CRITICAL EVALUATION OF COMPOSTING OPERATIONS AND FEEDSTOCK SUITABILITY

PHASE 2 – CONTAMINATION

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DEPARTMENT OF ENVIRONMENT AND SCIENCE

CRITICAL EVALUATION OF COMPOSTING OPERATIONS AND FEEDSTOCK SUITABILITY

Phase 2 Report – Contamination issues

Final

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SUMMARY

Arcadis has been engaged by the Department of Environment and Science (DES) to undertake a critical assessment, review and evaluation of composting operations in Queensland with a focus on odour management, feedstock suitability, contamination risks and the regulation of these aspects by DES.

Composting in Queensland is a significant industry which in 2017-18 converted 1.4 million tonnes of organic residues and waste into beneficial products which generally improve soil health and quality. There are around 25 companies of varying scales whose primary business is composting plus a number of other companies and councils that engage in organics processing in various forms and amongst other waste management activities.

Without a successful composting industry, significantly more organic waste would be landfilled or otherwise disposed to land without processing, resulting in a range of environmental and social benefits including significant greenhouse gas emission reductions and pasteurisation of land-applied compost products. However, the long-term success of the industry is highly dependent on consumer confidence in the quality of compost products to retain and expand offtake markets, and community support for the industry.

Anecdotally, it has been observed that in the past, composting operators were focused on the products - using organic waste streams such as green waste and food processing residues together with some clean inorganic materials as feedstocks to manufacture compost and soil products with a focus on product quality and soil health. However, in recent years, the activities of some parts of the industry have shifted to see a proliferation in the types and nature of waste streams incorporated into compost, both organic and inorganic. Concerns have been raised about the suitability of some of these materials in compost and whether parts of the industry have shifted from the previous primary focus on compost production, to being primarily waste treatment businesses. Open windrow composting offers a low-cost alternative for the processing or disposal of a range of different waste streams, which are not necessarily beneficial to the end products.

The role of composting in the broader waste management system is set to grow over the coming years as councils and businesses look for ways to divert more organic waste from landfill, particularly food waste. The draft Queensland Waste Strategy focuses on building a circular economy in Queensland and the recovery of organic waste is already a major contributor to that. The draft Waste Strategy sets ambitious targets for recycling waste and reducing landfill which will only be achieved if more organics are recovered, processed appropriately and directed to beneficial uses.

However, composting and the use of compost also has a high potential to negatively impact on local communities and the environment. The Department has received a considerable and growing number of complaints over recent years about odour nuisance from composting operations, particularly in the Swanbank area near Ipswich, but also near other composting operations. There have also been some high profile compost contamination issues over the past two years involving PFAS contamination of compost products, which have damaged the industry’s reputation and concerned the community. The Queensland Government has committed to reducing those impacts with a particular focus on addressing odour management issues and contamination of compost products, arising from the use of inappropriate feedstocks.

This study aims to improve the Department’s understanding of composting processes and odour emissions from composting; best practice management of composting; the suitability of different materials as feedstocks in composting and requirements for improving regulation of the industry. This report presents the findings of Phase 2 which focused on contamination of compost products, but also incorporates key findings from Phase 1 which focused on issues of odour control at composting facilities in Queensland.

Overview of Phase 2 findings

Composting regulation and standards

- Compost products and associated products such as soil conditioners, soil mixes and potting mixes are used in a wide range of applications, each with differing degrees of exposure and risk to human health and the environment.
- Waste acceptance conditions in existing composting Environmental Authorities (EAs) vary widely with some licenses having no or very few specific waste acceptance conditions stated, which limits the level of regulatory control over feedstock contaminants. While different EAs take different approaches, the current regulatory preference seems to place the responsibility on the operator to determine which feedstocks are suitable for processing.
- There is a general need for tighter regulation of feedstocks as the current inconsistency in regulation between otherwise similar sites. The current situation creates an un-level playing field commercially (real or perceived) which may be a barrier for new market entrants and to investment in upgrades and improvements.
- Given the general lack of requirements on most operators to characterise and analyse their feedstocks, there is very little data available on chemical and physical composition of feedstocks currently being used in Queensland composting operations, which is a significant and acknowledged data gap.
- The Australian Standard for composts, soil conditioners and mulches (AS 4454 – 2012) provides minimum requirements for the physical, chemical and biological properties of composts, soil conditioners and mulches in order to facilitate the beneficial recycling and use of compostable materials with minimal adverse impact on environmental and public health, by avoiding biosecurity and phytotoxicity risks associated with inappropriate product manufacture or selection. AS 4454 does not prevent any composter from producing superior compost free of contaminants and impurities that smells as it should (earthy odour) and delivers crop yields significantly higher than without use of compost. The standard is not the problem, the lack of clear regulations and the current business model of many composters (making most of the profit on processing liquid and regulated wastes) are the issue.
- Contaminant limits in the Australian Standard for composts (AS 4454 – 2012) and international (European) standards for composts and digestates do not vary markedly. Yet the legal / regulatory status of compost quality criteria specified in overseas standards is often very different to the situation in Australia, as is the organisational structure. AS 4454-2012 is the leading reference for composting industry but it is a voluntary standard and very little or no bulk compost / soil conditioning / mulch product is independently audited and accredited against AS 4454 – 2012 quality requirements in Queensland or Australia more broadly. Bagged compost and soil mix products are typically the only product lines subjected to certification and they represent a small proportion of the market by volume. In that respect, the self-assessment option for composters has detrimental effects, as it undermines production of good quality compost, and trust in the market place.
- AS 4454 does not prevent any composter from producing very high quality compost products that are free of contaminants and impurities, far exceeds any AS 4454-2012 requirements and delivers all benefits promised by the producer. At present, the vast majority of bulk compost producers in Queensland and indeed Australia, only offer the weakest form of guarantee under AS 4454 - ‘Self Declaration’, or none at all, and certainly not third party auditing and certification. The acceptability to customers of this approach depends on the reputation and past performance of the manufacturer and requires the customer to be informed of the risks, which they often are not or they do not have visibility of the supply chain. However, as compost suppliers increasingly target high value commercial agricultural and horticultural markets where food safety and biosecurity requirements become ever tighter, it is expected that the pressure will grow for compost production systems and compost products to be independently audited and certified by a third party.

- The existing End of Waste (EoW) framework in Queensland and associated EoW codes, although currently limited in number, provide good guidance and control over contaminants within defined waste streams that may be used in composting. This suggests that EoW codes could be an effective (existing) tool to better regulate or exclude high risk feedstocks.

Compost feedstocks

This study has identified a long and varied list of over 100 different feedstock materials that are thought to be, or are permitted to be, used as composting feedstocks in Queensland. The feedstocks have been broadly categorised by type, into groupings that have similar risk profiles and management requirements. These categories are described below.

Table 1: Summary of feedstock categories and general risks

Category	Description
Animal matter	Animal / livestock processing wastes including all residues from abattoirs and subsequent processing of tallow and hides; egg and milk waste, manures from intensive farming. High odour risk but assumed to be low contamination risk (no chemical residues), although question on chemicals used in hide curing effluent.
Plant matter	Predominantly clean plant material with minimal contamination. Includes green waste, gross pollutant trap (GPT) waste and clean (untreated) timber which may contain physical impurities, but otherwise includes mostly crop and forestry residues. Potential for trace pesticides and herbicides, but generally low contamination risk. Low odour risk and many of these materials can be used as bulking agents to balance / mitigate the odour risk of other materials.
Food and food processing waste	Wastes predominantly containing food and residues from food processing (predominantly crop / vegetable sources). Household and commercial food organics may contain physical impurities. Food processing wastes are assumed to contain minimal chemical contaminants. All materials present a high odour risk and low chemical contamination risk with the exception of organics extracted from MSW, which is predominantly food but can be highly contaminated.
Sewage and sewage treatment plant (STP) residues	Sludges and solids arising from the collection and treatment of human waste (sewage) including biosolids and septic tank sludges. Potential for varying degrees of chemical contamination (including metals and PFAS) and pathogens, depending on the degree of prior processing. High potential for odour issues.
Chemical fertiliser residues	Chemical residues and effluents from the manufacture of chemical fertilisers including wash waters and non-conforming product. Highly concentrated nutrients and risk of ammonia odours.
Industrial residues	A broad catch-all category for a range of solid, liquid and slurry wastes from industrial manufacturing processes or otherwise highly processed / treated materials. Contamination risk varies widely but is generally high, particularly for those materials that are poorly described. Odour risk is generally low although they may contain sulphur and nitrogen compounds that increase the odour risk.
Wastewater and washwaters	Another broad catch-all category for liquid effluent streams, contaminated stormwaters and washdown waters, mostly from commercial activities. Contamination risk varies but is generally high, particularly for the many materials in this category that are poorly described. Odour risk is generally low although they may contain sulphur and nitrogen compounds that increase the odour risk.

Category	Description
Earthworks & mining waste	Includes inert soils and slurries from earthworks and mining activities, as well as drilling mud from coal seam gas activities and mineral additives that can be beneficial soil conditioner additives (limes, gypsum). Contamination risk is generally low with the exception of chemical additives in drilling mud and residual contamination in treated soils. Other streams may contain naturally occurring contaminants (e.g. sulphate in acid sulphate sludge; heavy metals in earthen material; natural salts in drilling muds). Potential for extreme pH levels (lime, acid sulphate sludge).

