving

[20] What Is Wishcycling? Aspirational Recycling Hurts the Recycling Process (greenmatters.com)

number and type of products and avenues by which they are imported (e.g. via direct imports and online purchases), these controls can only ever be partial.

Given the difficulties in implementing controls, and the fact that controls are often reactive - arising in response to a problem, perfect control of contaminants in a linear system is ultimately likely to be impractical. In this context it will be effectively impossible to build a circular bioeconomy (or at least a circular system for organic wastes) within a linear economy. In other words, a circular economy for organic wastes is dependent on the advent of a wider circular economy - i.e., both sides of the 'butterfly diagram' need to be developed in tandem.

Another aspect of control using measures such as regulation and standards is that it requires resource to undertake, and there may be unintended consequences to controls that are put in place, such as high costs of compliance leading to lower levels of recovery, or restrictions on the use of one type of contaminating product or material that leads to substitution with another type of product or material that may also be a contaminant (for example, bans on single use plastic items resulting in substitution for paper items that may have PFAS contamination).

In a sense the most effective forms of control are where the actors are incentivised and empowered to do the right thing without the need for significant external monitoring and compliance. In this regard market mechanisms where customers demand high quality uncontaminated product can be particularly effective in ensuring high quality product is produced. Market mechanisms may not be sufficient alone however as the price incentive will lead to favouring the lowest cost solutions. This could either result in waste streams that are perceived as requiring decontamination not being recovered due to the added costs of decontamination, or potentially allowing the highest level of contamination that the market will tolerate.

All of this takes place within a dynamic system. New products, compounds and potential contaminants are constantly being developed and implemented. This is often without full knowledge or control of the downstream and longer-term consequences. This is illustrated by the relatively recent rise in concern about microplastics and PFAS, where we are only now recognising the issue and science is still trying to determine the level of potential harm. Similarly, new technologies and practices are implemented, such as the introduction of food waste collections, without a full understanding of what results they will produce in practice.

It is inevitable therefore that new solutions will be required to deal with new realities as they emerge. The pathway towards a circular economy will have to be cleared as we travel along it.

5.5 Implementation and Systems

The focus of this study is the types of mechanisms that may be appropriate in order to develop a system to ensure that organic waste is recovered to its highest value use, where possible, without causing the potential for harm. However, the corollary to this is, who is responsible for implementing, monitoring and enforcing whatever regime of measures is developed, and how this is done? In reality it is impossible to divorce the two. The most comprehensive and well-designed control regime, for example, would be ineffective if there is no implementation, monitoring or compliance.

It is beyond the scope of the present work to examine the current regime of agencies and organisations that have a role or an interest in minimising harm from organic waste contamination, or to advise on what that structure could look like to enable contaminant control in a circular economy. However, it is a vital part of the project to ensure interested organisations are identified and involved in the stakeholder engagement phase. A stakeholder list is being developed as part of the stakeholder engagement plan; however, some key organisations and their roles are noted here.

Table 4: Example Organisations in the Organic Waste Value Chain

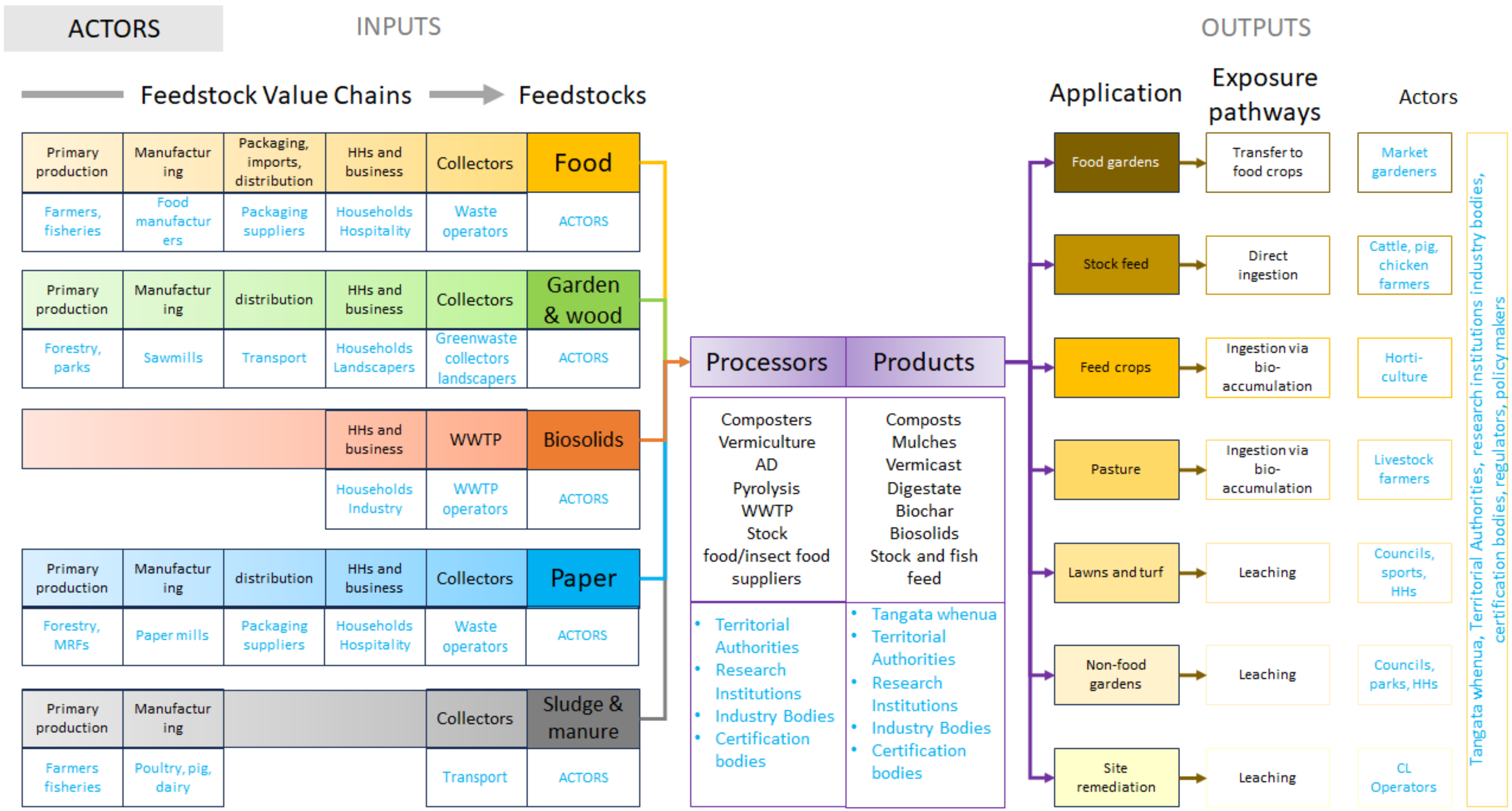
Organisation Type	Example organisations	Roles
Māori	Iwi Para kore Te Waka Kai Ora Te Taumata Pou Take Ahuarangi - Iwi Chairs Forum	Kaitiaki Promoting zero waste Indigenous food validation and verification Iwi leadership in education, language and well-being Leadership and research on specific issues
Government Agencies	Ministry for the Environment Ministry of Primary Industries MBIE Ministry of Health EPA	Waste policy and legislation Primary sector policy & legislation Manufacturing policy & legislation Health policy & legislation Environmental regulation and enforcement
Territorial Authorities	Regional Councils Local Authorities	Resource consents and monitoring Waste collection and processing
Research Institutions	Universities Callaghan Innovation Landcare Research Bioresource Processing Alliance Consultancies	Soils, animal and human health, and environmental research
Industry Bodies	WasteMINZ Organic Waste Sector Group Bioenergy Association Packaging Forum Plastics NZ Horticulture NZ NZ Institute of Forestry Beef and Lamb	Organic waste issues Use of digestates and char Packaging contaminants Plastic contaminants Advocacy for growers Advocacy for forestry Advocacy for meat producers

Organisation Type	Example organisations	Roles
	Federated Farmers Poultry Industry Association NZ (PIANZ)	Advocacy for farming sector Advocacy for poultry sector
Certification Bodies	Standards NZ BioGro Assure Quality Laboratories	NZS 4454: 2005 Organic certification Organic certification Input and output testing
Organic Waste Operators	Compost operators Anaerobic digestion Vermiculture Stock food/insect food suppliers Organic waste collectors	Feedstock users and output producers
Organic Waste Generators	Households Catering operators Farmers Fisheries Agricultural processors Fish processing Freezing works Canneries Food manufacturers Wastewater Treatment Plant Operators	Food waste, garden waste Food waste crop and stock residues, manures Plastic wastes Fruit and vegetable waste Carcass and shell wastes Meat and paunch waste Food waste Food wastes Biosolids
Packaging Producers	PACT Group Comspec Future Post Polymer Processing Hawk Packaging OJI Fibre Solutions Huhtamaki Opal Visy	Plastic packaging Plastic packaging Plastic packaging Plastic packaging Fibre packaging Fibre packaging Fibre packaging Fibre packaging Plastic, Fibre and glass packaging

The length of this partial list and the breadth of interests and parts of the value chain covered by the organisations noted above illustrates the potential complexity in formulating a comprehensive regime that is able to monitor and manage contamination through the value chain.