- The current nomenclature for feedstocks used by operators or quoted in various reference documents, is often vague and / or potentially inaccurate, with the majority of current feedstock descriptors insufficient to enable an assessment of potential contamination risk.
- In considering potential restrictions on some feedstocks, it is necessary to understand the alternative disposal and processing options available in the market and assess the potential for perverse outcomes. While other management pathways are available for many composting feedstocks, they may not necessarily be preferable from an environmental perspective. In particular, landfilling of organic materials and regulated wastes presents a range of potential risks and adverse outcomes, and government policy is to reduce and avoid landfilling of waste where possible.
- In some cases, the alternative options may be considerably more expensive than composting which leads to an increased risk of the materials being illegally dumped or otherwise inappropriately disposed, which could have significant environmental consequences. This in itself is not a reason not to take stronger regulatory action to protect the environment, but such risks need to be acknowledged and planned for.
- Other preferred processing solutions may exist but the infrastructure is not yet available in Queensland (e.g. anaerobic digestion plants for industrial / commercial organics, both solid and liquid), which suggests a transition period is needed to allow for new infrastructure development, if there is to be a shift away from open composting of some feedstocks.

Potential contaminants

- This report discusses a range of potential contaminants which may be found in composting feedstocks and products, based on an extensive literature review. Where possible, the behaviour and fate of different contaminants is discussed although the scientific knowledge on this aspect is limited for some of the emerging contaminants.
- Physical impurities in compost such as plastic, glass and metal fragments are undesirable from an aesthetic perspective which may limit the potential use and market value of these products. They can also have an impact on soil quality and the environment.
- Microplastics (< 5mm) are likely to be an emerging problem for recycled organics, particularly for the future use of compost derived from domestic sources (such as household food and garden organics, or FOGO collections) in agriculture and horticulture applications. Research from Europe highlights the scale of the issue but it is starting to be recognised in Australia also. Work has shown that over 90% of microplastics contained in sewerage are retained in the sludge or biosolids.
- Microplastics in the marine environment have gained much attention, but they can also adversely impact soils by introducing toxic and endocrine-disrupting substances that are added during plastics manufacturing such as chlorinated paraffins, plasticisers, and flame retardants. Plastic polymers can also be very efficient at accumulating other harmful pollutants during their useful life, which can then impact soils as they deteriorate.
- The Australian Standard for composting (AS 4454-2012) includes limits on physical impurities based on the percentage by weight. Area-based assessment of impurities should be considered to

better account for highly visible light weight impurities, rather than criteria based on weight proportion or number counts of items.

- Heavy metals and other naturally occurring trace elements are a common focus of soil and compost quality guidelines. There are around 40 heavy metals (density >5 g/cm^3), some of which can accumulate in specific body organs and cause health impacts to humans and other organisms.
- The presence and variation of metals and trace elements in the environment (i.e. soil, water, plants, animal and humans) is the result of the natural occurrence of elements, mainly depending on geological processes underlying soil formation, as well as human activities. Metals such as copper and zinc are essential to the healthy growth of plants and animals. There has been no evidence of adverse impacts on plants from application of composts and biosolids with typical levels of copper. Ruminant animals are sensitive to copper deficiency. Bioavailability of copper in compost tends to be low and copper toxicity to animals is unlikely to be caused arise from compost use. Zinc phytotoxicity has been observed in sensitive crops when biosolids with high zinc concentrations were applied to acidic soils (pH < 5.5.).
- Metals and trace elements in composted organic residues form various compounds or associations when applied to soil which can affect their uptake by plants and their mobility through soils. They can be complexed by organic compounds, co-precipitated in metal oxides, be in a water-soluble state, or bound on soil or organic matter colloids in an exchangeable form. Hence, measuring total trace element content in soil or organic amendments does not necessarily predict soil-plant interactions, i.e. bioavailability and plant uptake.
- As soil acidity increases, the solubility of metals and trace elements increases, and so does the potential for uptake by plants. However, this paradigm is not universally applicable as factors such as compost feedstock, soil type and plant species may affect uptake.
- Organic matter within compost has a high cation exchange capacity compared to mineral soil, and therefore tends to bind or chelate metal ions such as Cu, Ni, Zn and Cd. Organic matter binds metals more strongly at a soil pH below 7.5, which is why metal availability in acidic soil is lower when organic matter content is high compared to the same soil with low organic matter content.
- Metal-organic matter complexes play an important role in micronutrient cycles in the soil, and are relevant here as (i) soluble organic compounds that otherwise would precipitate, (ii) metal ion concentrations may be reduced to non-toxic levels through complexion, and (iii) trace element availability to plants may be enhanced by various organic-metal-organic complexes. Plant availability and plant uptake of metals (e.g. Cd and Zn) is lower from composted materials than from uncomposted organic soil amendments.
- There are a wide range of organic chemicals / contaminants that could potentially be present in composts from a range of different feedstocks, and new compounds of concern emerging constantly.
- Elevated total petroleum (TPH) and total recoverable hydrocarbons (TRH) have been detected in finished compost samples analysed by DES, at levels which are higher than in key feedstocks such as green waste and grease-trap waste, based on a limited number of sample results provided to Arcadis. Given many hydrocarbons are biogradable in a composting process, particularly those captured in the TPH and TRH analyses, it is not known where the hydrocarbons in the finished product might have come from and there is very little research or data in the literature on this topic. Further investigation and speciation of the hydrocarbons is needed to identify the source.
- The fate of organic contaminants in composting can involve a number of different pathways including mineralisation, partial biological degradation to secondary compounds, assimilation by microorganisms, abiotic transformation to secondary compounds, complexation with humic materials in the compost substrate (i.e. humification), or loss by volatilisation, leaching, runoff, and wind. Complete mineralisation to carbon dioxide is the ideal, since secondary compounds that can accumulate during partial degradation can still be toxic.
- In view of the difficulty of establishing limits for so many potential chemicals of concern, many countries instead focus on tight feedstock control together with source separation. In many cases,

only specific feedstocks that are unlikely to contain high concentrations of or unknown contaminants can be composted (positive list). Potentially problematic organic residues are excluded from composting. This contrasts somewhat with the current Queensland approach which puts the onus on the operator to determine which feedstocks are suitable for composting.

- Hazardous compounds that are ubiquitous in many man-made products, and therefore also in the environment, such as per- and poly-fluoroalkyl substances (PFAS), that are considered a major concern for human health and the environment need to be regulated at source (e.g. banned from production / use) to reduce long-term potential for contamination of composting feedstocks. In the shorter term, composters need to be vigilant and aware of the risks of these contaminants entering with certain feedstocks and have appropriate procedures in place. But only requesting organics processors to comply with stringent product and end-use requirements, without banning the use of these compounds is likely to be inequitable and counter-productive.
- On average, compost products from a variety of feedstocks tend to show comparable concentration levels for PAH, PCB, PCDD/F and PFC, with the sole exception of biosolids compost that tends to have higher PFC levels. Although few international limits exist, the exceedance of guidance values appear to occur most frequently for the PAH compound class. Other organic pollutants tend to show very low concentration levels in all finished products and are generally not considered as compounds of concern in most countries (though this might be changing).
- There are a range of emerging contaminants constantly being investigated and discovered. As new chemicals are manufactured and used, or as the understanding of the toxicity or persistence of chemicals currently or formerly in use progresses, new groups of emerging contaminants are likely to be identified over time. Ongoing analysis as new contaminants are documented and publicised is the only way to confirm their presence or absence in feedstocks.
- The use of source separated kerbside food organics and garden organics (FOGO) and green waste materials tends to lead to better results for heavy metals and organic contaminant concentrations than when mixed municipal waste or sewage sludge / biosolids are used as input material. This confirms the notion that source separation of domestic and commercial organic feedstocks is an important part of controlling contamination.

Risk assessment of feedstocks

- Due to the lack of specific and comprehensive data on feedstock composition, Arcadis has developed qualitative approaches to assess the risks associated with composting feedstocks, for both potential odour contribution and contamination of the products.
- The assessments help to prioritise feedstocks for further investigation and potential tighter management or regulatory controls, but the lack of data is a constraint on more accurate risk assessment at this stage.
- Feedstocks have been assessed to determine their potential odour contribution in a composting process (odour risk) and potential contamination impact on final products (contamination risk).
- The odour risk assessment considered factors such as the likely proportion of putrescible content (readily biodegradable solids or dissolved organics); and likely content of nitrogen and sulphur compounds, and likely content of proteins, fats and oils. A scoring system was developed to rate feedstocks on each of these factors to arrive at an overall risk rating.
- The odour risk assessment identified 14 feedstocks classified as high risk and 13 as very high risk of contributing to odour issues in a composting process. These materials should still be acceptable for use in composting but should be subject to tighter management controls including characterisation assessments to confirm their suitability; and appropriate blending with bulking agents to balance moisture and C:N ratios. It is likely that storage and mixing facilities may need to be enclosed to manage the risk of odour release from materials that are likely to be anaerobic or putrid upon receipt, and operators who manage high risk materials should assess the need for the initial composting phase to be enclosed.
- The initial contaminant risk assessment has identified 32 feedstocks considered to pose a high risk and a further 16 materials ranked as very high risk of leading to contamination in compost

products. In many cases, the high ranking is partly due to uncertainty in composition so could potentially be re-assessed and reduced with better data. If those with a very high risk rating are confirmed by further analysis, the materials should generally not be used in composting.