The following value chain analysis identifies the key actors across the value chain map:

Figure 8: Value Chain Map – Actors



6.0 Discussion and Conclusions

6.1 Principles for Contaminant Control in Circular Economy

The analysis undertaken here illustrates the complexity and interconnectedness of the issue that is being addressed. In essence almost anything can be a contaminant if it is in the wrong place and any contaminant can potentially be harmful depending on the receiving environment and the concentration.

By taking the circular economy principles as outlined in the NZ Waste Strategy as a starting point, a potential framework starts to emerge. The key principles include the following:

- To achieve a circular bioeconomy for organic wastes, progressive detoxification of organic waste will be required. This will in turn be dependent on broader moves towards a circular economy.
- A phased approach recognises that there are immediate issues which require addressing and which can be addressed, but that this should take place in the context of working towards a circular economy.
- The degree to which contamination is an issue (i.e. the degree to which it becomes pollution), is dependent on the use of products made from organic waste and the concentration of the contaminants.
- Determining where harm can potentially occur and the thresholds for potential harm is the role of science in coordination with mātauranga Māori. That is, it needs to be based on robust evidence and systematic understanding and application of Aotearoa’s community values.
- Identifying the most appropriate types of interventions and how they may be applied depends on correctly identifying the part(s) of the value chain where controls can most effectively and efficiently be applied.
- There may be multiple tools that can be applied (and may need to be applied) to achieve the desired outcome. For example, addressing plastic waste in organics may include restrictions on certain products or materials, education of householders, decontamination at a processing facility, and testing and certification of a final product.
- The framework that developed will need to provide flexibility to accommodate future change. Solutions will need to be developed in the context of an evolving landscape as new information, new materials, and new practices emerge.
- There are a wide range of stakeholders that will intersect with organic waste value chains. The more that willing, informed participation and compliance of stakeholders can be achieved, the greater the progress will be towards a

circular bioeconomy for organic wastes.

6.2 Prioritising actions

This framework aims to set a broad 'direction of travel' for control of contaminants within the organic waste space, with the high-level objective of enabling the recovery of maximum value from waste organic materials, while safeguarding health and environmental outcomes. It is intended that a set of prioritised actions is what emerges at the end of the study, following engagement with tangata whenua and industry stakeholders.

Developing the appropriate method and criteria for prioritisation will be an important part of this process.

Appendices

A.1.0 Contaminant Additional Detail

1.1 Heavy metals

- Arsenic has been extensively used in CCA treatment of timber, particularly pine, to stop rotting. Arsenic was extensively used as a pesticide in agricultural settings.
- Cadmium - levels building in soils across NZ as a result of metal being an impurity in phosphate fertiliser.
- Chromium has been extensively used in CCA treatment of timber, particularly pine, to stop rotting.
- Copper is ubiquitous in environment. Copper released from copper wiring (houses, factories, roads) binds to organic matter and builds up in the environment. Common contaminant in biosolids. Component of CCA timber treatment.
- Lead (potentially via sanding dust from red lead primer and or the same via ash when those treated timbers are burned)
- Zinc (i.e, associated with Galvanising plants via trade waste). Also is released (at low concentration) from roofing iron, binds with organic matter and builds up in environment.
- Nickel is relatively low in NZ environment due to low presence in soil. Associated with industrial waste - batteries.
- Mercury (one possible source is as a vacuum cleaner dust residue from broken FLTs/CFLs). Major global source of Hg in environment is use of mercury chloride as catalyst in making PVC. Not sure if this is an issue in NZ.
- Boron another timber treatment chemical used to prevent rot on internal framing timber (pink colour of housing timber)). Essential trace element for plants but dangerous at high concentration. Elevated B concentration in organic material can be a slow-release fertiliser. Is accumulated by some vegetation.

1.2 Radionuclide elements

- Silver active antimicrobial agent in plastics, deodorants and medical products

1.3 Legacy Chemicals

- Harmful legacy chemicals in soil which may input circular bio-economy systems i.e. the soil attached weeds roots
- Contamination associated with the production, (mis)storage and use of the pesticides and herbicide chemical (e.g., agrichemical sprays i.e., 245T, 24D. Dioxin

was created in 245T as an impurity during manufacture. Long lasting in the environment.
- the production, storage and use of gas, coal and petroleum products i.e. tar, creosote, benzene
- timber treatment – pentachlorophenol (PCP), Chlordane, light organic solvent preservatives (LOSP) etc.
- treatment of grass grub and other Ag remedies i.e., sheep dips ref. DDT, Dieldrin, Arsenic

1.4 Pharmaceutical compounds & metabolites

- Human medicines potentially present in biosolids from Wastewater Treatment
- Animal remedies / hormones potentially present in for example paunch grass as a waste product from freezing works as well as manures from feedlots truck washes etc.

1.5 Garden / lawn spray residues

- Clopyralid,
- Aminopyralid,
- Picloram
- Other synthetic hormone chemicals

1.6 Biological hazards

Biological hazards associated with food waste and manures include:

- *E. coli* as a bacterial indicator of *Campylobacter*, *Cryptosporidium*, *Enteric Viruses* (i.e. Noroviruses), *Giardia intestinalis*, *Salmonella spp.*, Protozoa & Helminth ova. [i.e. nematodes (roundworms) and cestodes (tapeworms)], inc. potentially pathogenic non-organism i.e. prions re. BSE etc.
- In-process and end-product bio-aerosols (Fungi, Actinomycetes & Endotoxin) and *Legionella fam.* of bacteria (and potentially secondary pathogen regrowth).

1.7 Road sweepings

Contaminants associated with organic matter from road sweeping i.e., microplastics from tyre wear, asbestos from brake pads, glass fragments motor oils/fluids and combustion residues.

1.8 Wastewater Treatment

Current and future cultural / social contamination issues associated with WWT / biosolids related sludges. For example, from growing acceptance of 'aquamation' (alkaline hydrolysis) of human bodies as a low carbon alternative to cremation, through to future waste from emerging nanotechnologies aka anything flushable can become or have an association with biosolids (NB: currently this will include hair fingernails which will be considered 'sensitive' by some communities)

1.9 Household wastes

Buring treated timber releases arsenic (As) into the environment. As is readily volatile. Secondary deposition into the household garden. Transfer of As from treated timber minimal. Addition of ash to compost or green waste can concentrate As in organic wastes.

High Phosphate fertiliser use in home gardens can lead to increased cadmium (Cd) in soil. Cd can be taken up by plants and bioconcentrate in organic wastes.

Chromium (Cr) remains in treated timber ash.

Multiple pathways for copper (Cu) to concentration in an urban environment. Partitioning Cu to organic material is strong. Cu in NZ biological systems is generally low - the increased Cu concentration in organic waste can have a beneficial impact in targeting copper deficiency in living systems. Copper from roads (particulate deposition from vehicles) can transfer via stormwater in water treatment plants and bioconcentration in biosolids.

Scraping and sanding of weatherboard and wood windows leads to transfer of lead (Pb) to soil. This can move through organic waste streams. Pb is not taken up by plants so primary contamination vector is exposure to particulates in soil.

Limited transfer of nickel (Ni) to organic wastes in urban environment due to low background concentration in NZ environment and lack of use of Ni as a fertiliser or agrichemical.

Uranium is a contaminant in some phosphate fertilisers. Limited evidence for transfer into urban environments.

Nanoparticulate silver is now regularly used. Potent antimicrobial activity.

A.2.0 Plastics Contaminants

Plastics are a complex mix of chemicals and there is significant complexity in terms of the potential sources of plastics pollutants in organic waste.

This is not just a microplastics issue, it is a physical and chemical issue. Plastics contain at least 13,000 chemicals. Extensive scientific data on the potential adverse impacts of about 7,000 substances associated with plastics show that more than 3,200 of them have one or more hazardous properties of concern.[21] Only 4% of these chemicals are regulated globally.

The UNEP notes the following in regard to plastics:[22]

- *Ten groups of chemicals (based on chemistry, uses, or sources) are identified as being of major concern due to their high toxicity and potential to migrate or be released from plastics, including specific flame retardants, certain UV stabilizers, per- and polyfluoroalkyl substances (PFASs), phthalates, bisphenols, alkylphenols and alkylphenol ethoxylates, biocides, certain metals and metalloids, polycyclic aromatic hydrocarbons, and many other non-intentionally added substances (NIAS).*
- *Chemicals of concern have been found in plastics across a wide range of sectors and products value chains, including toys and other children's products, packaging (including food contact materials), electrical and electronic equipment, vehicles, synthetic textiles and related materials, furniture, building materials, medical devices, personal care and household products, and agriculture, aquaculture and fisheries.*
- *Women and children are particularly susceptible to these toxic chemicals. Exposures can have severe or long-lasting adverse effects on several key period of a women's life and may impact the next generations. Exposures during foetal development and in children can cause, for example, neurodevelopmental / neurobehavioural related disorders. Men are not spared either, with latest research documenting substantial detrimental effects on male fertility due to current combined exposures to hazardous chemicals, many of which are associated with plastics.*
- *Chemicals of concern can be released from plastic along its entire life cycle, during not only the extraction of raw materials, production of polymers and manufacture of plastic products, but also the use of plastic products and at the end of their life, particularly when waste is not properly managed, finding their way to the air, water and soils.*