- Feedstocks have been assessed to determine their potential odour contribution in a composting process (odour risk). Following from these assessments, feedstocks have been classified into one of two categories as follows:
  - 27 feedstocks were considered to present a high or very high potential odour contribution risk and were therefore categorised as odour category 1 – suitable for composting but with additional controls.
  - The remaining 82 feedstocks were categorized as odour category 2 – suitable for composting, subject to standard composting practice, meaning that any odour risk is manageable through current / acceptable composting practices.
- Feedstocks have also been assessed to determine their potential contamination impact on final products (contamination risk). The assessment has classified feedstocks into one of four categories:
  - 16 feedstocks were categorised as *contamination category 1 – generally unsuitable for composting.* Many of these have vague and ambiguous names which imply a manufacturing or process industries origin but further clarification of the source and nature of the wastes may allow a reclassification.
  - 6 feedstocks were considered potentially suitable for composting but likely to require enhanced control measures (contamination category 2) such as maximum blending ratios within a compost mix, or potential restrictions on end use to minimise direct human contact (e.g. highway verges, mine rehabilitation, forestry).
  - 36 feedstocks were considered suitable for composting and unlikely to pose a significant risk (contamination category 3).
  - 51 feedstocks were classified as potentially suitable for composting but requiring more data (contamination category 4); reflecting the lack of useful data available to properly classify and assess feedstocks. Further analysis is required by operators who process these materials to demonstrate their suitability.

Of the 109 feedstocks identified and assessed, Table 2 below summarises the number of feedstocks in each classification and indicative high level control measures that may apply to each category, noting that more specific control measures will be appropriate for some feedstocks.

Table 3 following, presents the risk assessment and classification outcomes for each feedstock.

Table 2: Summary of feedstock classifications

Classification	Description	No. feedstocks	Suggested controls
Contamination risk categories			
1	Unsuitable for composting	16	Avoid composting, unless further analysis / definition demonstrates lower risk
2	Suitable subject to additional controls	6	Compositional analysis, blending as a minor proportion
3	Suitable for composting	36	Standard composting best practice, analysis to confirm risk
4	Potentially suitable but more data needed	51	Compositional analysis to refine rating

Classification	Description	No. feedstocks	Suggested controls
Odour risk categories			
1	Suitable subject to additional controls	27	Containment of reception / storage / blending, appropriate blending rates
2	Suitable for composting	82	Composition analysis, appropriate blending rates
TOTAL		**109**	

The feedstocks which were classified as unsuitable for composting (category 1) included a number of feedstocks with very vague and ambiguous names which imply some form of industrial origin. The unsuitable feedstocks were:

> hide curing effluent; filter/ion exchange resin backwash waters; dye Waste (water based); filter cake and presses; paint wash; process fluid; treated timber waste; water based inks; water based paints; bilge waters; effluent waste; forecourt water; leachate waste; sullage waste (greywater); treatment tank sludges and residues and waste water.

Table 3: Summmary of qualitative risk assessment results

Type	Feedstock material	Odour Contribution Potential	Odour Category	Potential Contamination Risk	Contamination Category
Animal matter	Abattoir waste	Very high	1	Low	3
	Animal manures, including livestock manure	High	1	Low	3
	Animal processing waste	Very high	1	Low	3
	Animal waste, including egg waste and milk waste	Very high	1	Low	3
	Hide curing effluent	Very high	1	Very High	1
	Paunch material	High	1	Low	3
	Tallow waste	Very high	1	Low	3
Chemical residues	Ammonium nitrate	High	1	Low	3
	Dewatered fertiliser sludge	High	1	Medium	4
	Fertiliser water and fertiliser washings	Low	2	Medium	4
	Filter/ion exchange resin backwash waters	Low	2	Very High	1

	Pot ash	None	2	Low	3
Food & food processing waste	Food organics	High	1	Low	3
	Organics extracted from mixed household waste / MSW	Very high	1	High	4
	Quarantine waste treated by an AQIS approved facility	High	1	High	4
	Beer	Medium	2	Low	3
	Brewery effluent	Medium	2	Low	3
	Food processing effluent and solids	High	1	Low	3
	Food processing treatment tank or treatment pit liquids, solids or sludges	High	1	Medium	4
	Grain waste	Low	2	Low	3
	Grease trap - treated grease trap waters and dewatered grease trap sludge	Very High	1	Low	3
	Grease trap waste (untreated)	Very High	1	Low	3
	Molasses waste	Medium	2	Low	3
	Soft drink waste	Low	2	Low	3
	Starch water waste	Low	2	Low	3
	Sugar and sugar solutions	Low	2	Low	3
	Vegetable oil wastes and starches	Medium	2	Low	3
	Vegetable waste	Medium	2	Low	3
	Yeast waste	High	1	Low	3
Industrial residues	Abrasive blasting sand (excluding heavy metal contaminated sands)	None	2	High	4
	Amorphous silica sludge	None	2	High	4
	Ash	None	2	Medium	2

Bauxite sludge	None	2	High	4
Carbon Pellets	Low	2	High	4
Cement slurry	None	2	Low	3
Coal ash	None	2	Medium	2
Compostable PLA plastics	Low	2	Medium	4
Coolant waste	Low	2	Medium	4
Dye waste (water based)	None	2	Very High	1
Filter cake and presses	Medium	2	Very High	1
Fly ash	None	2	Medium	2
Foundry sands	None	2	High	4
Paint wash	Low	2	Very High	1
Paper mulch	Low	2	High	4
Paper pulp effluent	Medium	2	High	4
Paper sludge dewatered	Medium	2	High	4
Plaster board	Medium	2	High	4
Polymer water	Low	2	Medium	4
Process fluid	Low	2	Very High	1
Total Petroleum Hydrocarbon (TPH) water	Low	2	Medium	4
Treated timber waste	Low	2	High	1
Water based inks	None	2	Very High	1
Water based paints	None	2	Very High	1
Water blasting wash waters	Low	2	High	4
Water-based glue	None	2	Medium	4
Water-based Lacquer Waste	None	2	High	4

	Wood molasses	High	1	Medium	4
Plant matter	Cane residues	Low	2	Low	3
	Cypress chip	Low	2	Low	3
	Forest mulch	Low	2	Low	3
	Gross pollutant trap (GPT) waste	Medium	2	High	4
	Green waste	Medium	2	Low	3
	Mill mud	Medium	2	High	4
	Mushroom compost (substrate)	Medium	2	Low	3
	Natural textiles	None	2	Medium	4
	Pine bark	Low	2	Low	3
	Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Low	2	Medium	4
	Tub ground mulch	Medium	2	Medium	2
	Wood chip	Low	2	Low	3
	Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs	Low	2	Medium	2
	Worm castings suitable for unrestricted use	Low	2	Low	3
Sewage & STP residues	Activated sludge and lime sludge from wastewater treatment plants	High	1	High	4
	Biosolids	High	1	High	4
	Nightsoil	Very high	1	High	4
	Septic wastes	Very high	1	High	4
	Sewage sludge	Very high	1	High	4
	Sewage treatment tank or treatment pit liquids, solids or sludges	Very high	1	High	4
	Acid Sulphate Sludge	High	1	Medium	4

Earthworks waste and additives	Bentonite	None	2	Medium	4
	Crusher dust	None	2	Low	3
	Drilling mud / slurry (from Coal Seam Gas industry)	Low	2	Medium	2
	Gypsum	Medium	2	Low	3
	Lime	None	2	Low	3
	Lime slurry	None	2	Low	3
	Mud and dirt waste	None	2	High	4
	Sand	None	2	Low	3
	Soil	None	2	High	4
	Soil treated by indirect thermal desorption	None	2	High	4
Wastewater & wash-waters	Bilge waters	Low	2	Very High	1
	Boiler blow down water	None	2	High	4
	Brine water	None	2	Medium	4
	Calcium water	None	2	Medium	4
	Car wash mud & sludge	Low	2	High	4
	Carpet cleaning wash waters	Low	2	High	4
	Effluent waste	Medium	2	Very High	1
	Forecourt water	Low	2	Very High	1
	Ground wWater	None	2	Medium	4
	Latex washing	Low	2	High	4
	Leachate waste	Very high	1	Very High	1
	Low level organically contaminated stormwaters or groundwaters	Low	2	Medium	4
	Muddy water	None	2	Medium	4

Oily water	Low	2	High	4
Soapy water	Low	2	Medium	4
Stormwater waste	Low	2	High	4
Sullage waste (greywater)	Low	2	Very High	1
Treatment tank sludges and residues	High	1	Very High	1
Vehicle wash down waters	Low	2	High	4
Wash bay water	Low	2	High	4
Waste water	Medium	2	Very High	1

Recommendations

Odour Control Recommendations

A number of recommendations were proposed in Phase 1 to improve the management and regulation of odour from composting facilities. Those recommendations are presented below for completeness.

Best Practice Management Guidelines – Odour Control

A number of the recommendations made in Phase 1 related to operational measures to control or minimise odour and while it is up to DES to determine the most effective way to implement these measures or encourage their implementation by industry, one option is to develop a Queensland specific Best Practice Environmental Management Guideline for organics processing, which may include and build upon these recommendations. The following recommendations can be considered best practice measures that could be incorporated into any future guidance, noting that any such guidance would need to cover a broader range of operational and management aspects beyond those on which this study has focused, such as siting, water management, dust, noise, fire / safety and monitoring.

1. Turned windrow management – there is no best practice standard for the frequency and method of turning. Turning methods and schedules need to be optimised for the feedstock mix, available machinery and site requirements. This requires a balancing of several factors such as maintaining aerobic conditions versus releasing accumulated odours; loosening of the compost and breaking up clumps versus reducing the porosity of the compost mix; and redistribution of moisture. The optimal turning strategy should be determined by an experienced operator through site trials and measurements.
2. That said, there are some common considerations in optimising the turning strategy for an open windrow operation:
    - Focus on adequate porosity - mix odorous materials with a generous and appropriate ratio of bulking material (e.g. shredded green waste) that has both readily available carbon sources and large, structurally stable particles that are able to maintain adequate porosity (ideally 35-45%) to facilitate passive aeration of windrows, which is driven by the temperature gradient between internal and external windrow temperatures.