[21] Chemicals in Plastics - A Technical Report | UNEP - UN Environment Programme
[22] Chemicals in Plastics - A Technical Report | UNEP - UN Environment Programme

In addition to microplastics, nano plastics are also a significant issue. Plastics micro and nano-particles significantly and detrimentally impact microbial and soil health, root growth[23] and potentially food security, safety, and sovereignty in Aotearoa.

Similarly, bioplastics present concerns: biobased and biodegradables pose different risks– biobased are sourced primarily from biomass, while biodegradables may be based on fossil fuel-based feedstocks, or on some combination. Each product will have different degradability qualities, and most contain endocrine disrupting chemicals and other substances of concern including persistent chemicals. Bioplastics (like fossil-fuel based polymers) often present similar hazards to conventional fossil fuel-based plastics when released into terrestrial ecosystems.

All plastics (e.g., micro/nano-) cannot be treated in the same in the way. No polymer is chemically the same (e.g., PS, PC, PU, PE) and then additional chemicals are added to manufacture a product. Further, when plastics are recycled, more chemicals are added. This is why recycled plastic 'products' tend to contain more toxic additives than virgin polymers.

When considering plastics, the type of products, polymers, chemical composition, feedstocks, and sourcing of feedstocks all can impact on the risk presented by plastic wastes. This means that no micro or nano particle is equal in terms of its hazardousness nor contaminating or polluting potential. And the receiving environment also has a significant impact when exposed to each (chemical and physical availability and risk). This could include microbial presence, temperature, light, moisture etc.

2.1 Plastics and Plastic Contaminants

Bioplastics Plastic packaging

Biobased plastics/bioplastics refers to polymeric products derived from biomass sources, which are not necessarily biodegradable.

Biobased polymers

- Polylactide (PLA) polyolefins: biomass can be either chemically or bio catalytically converted into building blocks for other polymers.
- Polybutylene succinate (PBS)
- polyhydroxyalkanoates (PHA): produced by microorganisms in fermentative processes
- Cellulose and starch

'Biodegradable' plastics:

Should be minerizable by the action of microorganisms in their natural environment (e.g., in soil, surface waters or compost).

[23] Nanoplastics in the soil environment: Analytical methods, occurrence, fate and ecological implications - ScienceDirect

Oxo-biodegradable plastics

- bio-based plastics
- PE, PP and PEF

Bio-nanocomposites:

- Might be used for food packaging. They consist of a biopolymeric matrix stabilized by nanoparticles.
- Organic clays,
- Silver nanoparticles

Materials

- PLA: polylactide biodegradable, thermoplastic polyester
- PHA: Polyhydroxyalkanoates, biodegradable polyester
- Biobased polypropylene (PP) and polyethylene (PE): Non-biodegradable vinyl polymers.
- Cellulose-based polymers: Biodegradable polysaccharide
- Partially biobased PET; Non-biodegradable aromatic polyester
- Biobased polyethylene furanoate (PEF): Non-biodegradable aromatic polyester.
- Aliphatic (co)polyesters: Biodegradable polymers
- Aliphatic-aromatic (co)polyesters: Biodegradable polymers
- Polycaprolactone (PCL): Biodegradable polymers
- Polyvinyl alcohol (PVOH): Biodegradable vinyl polymer (although PVOH-degrading microorganisms need selective enrichment to efficiently mineralize PVOH or PVOH-blends
- Polyamides (PA): Non-biodegradable polymer.
- Others: from animals (Chitosan, derivative of chitin technically derived from shellfish; whey protein isolate; gelatine), plants (soy protein isolate; gluten and zein)

Additives

Note: Biodegradable materials generally do not perform as well as conventional plastics and require additives to deliver functionality.

- plasticizers (bisphenol A (BPA), bisphenol S (BPS) (which are endocrine disruptors), vinyl chloride and acrylamide, benzophenones and dithiocarbamates (persistent, bioaccumulative and toxic (PBT))
- antioxidants
- light and UV stabilizers,
- releasing agents,
- cross-linking agents
- NIAS (non-intentionally added substances (NIAS), which include impurities, reaction by-products, and breakdown products).