  - Minimise turning events for windrows containing odorous feedstocks, especially during the first 7-10 days of composting, with only the minimum turning required to support pasteurisation and moisture redistribution. This enables the odorous by-products generated during this initial phase to be oxidised to less odorous compounds before they are released to the atmosphere. The compounds will continue to decompose as they move through the windrow mass.
  - When turning with a front-end loader, ensure that the operators do not drive up on the compost when windrows are being formed, which can cause compaction and reduce airflow.

3. Composters processing odorous materials in open windrows should be encouraged to experiment with caps (or blankets) of mature compost as a measure to reduce odour emissions during the initial stage of composting and to ultimately implement this is as a regular operational control.
4. Composting operations that process highly odorous materials and/or are located close to sensitive receptors should consider enclosing the waste reception / storage / blending functions and assess the implementation of some form of forced aeration and/or enclosed composting process, for at least the initial phase of composting.
5. Forced aeration, if adopted, needs to be optimised for a particular compost mix, so as not to have an adverse impact on odour emissions.
6. Engineered biofilters are a very efficient and cost-effective method of treating odours if they can be captured within an enclosed or forced aeration composting system. They could similarly be applied to treat air from an enclosed feedstock receival and mixing building. Other measures including physical and chemical treatments are unlikely to be as effective.
7. For best practice feedstock receival, operators should:
    - Keep an ample stockpile of bulking agent or high carbon material at the receiving area to immediately mix with all deliveries of odorous materials
    - Immediately mix potentially odorous materials upon receipt and ensure that materials are mixed uniformly throughout
    - Consider enclosing the receival facilities for highly odorous materials and the initial mixing operation, with appropriate ventilation and biofilter systems
    - Consider blanketing odorous solid materials with a thick layer of bulking agent
    - Work with generators and transporters of commercial organic residues to increase collection frequency
    - Have a system in place to assess and reject unacceptably odorous materials and eliminate troublesome feedstock sources
    - Undertake small scale trials of new feedstocks prior to accepting regular full loads, to assess the practical aspects of handling the new material and to monitor its performance in a composting pile.
8. Operators should have a clear procedure in place to ensure the initial compost mix is optimal in terms of C:N ratio, moisture and porosity and to understand the odour potential of each feedstock. This should include testing and analysis of feedstocks to understand their physicochemical characteristics. Such testing need not be of every load for consistent feedstocks, but sufficient to understand the key parameters and variability.
9. Parameters such as temperature and pH should be regularly monitored throughout the composting process. Other parameters such as moisture content and oxygen levels may also be measured, at least during critical phases (e.g. the first few days) and particularly when processing wet or odorous feedstocks.
10. Compost piles should not be moved to the maturation or curing stage until the thermophilic stage of composting has been completed, indicated by consistent temperatures below 45°C (assuming all other aspects managed correctly).
11. Maturity tests such as Solvita™ are widely accepted and can be done on site, to ensure compost is mature enough to be safely stored.

Regulation of odour

Regulation of composting facilities is primarily controlled by conditions set out in the Environmental Authorities of each composting facility as well as general obligations which apply to all businesses in Queensland under the *Environmental Protection Act 1994*.

A review of those EAs has identified vast differences in the degree of control and regulation applied to each operator. In some cases, this is due to operators undertaking other environmentally relevant activities which increases the risk associated with the operation, such as processing of regulated wastes under ERA 55. In most cases though, it is a function of the age of each approval and the difficulty of changing an existing approval unless the operator voluntarily agrees to those changes.

The discrepancy means that there are some composters, including some very large-scale operations, which are operating with minimal controls over key environmental risk aspects such as waste acceptance, product quality, and management of odour, leachate and stormwater.

12. DES should investigate options to harmonise and reduce the inconsistency in EA conditions for composting operations with a similar risk profile and implement consistent minimum standards on key aspects such as waste acceptance (including testing requirements), product quality and odour control. There are good examples amongst some of the more recent existing EAs which may serve as a template, but the main focus should be on achieving consistency. The initial (and so far, limited) feedback from industry suggests they are open to changes provided it applies consistently to all and helps to ‘level the playing field’.
13. DES should consider whether there is a need for more stringent regulation or conditioning on sites that receive feedstocks considered to have a high or very high contribution to odour risk (as assessed in the Phase 1 report). This is not to suggest that these feedstocks are not suitable for composting, but that additional control measures may be warranted such as maximum blending ratios with green waste in the compost mix, additional requirements for their storage and mixing, more sophisticated processing (aerated / enclosed), and/or additional analysis and documentation requirements.
14. With respect to odour, DES should consider whether the current outcomes-based approach is appropriate for regulating odours from composting facilities. Outcome based conditions are generally preferred by industry but challenging to enforce when the outcome itself is difficult to measure and quantify, or to trace back to a specific activity. These challenges are heightened even more so when there are multiple operators potentially having a similar impact in one area, as is the case at Swanbank and elsewhere. The existing outcome based conditions should be retained but could be supplemented with specific additional conditions which address the root causes of odour as discussed in detail in the Phase 1 report (e.g. feedstock storage and blending; characterising feedstocks, and monitoring of key process parameters). There is a fine balance to be struck between being overly-prescriptive and maintaining flexibility for lower risk applications, which other states have not necessarily achieved in full. Therefore, a Queensland specific approach is recommended, considering some of the operational methods noted in the Phase 1 report but refined in consultation with industry.
15. It is apparent that waste collectors and transporters exert a high degree of power within the organic waste management supply chain (commercially and in terms of controlling feedstocks), yet it is the composters at the end of that chain that bear the brunt of regulation. In considering how to better regulate the composting industry, DES should be cognisant of this and consider options to better regulate the whole supply chain, making sure that waste generators and transporters are taking responsibility for providing adequate and accurate information about their waste streams, and ensuring they are managed appropriately. The new amendments under the Regulated Waste Framework will go some way to addressing this (for regulated wastes), provided they are properly applied by all parties in the supply chain and enforced by DES.
16. It is also apparent that the current waste tracking system is ineffective at tracking and flagging anomalous waste movements which may indicate waste has been taken to an inappropriate facility. DES should consider options to upgrade or overhaul the Waste Tracking System to an electronic platform that ensures that critical information is accessible to transporters, operators and the regulator in real time. This could potentially stop, for example, transporters ‘shopping around’ for an alternative disposal option after being rejected from one facility.

17. For new facilities, industry, local governments and residents could benefit from clear guidance produced by DES on the regulation of composting facilities including aspects such as locating composting facilities, separation distances, process and operational controls to minimise odour issues. Guidance documents from other states provide examples which may be considered, but the guidance should be tailored to Queensland context, be risk-based and allow a degree of flexibility for low risk applications.

18. To improve standards at existing facilities, industry seems open to measures to lift operational standards and knowledge levels. However, commercial competition means that measures such as voluntary codes of practice are unlikely to be developed by industry in isolation and may not be universally adopted. Government may have a role to play in leading and facilitating the collaborative development of minimum standards and training requirements. Consideration would need to be given as to how to incentivise existing operators to comply with the standards, if not regulatory.

Assessing odour from composting facilities

The Phase 1 report presented extensive information about different odour assessment and measurement techniques. It is apparent that some composters have rather limited technical understanding of how odours are caused and dispersed in the atmosphere, and it seems that the use of odour modelling and other tools to inform that understanding for their specific site, is limited. As such, the project team recommends more robust assessment and analysis of odour sources and dispersion mechanics, including the use of modelling and sampling where appropriate, but also training and development of industry knowledge on these aspects.

19. For any new proposed composting facilities, an odour impact assessment should be undertaken as part of the site's environmental and development approval processes. The assessment may vary depending on the risk posed by the scale, feedstocks and location but would generally include the following components:

    - An assessment of background odour in the existing environment. The assessment should include all sources of odour emissions from other existing activities in the local area with specific attention given to activities that may generate odours of a similar character or degree of offensiveness. This is to understand the current odour situation in the area, the frequency of potential odour episodes and the likelihood that the community is sensitised to odour or not. It is not for inclusion as background odour concentrations for use in an odour dispersion model unless the odour is deemed to be similar in character or from a sources at a similar activity, e.g., a proposed composting facility is located near an existing composting facility, landfill, waste transfer station, wastewater treatment plant or other activity where similar volatile sulphur and organic compounds may be released.
    - A representative odour dispersion model should be developed to assess the odour footprint of facility operations under all site-specific operating and meteorological conditions. The model should adequately represent the important features of the region's topography, land surface characteristics, and sensitive receptor locations and density.

20. For higher risk facilities, once it is approved and commences operation, an odour emissions audit should be conducted to develop a representative odour emissions inventory of the site's operations. A representative number of samples from each emission source should be collected and analysed by the methods prescribed in the Australian standards e.g., AS4323.3 and AS4323.4, to suitably assess the site's odour footprint. Further details of odour sampling, testing and assessment techniques are provided in the EPAQ (1997) and EPA (2006). Notwithstanding the guidance provided in these standards, consideration should be given in sampling device selection to the conditions, chemical mass transfer properties and diffusion mechanisms taking place at the surface of each odour source being sampled to ensure worst case emissions are captured for analysis.

    Once operational data is collected, it can be fed back into the site odour dispersion model (developed for the facility's environmental approvals) to calibrate and refine the model. The odour impact assessment can then be reviewed to evaluate whether the facility is likely to comply with the conditions under which it was approved, or whether further control measures may be warranted to ensure ongoing compliance. The calibrated dispersion model will then be a valuable tool for the operator to understand how their operation can impact on sensitive receptors under different conditions.