Types of plastics attending to size

- Microplastics: refers to plastic particles between 1µm and 5 mm in diameter. They are either used intentionally in certain products and industrial processes (primary microplastics), or formed unintentionally when larger plastic products break down into smaller fragments (secondary microplastics). Secondary microplastics are also generated as a consequence of breakdown of primary microplastics, fibres from synthetic textiles, as paint flakes, or as tire wear particles due to the abrasion of rubber tires from vehicles in contact with road surfaces.
- Nanoplastics: are plastic particles <1 µm in diameter.
- Macroplastics: plastic items with a diameter ≥ 5 mm

Types of plastics attending to precedence:

- Primary plastics: a voluntary addition to products such as scrubbing agents in personal care products (shower gels, creams, etc).
- Secondary plastics: originate mostly from the degradation of large plastic waste into smaller plastic fragments once exposed to the marine environment
- Microplastics (most common types in the marine environment)
- polyethylene (PE),
- polypropylene (PP),
- polystyrene (PS)
- polyamide (PA, e.g., nylon)
- polyester (PES)
- acrylic (AC)
- Nano plastics in the environment
- polyethylene,
- polyethylene terephthalate (PET)
- polyvinylchloride (PVC)
- polystyrene
- polypropylene

2.1.1 Polymer types

Thermoplastics

- Polyethylene (PE)
- Polypropylene (PP)
- "Polyvinyl chloride (PVC)
- Polyethylene terephthalate (PET)
- Polystyrene (PS)
- Expanded polystyrene (EPS)
- Acrylonitrile butadiene styrene (ABS)
- Polyamides (PA)
- Polycarbonate (PC)

- Poly methyl methacrylate (PMMA) (also known as acrylic, acrylic glass, or plexiglass)
- Thermoplastic elastomers (TPE)
- Polyarylsulfone
- Fluoropolymers, e.g., polytetrafluoroethylene (PTFE)*
- Polyether ether ketone (PEEK)
- Polyoxymethylene (POM)
- Polybutylene terephthalate
- Polybutylene succinate (PBS)
- Polybutylene adipate terephthalate (PBAT)
- Polycaprolactone (PCL)

Thermoset plastics

- Polyurethane (PUR)
- Unsaturated polyester
- Epoxy resins
- Melamine resin
- Vinyl ester
- Silicone
- Phenol – formaldehyde resin
- Urea – formaldehyde
- Acrylic resins

2.1.2 Additive types in the global plastics production

- Light stabilizers (e.g., phenolic benzotriazoles (e.g., UV-328), cadmium compounds (e.g., cadmium oxide), lead and lead compounds) (1%) in: PE, PP, PVC
- Lubricants (e.g., fatty acid esters, hydrocarbon waxes, metal stearates, amide waxes, ester waxes) (2%) in: PVC, PS/ABS, PP, PE
- Colorants (2%):
- Impact modifiers (e.g., cadmium compounds, lead compounds, nonylphenol, barium and calcium salts) (5%): PVC
- Antioxidants (6%): LDPE, HDPE, high impact polystyrene (HIPS) and ABS
- Flame retardants (13%): Foam; plastic
- Plasticizers (e.g., phthalates and short- and medium-chain chlorinated paraffins (SCCPs/MCCPs)) (34%)
- Antistatic Agents (e.g., long-chain alkyl phenols, ethoxylated amines, glycerol esters such as glycerol monostearate) in: PE films, PE and PP foams, PVC, PP injection moulding applications
- Blowing agents (e.g., C, C'-azodi (formamide) (ADCA); fluorinated greenhouse gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6)) in: PVC, PE, epoxy resins
- Biocides (e.g., organic tin compounds, arsenic compounds; triclosan) in: PUR; PVC

- Frances (e.g., natural extracts; synthetic fragrances) in: PE, PP, PS, PC, PET, EVA, PLA, nano particles
- Catalyst (e.g., chromium and chromium compounds (e.g., chromium trioxide), mercury and mercury compounds) in: PVC, PE, PP and other non-specified polymers.

2.1.3 Chemicals of concern in plastics (UNEP 2023):

Of the more than 13,000 chemicals associated with plastics and plastic production, 7,000 have been screened for their hazardous properties (Annex 1). Of these 7,000, more than 3,200 have been identified as substances of potential concern based on their hazardous properties (Aurisano et al. 2021b; Wiesinger et al. 2021). Hazardous properties considered include carcinogenicity, mutagenicity, reproductive toxicity, endocrine disruption, and ecotoxicity to aquatic organisms (UNEP 2023)

The Stockholm Convention lists several additives as POPs, including some flame retardants used in plastics and other polymers (PBDEs, HBCDD, and HBB), as well as some PFASs (PFOS and PFOA and related precursor substances)

In flame retardants:

- Brominated and chlorinated flame retardants (BFRs/CFRs), often used with antimony (Sb) as a synergist. polybrominated diphenyl ethers (PBDEs), decabromodiphenyl ethane (DBDPE), hexabromocyclododecane (HBCDD), and tetrabromobisphenol A (TBBPA)
- Organophosphorus flame retardants (OPFRs) such as tris (2-chloroethyl) phosphate (TCEP), tris(1,3-dichloroisopropyl) phosphate (TDCPP), tris(2-chloroisopropyl) phosphate (TCPP), tris(2-butoxyethyl) phosphate (TBOEP), triphenyl phosphate (TPhP)
- Inorganic flame retardants such as aluminium and magnesium hydroxides and boron.

Per- and polyfluoroalkyl substances (PFASs)

Phthalates: are a family of additives used as plasticizers, mainly in PVC production, fragrances, can easily leach into the environment during plastic manufacturing, use and disposal, and have been found in a wide range of environments

The EU has restricted Di-2-ethylhexyl phthalate (DEHP), dibutyl phthalate (DBP), benzyl butyl phthalate (BBP), and Di isobutyl phthalate (DIBP) in toys, childcare articles, and all indoor and outdoor articles with prolonged contact with human skin.

Bisphenols

Bisphenols are a group of aromatic compounds with two hydroxyphenyl functionalities. They are the monomers of polycarbonate plastic products (including water bottles, food storage containers and packaging, sports equipment, and compact discs) and of the epoxy resin liners of aluminium cans.

BPA is a known reproductive toxicant that impacts female reproduction and has the potential to affect male reproductive systems in humans and animals disrupts thyroid.

BPA and BPB: are listed as Substance of Very High Concern.

BPF and BPS (detected in foodstuffs, personal care products, house dust, sediments of rivers and lakes, and in human biological specimens). BPF has in animals has shown to have effects on uterine growth and testes weights, demonstrating impacts on the oestrogen and androgen pathways, respectively.

BPB, BPS, and BPF also appear to have BPA-like effects.

Certain alkylphenols and alkylphenol ethoxylates (APEOs)

Nonylphenol (NP) is commonly used as a stabilizer and intermediate in plastics production. 4-tert-Octylphenol has major uses in formaldehyde resins. NP is an endocrine disrupting chemical and suspected to be toxic to reproduction.

4-tert-Octylphenol is a potential environmental pollutant and exhibits estrogenic and anti-androgenic activity in human reporter cell lines

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are a class of chemicals that occur naturally in coal, crude oil, and gasoline and are formed during pyrolysis or incomplete combustion processes.

Biocides

Biocides are antimicrobial substances classified by their target organism e.g., bactericides, fungicides, insecticides, and rodenticides)

These additives are organic tin compounds (e.g., tributyltin (TBT) and bis(tributyltin)oxide), usually applied in PUR foam (PUF) and PVC; arsenic and arsenic compounds (e.g., 10,10'-oxybisphenoxarsine), mostly applied in plasticized PVC, PUR, LDPE and polyesters; and triclosan, usually applied in PE, PP, PVC, polyester and polyamide fibres.

Biocides applied in or on FCMs include alcohols, organic acids and their esters, aldehydes, amines, quaternary ammonium compounds (QACs), halogen compounds, ionic silver and nano silver, oxidizing agents, isothiazolones, phenols and biguanides.

Most biocides pose environmental hazards since they strongly interact with living organisms, but some are also classified as hazardous to human health.

UV Stabilizers: prolong the lifespan of plastics by protecting them from photo-degradation initiated by UV light, absorbing radiation before it reaches photosensitive moieties in the polymer.

Benzophenones: used in polyolefins and PVC. Potential ecotoxicity. Some derivatives exhibit estrogenic and hormonal activities in vitro, Induce allergies.

Benzotriazoles (BZTs): BZTs are used in ABS, HIPS, PVC, PES, PC, POM, PMMA, polyvinyl butyral (PVB), and PUR fibres. Endocrine disruptors and organ toxicity

Hindered amine light stabilizers (HALS): used in polyolefins, styrenics, polyamides, polyurethanes, polyacetals, adhesives, and sealants. HALS like Tinuvin 770 and Chimassorb 944, are classified as having high toxicity (class III) according to Cramer rules.

Metals and metalloids: hazardous additives consist of substances containing metals, including antimony, cadmium, chromium, lead, mercury, cobalt, tin, and zinc.