The performance of the odour dispersion model generated for the actual operating conditions could be evaluated and verified through a series of field ambient odour assessments. A minimum of ten field odour surveys in a period of 30 days should be conducted at different times of the day and in different meteorological conditions. This assessment could be repeated at least once during a different season within the first year of operation. Selection of seasons should be informed by dispersion model results and consider the following:

- Times of the year when winds are most likely to blow emissions towards key identified sensitive receptor areas,
- Peak odour emissions (e.g. potentially summer time) when ambient and compost temperatures are likely to be at their maximum, thereby generating peak odour emissions. This may also coincide with the period when compost material volumes are at their peak.
- Worst case dispersion conditions (e.g. winter time), particularly at night and around sunrise and sunset, but not limited to these times, and elevated ground-level odour concentrations.

An odour impact assessment technical report of these studies should be prepared by a suitably qualified and experienced person. This level of odour assessment will not be required for all facilities and is not directed at facilities that are demonstrably at low risk of impacting on sensitive receptors.

21. For an existing composting facility that has been the subject of a certain number of complaints (to be determined by the regulator) from the community related to offensive odours that may cause nuisance, the proponent of the facility should be required to conduct an odour impact assessment of its operations. The assessment should include, but not be limited to:
    - An odour emissions audit, with sampling and measurement by the methods prescribed in the Australian standards e.g., AS4323.3 and AS4323.4. The results of the audit should be compiled into an emissions inventory for comparison with the inventory developed after the facility's approval.
    - An odour impact assessment report should be prepared which considers the likely contribution from all sources including:
        a. all phases of processing (e.g. pre-treatment, decomposition, aeration and maturation),
        b. raw organics and organic products managed at the premises, including impacts during receipt and storage (i.e. including stockpiling of organics),
        c. movement of raw organics and organic products at and to/from the premises.
    - An odour dispersion model may be a useful tool to understand the interactions and contributions of different sources / activities. Field ambient odour surveys should be conducted to evaluate odour model performance and provide an actual assessment of odour experienced in the surrounding area.
    - Consideration may also be given to ongoing and routine field ambient odour assessment surveys as an odour management tool. Surveys should be conducted by suitably trained and qualified odour assessors, and preferably independent of the occupier's organisation. Should staff from the occupier's organisation conduct these surveys, they should not be plant operators that spend their time on the site and are desensitised to the odours released. These surveys should be recorded and documented appropriately in order for the regulator to assess compliance upon request.
22. For all facilities, operators should undertake an odour audit or odour balance study, which can be a useful exercise to identify and quantify odour emissions from each stage of the process, resulting in an odour emissions inventory for the site. The sophistication and level of detail of such a study will vary for each site in accordance with the scale or the operation and risk profile (function of waste types, process, proximity to sensitive receptors). It is worth noting the receival

area and curing piles can be major odour sources which should not be overlooked, in addition to the mixing and composting stages.

23. Ongoing environmental management of existing and future composting facilities may include, but not be limited to:

    - A site-specific odour management plan, the purpose of which is to identify odour sources and proactively reduce the potential for odour generation as well as to have a reactive plan for managing odour during upset conditions. The complexity of the plan should match the risk posed by the operation but a typical odour management plan may include the following:

        a. An inventory of all sources of odour,

        b. Odour sources and controls under normal conditions,

        c. Odour monitoring and recording regime,

        d. Odour management during upset conditions, and

        e. Routine maintenance of odour control equipment (where installed).

    - Site-specific meteorological data should be collected and recorded in accordance with the Australian standard AS3580.14 (2014) and EPA NSW (2016). The establishment of meteorological stations at all higher risk composting and related organics processing facilities should be encouraged to help verify odour complaints and evaluate or enhance dispersion model performance. The meteorological monitoring station should be maintained in good working order. Meteorological stations installed at composting and related organics processing facilities should, where practicable, continuously measure and electronically log the following parameters, at a minimum, in accordance with the Australian standard AS3580.14 (2014):

        a. Wind speed at 10 metres (m/s),

        a. Wind direction at 10 metres (°),

        b. Ambient temperature at two levels (2 metres and 10 metres) (°C),

        c. Parameters needed to determine the Pasquill-Gifford stability class—that is, either sigma theta (°) or solar radiation (W/m2).

    - All complaints reported to the occupier regarding odour must be considered in the light of meteorological data and/or site activities such as delivery of unusual organics to identify any correlations.

Contamination Recommendations

A number of recommendations are made to reduce the risk of compost product contamination, primarily by better managing and regulating feedstocks used in composting. The recommendations are set out below.

Composition data and feedstock characterisation

24. The initial contaminant risk assessment has identified 32 feedstocks considered to pose a high risk and 16 ranked as very high risk of leading to contaminants in compost products. Where there is reasonable confidence in the composition of the feedstocks and a high or very high rating is still applied (contamination category 1 materials), these should generally be banned from composting. In many cases though, the high ranking is partly due to uncertainty in composition so could potentially be reduced with better compositional data. The onus should generally be on operators to undertake sufficient analysis to demonstrate that the risk profile of their feedstocks is acceptable.

25. The lack of detailed data on feedstock composition has been a significant barrier in this study and more broadly in understanding and quantifying the scale of the issues. DES should establish a database of feedstock compositional analyses, by collecting data through a number of means such as:

   a. For common and consistently used feedstocks, DES could undertake sampling and analysis and make data available to industry
   b. For less common or more variable feedstocks, require operators to undertake regular sampling and analysis
   c. DES could require operators that need to analyse and characterise feedstocks to satisfy EA conditions, to regularly submit that data to supplement a non-published database.

26. Better analysis and data collection by industry is also needed to characterise and risk assess their own feedstocks, but DES could provide a framework and clear guidance on how to do this.
27. In general, composters should not be accepting wastes which are of unknown origin or composition. Where the composition of a waste is not known, it should conservatively be considered high risk until shown otherwise. If the waste generator or transporter fails to provide this information, there should be a clear mandate for the operator to reject the material and measures to restrict other operators then accepting it.
28. Likewise, it would be advantageous if compost quality data, differentiated into product types (feedstock, end-use based) was collated centrally by industry or a quality assurance organisation, and made available as collated anonymous information for public-interest interrogation.
29. The government should allow an adequate transition period for any regulatory changes which will divert materials away from composting, where there may be a need for industry to develop new infrastructure, to prevent perverse disposal outcomes and worsened environmental outcomes.
30. It would be beneficial to have a standard list of feedstock names which provide a more accurate and descriptive picture of the material, including the source industry or sector and accompanied by a short statement regarding source and composition of each feedstock. This is an important piece of information to record as it will assist in guiding management decisions on the assessment of new feedstocks, and consistency in terminology used across industry will aid in ensuring that incoming feedstocks are classified in a consistent manner upon receipt at composting facilities and that risks are better understood.
31. Further work is also needed to collate data on organic contaminants (and other characteristics) in compost products from a wide variety of sources to establish what proportion of products exceed the AS4454/ Biosolids limits, and which compounds are causing issues. Without sufficient data, it is impossible to have an informed discussion and to make informed decisions.
32. Further investigation is needed to evaluate the risks associated with new ‘emerging’ chemicals of interest, especially PFOS/PFAS. An approach similar to that used by Clarke and Smith (2011) as referenced in this report would be highly valuable, in which emerging contaminants were scored on certain criteria in order to prioritise for further research. This research could be used to reset the proposed suite of Organic Chemicals to be tested. This list may vary a little depending on the waste being composted.
33. Further investigation is needed to assess whether elevated TPH and TRH levels found in the finished compost samples collected by DES in 2017 are widespread and common, and what the specific hydrocarbons are and where they came from. TPH and TRH have been detected in common feedstocks including green waste and grease-trap waste but these do not fully account for the levels detected in finished compost products and the fact that most volatile hydrocarbons are readily biodegradable in a composting process. It is possible that compounds are being formed during the composting process, which are being detected in the TPH / TRH tests, but this needs to be confirmed.
34. There is also a need for improved management procedures for tracking, assessing, and managing contamination risks, which may include:
    - Procedural improvements – develop templated forms and record keeping requirements, including forms to document feedstock sources, volumes, testing done, etc.
    - Procedural improvements – require improved record keeping of composting processes, to ensure biological hazards are being managed (i.e. pasteurisation requirements)

- Improved guidance on analytical requirements – to be developed following further data collection on current feedstocks.

Regulation of contaminants

35. As with odour regulation, DES should investigate options to harmonise and reduce the inconsistency in EA conditions relating to the management of contamination in feedstocks and compost products. The main focus should be on achieving consistency and there is a case for more prescriptive conditions to regulate some aspects, such as feedstock characterisation, risk assessment and product testing.

36. There is a strong need to restore consumer confidence in the quality of compost products in the Queensland market and in the ingredients used in composting. Feedstocks which have been rated as high or very high risk of causing product contamination need to be further investigated and characterised to confirm the risk and then consideration given to whether they are appropriate feedstocks, or whether the risks can be adequately controlled with management and regulatory measures.

37. The government should consider whether feedstocks which are confirmed as high or very high risk in terms of contamination, including those processed under ERA's 55 and 58, should be processed in physically separate composting facilities, or indeed whether other treatment technologies are more appropriate. The combining of ERA 53 composting with ERA 55 activities, and in some cases ERA 58, seems to add to the risk of product contamination and certainly undermines consumer confidence in the product.

38. This review has considered whether there may be a case for differentiation in labelling and permitted end uses of compost products that are derived from low risk organic feedstocks (under ERA 53) versus those which incorporate higher risk feedstocks. The idea may be that only the low risk feedstocks would be permitted to be used in sensitive applications such as food production and horticulture, residential, commercial, institutions and public space landscaping. Higher risk and poorer quality products, whilst still complying with minimum standards, would then be confined to applications that minimise the likelihood and frequency of human contact or environmental impact, such as rehabilitation of mines, landfills and contaminated sites, highway verges and forestry. However, the project team has come to the view that such an approach will be difficult to implement and potentially counter-productive. It is better to aim for one final product standard, which allows use in any application (unrestricted) to avoid potential confusion in the market place. This will be much more practical to implement and enforce / monitor. Industry feedback supports this approach but further consultation with industry on this point is recommended.

39. The government should generally reconsider its current approach of allowing operators to be primarily responsible for determining which feedstocks are suitable for composting as set out in the Composting Guidelines, or at least provide much more specific guidance around assessing feedstock suitability. This approach and the exclusion of waste acceptance criteria from a number of EAs, has undoubtedly allowed the current proliferation of composting feedstocks and the apparent shift from production of beneficial soil products, to low cost treatment of waste streams.

40. Further work is needed to establish the suitability of the AS4454/ Biosolids organic contaminant limits to the current situation with respect to organic waste recycling. Most of these chemicals have been phased out for many years and studies overseas show that they are usually virtually absent in compost products. Conversely, there are numerous contaminants not included in these standards which could be relevant. The NEPM Soil Health Investigation Levels provide a more contemporary and comprehensive list of contaminants that should be considered, although the actual thresholds should be tailored to suit the application of compost to land (rather than the assessment of existing contamination, as the current HILs are designed for).

41. In regulating physical impurities, area-based assessment of impurities should be considered as a superior method (compared to weight or item number based measures) to better account for highly visible light weight impurities such as film plastics, which are likely to break down into microplastics over time.

42. End of Waste codes may provide a powerful tool, with minimal regulatory change, to better regulate the contaminant risks associated with specific high risk feedstocks, or to introduce regulatory limits on compost products.

43. The requirement for some composters under their EA conditions to demonstrate that new feedstocks do not have detrimental effects on the composting process or the quality / usability of finished products is good in its intention, but potentially too loosely defined. It could be tightened and industry provided with specific guidance on how to undertake such assessments, including analysis of contamination risks, which could result in utility and risk scores, that determine whether new feedstock enhance or detract from the composting process and the generated product.

1 INTRODUCTION

Arcadis has been engaged by the Department of Environment and Science (DES) to undertake a critical assessment, review and evaluation of composting operations in Queensland with a focus on odour management, feedstock suitability, contamination risks and the regulation of these aspects by DES.

Composting in Queensland is a significant industry which in 2017-18 converted 1.4 million tonnes of organic residues and waste into beneficial products which generally improve soil health and quality. There are around 25 companies of varying scales whose primary business is composting plus a number of other companies and councils that engage in organics processing in various forms, amongst other waste activities.

Without a successful composting industry, significantly more organic waste would be landfilled or otherwise disposed to land without processing, resulting in a range of environmental and social impacts including significant greenhouse gas emissions. It also produces soil conditioner products that improve soil quality and reduce the need for chemical fertilisers and could potentially play a much greater role in supporting sustainable agriculture in Queensland.

The role of composting in the broader waste management system is set to grow over the coming years as councils and businesses look for ways to divert more organic waste from landfill, particularly food waste. The draft Queensland Waste Strategy sets ambitious targets for recycling waste and reducing landfill which will only be achieved if more organics are recovered and directed to beneficial uses. The Waste Strategy focuses on building a circular economy in Queensland and the recovery of organic waste is already a major contributor to that.

However, composting also has a high potential to impact on local communities and the environment. The Queensland Government has committed to reducing those impacts with a particular focus on addressing odour management issues and contamination in compost products, arising from the use of inappropriate feedstocks.

As such, the Department has commissioned the current study to take a holistic view of the composting industry in Queensland and provide expert advice on best practice environmental management for composting operations and the suitability of different waste streams in the manufacture of compost and soil conditioners, particularly with respect to odour risk and contamination in the final products. The study is also expected to provide advice in relation to potential adverse consequences from waste suitability determinations and any regulatory change to address these. The brief also identifies that the study should:

- Ensure that waste acceptance criteria imposed in Environmental Authorities is adequate to protect surrounding communities from nuisance odours.
- Look at the materials the Swanbank industries currently accept for composting and determine whether any changes are required.
- Scientifically review the Environmental Authority waste acceptance criteria for composting operations.

DES has noted that in the past, composting operators have traditionally used organic waste streams such as green waste and some clean inorganic waste streams in the manufacturing of compost and soil products. However, in recent years, the activities of the industry have shifted to see a proliferation in the types and nature of waste streams incorporated into compost, both organic and inorganic. Concerns have been raised about the suitability of some of these materials in compost and whether parts of the industry have shifted from a primary focus on compost manufacture, to being primarily waste treatment businesses. Open windrow composting offers a low cost alternative for the processing or disposal of a range of different waste streams, which are not necessarily beneficial to the end products.

At the same time, DES has received a considerable number of complaints about odour nuisance from composting operations, particularly in the Swanbank area near Ipswich, but also near other composting operations. DES has established the Swanbank Odour Abatement Taskforce which has, and continues to, conduct extensive odour investigations in that particular area. DES considers there are opportunities to improve the regulation of nuisance odour from composting operations in Swanbank and more broadly across Queensland.

This study aims to improve the Department's understanding of composting processes and odour emissions from composting; best practice management of composting; the suitability of different materials as feedstocks in composting and requirements for improving regulation of the industry.

1.1 Scope and purpose

The study aims to improve the Department's understanding of:

- odorous air emission sources arising from composting operations;
- best practice management of composting facilities;
- the suitability of various waste streams (feedstocks) in the manufacture of compost and soil conditioner products and how these feedstocks should be managed;
- requirements for improved regulation.

The study has been undertaken in two key phases.

Phase 1 was a review of composting operations with a focus on odour sources, management practices and regulation, using facilities in the Swanbank Industrial Area as a case study. The findings of Phase 1 were presented in a separate report titled *Critical Evaluation of Composting Operations and Feedstock Suitability, Phase 1 – Odour Issues*, dated 20 March 2019 (final version). The Phase 1 report included:

- An extensive review of odorous air emissions arising from composting activities generally, including sources of odour, odour management practices, effect of climatic conditions, effectiveness of odour management controls and/or practices and any Environmental Authority conditions (or lack thereof) that may result in the release of offensive odorous air emissions affecting surrounding sensitive receptors. This included and was based on a review of relevant literature.
- Identification of odorous feedstocks used in compost and soil conditioner manufacture and management practices that may result in odour impact on sensitive receptors. Report on national and international best practice management, standards and methodologies at composting facilities to manage odour risk and odorous feedstock.
- To inform the above, an investigation of composting operations within the Swanbank Industrial Area has been undertaken. Two case studies of major composting facilities have been developed with consideration of potential odour sources and any management practices that may give rise to offensive odorous air emissions, resulting in impacts to surrounding residents and other sensitive receptors.

Phase 2, the findings of which are presented in this report, focuses on managing contaminants in compost products, including a critical review of the suitability of compost feedstocks and identifying the risks to the environment with regard to the unrestricted distribution of the manufactured products.

The scope of Phase 2 included:

- A critical review and evaluation of current feedstocks accepted by composting operations in Queensland, considering current acceptance criteria as outlined in existing environmental authorities and determine if these criteria are appropriate for the management of any environmental risks posed by the manufactured products due to their unrestricted distribution across Queensland or interstate.
- Scientific assessment of the chemical constituents in compost feedstock (desktop only) and determine whether the composting process is a suitable method for the management of those chemical constituents in the context of their unrestricted distribution/end use and potential environmental harm resulting from migration of those chemicals from the final products.
- Determine whether all potential contaminants added to the compost, whether digested, decomposed, unchanged or subject to potential chemical interactions are compatible with the

composting process, and using a risk-based assessment, categorise feedstock into the following schedules:

  - suitable for composting and soil conditioner manufacture for any (unrestricted) end use;
  - requires further assessment or specific management measures to be considered for composting and manufacturing of soil conditioner;
  - suitable end uses for final product taking into consideration the environmental risk of waste accepted and maximum contaminant concentrations. These include but are not limited to AS3743, AS4419, AS4454, AS4736, National Environmental Protection Measures (NEPM) guidelines;
  - unsuitable for compost and soil conditioner manufacture;
  - considered high risk for odour generation.

  Note: Additional categories may be required, subject to the findings of the assessment. Where possible assess and categorise all feedstocks identified in this review.

- Consider and provide guidance on how to conduct a risk assessment to determine suitability of waste to be incorporated into composting and soil conditioning manufacturing operations, to enable new and emerging feedstock to be assessed for suitability as compost feedstock. Guidance material should include, but not be limited to, considerations for contaminant quality characteristics, mixing ratio's, operational parameters, product quality and end use. This should reflect the risk assessment process conducted to develop the schedules above.
- Consider and provide advice/recommendations on any potentially perverse outcomes (e.g. increased waste dumping) identified that could result in a change to existing practices, e.g. new exclusions or restrictions on the use of certain feedstocks, specialised composting processes required to manage certain feedstocks (e.g. additional pasteurisation time etc.), and outline any recommended strategies to mitigate these potentially perverse outcomes.
- Conduct a review of national and international literature and practices of feedstock acceptance and end use suitability, identifying best practice. Consider how waste acceptance regulation and conditions of environmental authorities could be improved to support best practice management.
- Conduct a review of national and international literature and practices on best practice environmental management having particular regard for environmental risks with potential to cause environmental harm and nuisance. Review the findings of the assessment and prepare a report that establishes best practice environmental management for composting operations.