2.1.4 AgriPlastics[24]

Packaging

- Fertiliser packaging Pesticides packaging: HDPE, PS

Greenhouse

- Irrigation systems (Irrigation tape Water dropper Pegs, Pipes, Rubber seals): PE, PVC
- Structure (I.E., Tunnelling plastics Nets (i.e., Mosquito nets) Ventilation strips Double-roofs Greenhouse covers): PP, HDPW, EVA, LDPE,
- Greenhouse flooring (Thermal insulation blankets, Microperforated plastics, White & black solarisation, Mulching): LDPE, EVA, PP Trellising (I.E., Clips, Raffia, Rings): LDPE, PP
- Others (gloves, sack bands, thermochromics, pollinator hives, biological control product packaging, Seedling trays): latex, LDPE

Storage and packing:

- Microperforated bags
- Flow packing: LDPE, EVA
- Pallet strapping
- Agricultural boxes: HDPE

Food Packaging

Plastic Foil	PET (polyethylene terephthalate)	Formaldehyde Acetaldehyde Antimony UV Stabilizers Polybrominated Dimethyl esters (PBDE)	Yoghurt cup lids
	PE	Polyolefin oligomeric saturated	Freezer bags, frozen poultry and ham bags, prepackaged

[24] (Taken from Porcuna 2023)

		hydrocarbons (POSH) Nonylphenol	fresh produce, food storage containers
	PVC	Vinyl chloride Organo tins Adipates Plasticiser nonylphenol]	Shrink foil, shrink foil prepackaged meat, cheese, fruit and vegetables
	HDPE	Antimony Polybrominated Dimethyl esters (PBDE)	Milk, dairy products
	Cellulose	Triacetin	Meat packaging
Plastic bottle	PET (polyethylene terephthalate)	Formaldehyde Acetaldehyde Antimony UV Stabilizers Adipates <u>Phthalates</u> <u>Polybrominated Dimethyl esters (PBDE)</u>	Soft drinks, CSD** (single use)
	PC (polycarbonate)	Bisphenol A Antimony Polybrominated dimethyl ethers (PBDE) 4-nonylphenol	Repeated use water bottles, baby feeding bottles
	PVC (polyvinylchloride)	Vinyl chloride Plasticiser Organo tins Nonylphenol	Water and soft drink bottles (single use)
Plastic trays and inserts	PVC (polyvinylchloride)	Vinyl chloride Plasticiser Organo tins	Chocolate box inserts, food trays, biscuit tins

		Plasticiser Nonylphenol	
	PS (polystyrene)	Styrene (found for cups) Styrene trimers Polybrominated dimethyl esters (PBDE)	Yoghurt, dairy product, honey, syrup and ice cream, marmalade and jam tubs and containers; trays for prepackaged meat and fruit
Plastic trays(oven proof)	PET (polyethylene terephthalate)	Formaldehyde Acetaldehyde Antimony UV Stabilizers	oven proof or microwavable food
Plastic cups	PP (polypropylene)	Polyolefin oligomeric saturated hydrocarbons (POSH) Erucamide, oleamide Antioxidants Phthalates	
	PS (Polystyrene)	Styrene Styrene trimers Polybrominated dimethyl esters (PBDE)	Vending cups
Plastic pouches	Aluminium	Aluminium	
	PP (polypropylene)	Polyolefin oligomeric saturated hydrocarbons (POSH) Erucamide, oleamide Antioxidants	Crisps, biscuits, snack foods, sugar, grains, and vegetables
	PET	Formaldehyde Acetaldehyde	Boil in the bag food

		Antimony UV Stabilizers	

*Layer in direct contact with food

** carbonated soft drinks

Source: https://www.foodpackagingforum.org/food-packaging-health/food-packaging-materials/plastics/common-contaminants

A.3.0 Landfill Classes

Landfill Class	Description
Class 1	Municipal disposal facility Accepts any of the following: • household waste • waste from commercial or industrial sources • waste from institutional sources (eg, medical waste) • green waste • waste that is not accepted at the other types of landfills below.
Class 2	Construction and demolition disposal facility Accepts waste from construction and demolition activities. Does not accept class 1 waste.
Classes 3 and 4	Managed or controlled fill disposal facilities Accepts any of the following: • inert waste material from construction and demolition activities • inert waste material from earthworks or site remediation. Does not accept class 1 or 2 waste.
Class 5	Cleanfill Accepts only virgin excavated natural material (such as clay, soil or rock) for disposal.
Industrial monofill	A facility accepts disposal waste that: • discharges or could discharge contaminants or emissions • is generated from a single industrial process (eg, steel or aluminium-making, or pulp and paper-making) carried out in one or more locations.

From: determining-your-disposal-facility-class-fact-sheet.pdf (environment.govt.nz)

A.4.0 Value Chain Mapping Detail

Please refer to separate excel file.