This report presents the findings of Phase 2 in detail, but also incorporates the key findings from Phase 1 such that this report can be read as a stand-alone document. However, for more detailed information and background on odour issues and the investigations undertaken, including literature review and information sources, the reader should reference the Phase 1 report.

1.2 Report structure

This report presents the findings of the Phase 1 investigation into composting operations and the management of odour issues in composting. The report is structured as follows:

- Chapter 2 provides an overview of the composting process and technologies, process control factors, odour sources and measurement of odours and compost end uses
- Chapter 3 provides an overview of composting regulation and standards.
- Chapter 4 presents and discusses the wide range of feedstocks used in Queensland composting facilities and the adopted approach to categorising them.
- Chapter 5 provides a detailed discussion of the key potential compost contaminants of interest, based on literature review.

- Chapter 6 describes the qualitative risk assessment approaches adopted to assess the risk of odour and contamination as they relate to composting feedstocks.
- Chapter 7 provides recommendations arising from both Phase 1 and 2 of the study, noting that industry consultation is ongoing to gain feedback on these.

At the end of each chapter is a summary of key findings from that chapter and recommendations arising as relevant.

1.3 Project team

Arcadis is a global engineering and environmental consultancy which in Australia, is a leading provider of strategic and technical advice on waste management to local and state governments and private industry. In undertaking the study, Arcadis has partnered with a team of specialists including:

- Air Environment is one of Australia's leading air quality and odour assessment and management consultancies. Air Environment is led by Andrew Balch and Brisbane based, bringing extensive experience in assessing odour issues in relation to composting and waste management facilities. AE's role on the project is to advise on odour management, measurement and assessment aspects.
- Frontier Ag and Environment, led by Kevin Wilkinson, is a specialist consultancy providing advice on organics processing and the use of organic soil amendments for soil and crop health. Frontier Ag and Environment is providing specialist input on composting knowledge and science and best practice management.
- The Centre for Recycling of Organic Waste and Nutrients (CROWN) at the University of Queensland, led by Johannes Biala. CROWN is an independent research, training and advisory organisation that covers all aspects of organics recycling and resource recovery supply chains. It is part-funded by the Department of Environment and Science. CROWN's role on the project is to contribute research and technical advice on best practice composting methods and contaminant assessment / management.

Arcadis acknowledges and thanks the project partners for their valuable contributions.

As part of the study, the project team consulted extensively with two composting operators to better understand their operations and some of the issues facing industry, as presented in the Phase 1 report. The project team extends our thanks to those operators for their openness and willingness to support the study, and their valuable insights and information.

2 COMPOSTING BACKGROUND & BEST PRACTICE

2.1 Composting process

Composting is the controlled biological decomposition of organic materials under aerobic and thermophilic or naturally self-heating conditions. Industrial scale composting is a controlled process that requires careful management of the inputs and process conditions, like any other manufacturing process. Failure to adequately control composting process parameters can rapidly lead to adverse environmental and public health impacts and poor product quality. This is particularly true in that composting is a biological process and the organisms involved need the right environmental conditions to thrive.

Composting is an aerobic process in that the decomposition of organic materials by oxidation takes place in the presence of air and the organisms need oxygen to biodegrade materials. Failure to ensure adequate air flow and maintain composting conditions in an aerobic state, slows the composting process and results in anaerobic conditions that lead to nuisance odours.

Composting is also a thermophilic process, meaning that heat is produced naturally by the process and it takes place at temperatures above 45°C for extended periods during processing. Thermophilic composting is desirable for a number of reasons – higher temperatures result in faster rates of decomposition, speeding up the composting process. It also has a pasteurisation effect, assisting in the elimination of pathogens and weed seeds that might be present in the feedstock material. Managing oxygenation and temperature in a compost pile are key process control variables in composting, and commercial composters must understand what role they play in the generation and management of odours during composting.

Whilst composting is principally a biologically mediated process, decomposition itself can be described as a series of chemical reactions in which complex organic compounds are broken down into their constituent parts. The main components of most organic materials are proteins, carbohydrates and fats; containing various combinations of carbon, hydrogen, oxygen, nitrogen and sulphur. Proteins will decompose into their constituent polypeptides, which in turn, break down into amino acids. Each category of decomposition has several subcategories, many of which are intermediate byproducts of the decomposition process.

During the thermophilic stage of composting, a vast number of reactions take place simultaneously. This confirms that composting is a complex process involving many different compounds and intermediate biological and chemical processes. Similarly, the compounds that cause odours in composting are a complex mix and vary as the process progresses. Contaminants in feedstocks react differently to these processes – some contaminants degrade and oxidise, others change form or state.

The dynamic character of decomposition during composting is typically described in general terms due to its complexity. This dynamism is associated with the complex inter-relationship that exists between food source (feedstock), environmental conditions (e.g. temperature, air and water) and metabolic activity (microbial species, diversity and activity) as depicted in Figure 1.

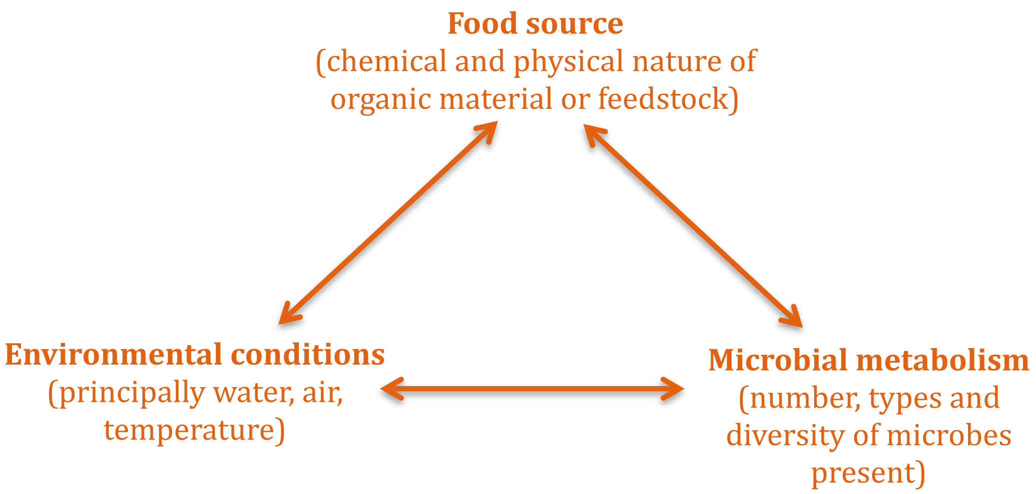

Figure 1: Overview of complex inter-relationships in composting reactions

Understanding the relationships between food source (feedstock), environmental conditions (e.g. temperature, air and water) and metabolic activity (microbial species, diversity and activity) is critical to successful operation of a composting process, including how odours are generated and managed and how some contaminants are degraded.

Getting the physicochemical composition of the feedstock mix right (i.e. optimal physical characteristics such as particle size and porosity plus optimal ratios of carbon, nitrogen and other nutrients) is the key to maintaining optimal process conditions, including the consistent aerobic conditions necessary for rapid decomposition and low odour emissions, regardless of the composting system employed.

The key stages in any composting process include:

- Feedstock receival, preparation and storage
- Mixing and blending of feedstocks and forming into windrows
- The main thermophilic compost stage
- Curing or maturation of the compost
- Screening, refining and storage of the finished product

Each stage requires different management and control measures, and the Phase 1 report provided details around managing odour emissions from each stage. Process control measures are highlighted in 2.3 below.

2.2 Composting technologies

The vast majority of organic wastes recovered in Queensland are processed through open windrow composting facilities. This is typically a passively aerated process – it relies on air naturally permeating and moving through the windrow pile to provide oxygen for the organisms involved in decomposition.

Turning of the windrows is an essential part of any open windrow process. It helps to homogenise the compost mix, redistribute moisture and nutrients, ensure even pasteurisation throughout the pile, breakdown particles and support passive aeration of the pile.

While turning the windrow introduces fresh air into the windrow and releases decomposition gases such as carbon dioxide, it has a limited direct effect on maintaining aerobic conditions. Studies have shown that any oxygen which is introduced into a windrow during a single turning event is generally consumed within hours.

The more important factor for maintaining aerobic conditions in a passively aerated pile is the porosity (or void space) of the material, which is primarily a function of material particle sizes and determines how freely fresh air can flow into the voids within the pile and penetrate into the middle of the pile, as well as how easily other gases can escape.

Turning a windrow also releases the odorous gases and vapours that may have accumulated within the windrow voids. Without turning, those compounds would slowly migrate outwards from the pile centre and be subject to oxidation and degradation as they move. By the time they exit the pile surface, the various compounds will be broken down, significantly reducing the odour impact.

Composters in Queensland use a number of different methods to turn windrows – some use specialised windrow turning machines while others use generic plant such as excavators or front-end loaders. This aspect was considered in some detail in Phase 1, which concluded there is no best practice approach to turning – a turning strategy needs to be tailored to the specific conditions of a facility including feedstock mix and characteristics, climate, scale and financial considerations. Key points to note on turning include:

- Turning frequency has less impact on the composting process than other key process variables such as feedstock physicochemical characteristics, moisture content and windrow size; but it can influence such things as the rate of decomposition, compost bulk density and porosity, and the time required to reach maturation.
- Turning a windrow in itself, has only a short term impact on oxygen levels in the windrow. As such, the porosity of the composting materials is far more important, because it determines how freely air can move through the pile. A degree of turning can help to improve porosity by loosening the materials and redistributing moisture (saturated material inherently has poor porosity). The use of bulking agents such as green waste or wood chips at appropriate particle sizes and ratios, is critical to maintaining porosity and air flow in passively aerated windrows. Aerobic conditions cannot be maintained in a compost mix of low porosity simply by increasing the rate of turning.
- On the other hand, care must be taken not to overwork or excessively turn a windrow. An aggressive turning schedule or method can reduce the porosity of a windrow by breaking down compost particles, which can reduce air flow and lead to anaerobic conditions.
- Turning also potentially facilitates the release of odorous gases that may have accumulated within the windrow voids and before they have had a chance to oxidise as they move outwards through the windrow. Research has shown that increased turning may increase the loss of ammonia gas in particular, which is odorous and its loss also reduces the nutrient value of the compost product.
- Specialised turners are more effective at turning and mechanical agitation and generally more efficient in terms of labour and time, compared to generic plant such as front-end loaders or excavators. However, they can be quite aggressive and over-use of windrow turners may reduce particle sizes and have an adverse effect on porosity. In some cases, the more gentle action of a front-end loader may be beneficial for some feedstock mixes, provided the porosity of the mix is optimised.

Turning is required in open windrow systems, but the frequency of turning needs to be optimised to balance the benefits with the adverse impacts. In terms of odour impact, there is significant debate within industry and in literature as to whether the frequent release of moderate odours from frequent turning is better or worse than infrequent turning and occasional release of strong odours.

The organics industry nationally in Australia is increasingly shifting towards enclosed and/or forced aeration composting systems, particularly to process more difficult feedstocks, and some operators in Queensland are also progressing towards this. Enclosed and forced aeration composting systems come in many forms with varying degrees of sophistication and cost. All of them offer the potential of more precise control over process conditions, ensured continuous aerobic conditions, rapid pasteurisation and decomposition, and improved odour containment and control.

Aerated static piles (ASPs) are the simplest form of forced aeration system and can be a cost-effective alternative to turned windrow systems. While there will be a moderate additional capital investment in the aeration floor / pipework and fan systems, there is usually reduced need for turning equipment and less land required for a given throughput as the process is more intense.

Covering the aerated piles with specialised breathable textiles (e.g. proprietary Fabcom® or Gore® Waste Covers) provides a level of containment which helps to control odours and moisture.

The next step up is in-vessel composting which comes in many forms including bunker systems, agitated bays and tunnels. These systems are generally more capital intensive than windrow-composting facilities, though the range in cost is extremely wide, depending on the type of technology used and its scale.

These systems are typically favored by regulatory authorities for processing of odorous organics throughout the world due their perceived advantages, which include:

- Precise process control of composting conditions (temperature, aeration and moisture addition);
- Rapid pasteurisation and rapid rates of decomposition due to more uniform distribution of high temperatures occurring throughout the compost matrix;
- They are often established under a roof, in a building or vessel, providing protection from the elements; and
- They typically are associated with improved systems for odour containment and control.

This study has focused on composting, but anaerobic digestion (AD) is also an alternative biological processing method for some organic wastes which is fully enclosed and offers many of the same advantages as enclosed composting. Liquid and high moisture content wastes (dry matter < 15%) can be processed through wet AD systems, of which there are several reference examples in Queensland and Australia processing streams such as animal manures, sewage sludge / biosolids, food and food processing wastes.

Dry AD systems are more suited to processing organic residues with dry matter content between 25% and 50% such as FOGO and are gaining popularity in Europe and North America as an alternative to in-vessel composting. All AD facilities decompose organic waste in enclosed vessels under anaerobic conditions to produce methane rich biogas which can be captured and used for energy purposes.

AD is a potential alternative to composting for processing highly odorous and wet waste streams. It has not generally been commercially viable other than in the discrete applications noted above, due to the prominence of low cost open windrow composting and/or other relatively cheap disposal methods such as landfill and land spreading. The introduction of the landfill levy and associated funding programs may support the broader implementation of AD in Queensland and there are a number of proponents exploring this option.

2.3 Process Control

As noted above, optimal control over process conditions is essential to ensure that composting systems perform as expected in terms of odour release, pasteurisation and product quality.

The first key step in managing any composting process is to understand and manage the risks associated with different feedstocks, particularly around odour causing potential and contamination. An operator needs to understand the characteristics of the feedstocks they receive in order to consider whether it can be effectively handled on site and whether it will negatively impact compost quality and the environment.

It was apparent through the Phase 1 investigations that composters have varying approaches to characterising feedstocks and therefore varying degrees of understanding of their feedstocks. In some cases, this is very limited. Key aspects to consider are:

- The organic components of wastes are comprised of readily degradable, slowly degradable and non-biodegradable fractions of organic matter. Highly putrescible materials have especially high contents of the readily biodegradable organic matter (or biodegradable volatile solids, BVS) and this has a pronounced effect on odour generation. Highly putrescible materials often arrive at a composting facility in an anaerobic or putrid condition due to the time and way they have been stored by the waste generator. There needs to be appropriate facilities in place to receive and store those materials safely and without excessive odour release.

- Highly putrescible feedstocks also decompose rapidly in a composting environment and can quickly consume available oxygen in the pile, threatening the aerobic conditions which are essential to the process. The solution to this issue is to blend and dilute highly putrescible or potentially odorous feedstocks with slowly degradable materials and bulking agents such as green waste, in appropriate ratios to control the decomposition rate. Potentially odorous material must be combined in a mix as quickly as possible upon arrival at a composting facility, although odours will inevitably be released during this process.
- Preparing the right mix of feedstocks for composting is critical, with particular attention to the carbon:nitrogen ratio (C:N ratio), moisture content and porosity. The ideal C:N ratio for composting is in the range 25 to 40 and operators should understand and monitor the C and N content of their feedstocks, including lab analysis to characterise feedstocks as appropriate.
- Compost mixes outside the ideal range may still heat up and appear to be composting well. However, high C:N ratio mixes (low on nitrogen) will take longer to mature and increase the risk of odour formation in the curing piles. Low C:N ratio mixes (excessive nitrogen) can lead to loss of nitrogen as odorous ammonia gas.
- The optimum moisture content for composting is considered to be around 50% but some forced aeration systems perform better at slightly higher moisture contents of 55%. Above 60%, the pore spaces in the compost are filled with water, impeding air flow and leading to anaerobic conditions.
- It is generally better to focus on achieving an optimal C:N ratio whilst erring on the side of a drier mix. It is easy to add water to a mix, but difficult to remove moisture.
- The porosity of the mix (the proportion of free air space in the voids) should be around 40% and ideally in the range 30-50%, noting that it will decrease over time as particles breakdown. Bulk density is often used as a surrogate for porosity (there is a linear relationship) and is easier to measure on site. Bulk density of the mix should generally be below 650 kg/m^3.

Operators need to know the physical and chemical characteristics of their feedstocks, particularly C and N content, moisture, porosity, pH, and any contaminants of concern. This should be informed by sampling and lab or on-site analysis at appropriate intervals. For feedstocks that are known to be consistent, an initial characterisation assessment and occasional verification sampling may be adequate. Operators should also establish systems to ensure optimal feedstock mixes are achieved and documented.

Once the feedstocks are mixed, and the composting process commences, there is a need for ongoing monitoring to ensure that optimal conditions are maintained. Parameters such as temperature and pH should be regularly monitored throughout the composting process and other parameters such as moisture content and oxygen levels may also be measured, particularly when processing wet or odorous feedstocks, or when undertaking trials to optimise the system.

Temperature is an important and relatively easy parameter to monitor during the composting phase. The ideal range for thermophilic decomposition is around 45°C to 60°C, while 55°C is considered the minimum to achieve pasteurisation. Temperatures significantly above this level may have adverse impacts as higher temperatures can increase the volatility of odorous compounds and there is a direct relationship between temperature and odour emissions up to around 65°C.

Maintaining adequate moisture levels throughout the composting process is also important. Moisture levels will naturally decline as the composting process progresses, but if the material gets too dry it may inhibit the process. Moisture levels can be tested on site with relatively simple methods.

The optimum pH level for most composting organisms is considered to be pH 5.5 to pH 8.0. Acidic conditions (low pH) are common in the initial phase of composting due to formation of organic acids but prolonged low pH conditions can lead to increased release of VOCs. High pH conditions can facilitate release of ammonia gas. The solution to managing pH levels is adjusting the C:N ratio of the initial mix, rather than direct adjustments, e.g. by adding lime.

Oxygen levels are more challenging to measure but can be checked with the appropriate probes and a trained operator. An oxygen level of 5% within the windrow voids is generally considered to be the minimum threshold for ‘aerobic’ conditions, though above 10% is preferable.

As noted above, maintaining aerobic conditions is critical during the composting phase. In passively aerated windrows, this is mainly down to the porosity of the material and turning regime. In forced aeration and enclosed systems, aeration rates need to be carefully controlled and balanced. Too much air will drive out heat and undermine pasteurisation, and care must be taken in forced aeration systems to ensure that elevated aeration rates do not strip odorants out of a pile before they have had time to fully oxidise and decompose.

It is also generally considered that increased rates of aeration result in a decrease in concentration of odorous compounds emitted, but an increase in total mass emissions. Operators need to determine the optimal aeration strategy for their particular compost mix through site trials and sampling in the commissioning phase.

As the thermophilic phase of composting nears the end, temperatures will start to consistently decline below 45°C, at which point the curing or maturation phase can begin. The curing phase of composting can be a surprisingly significant source of odours, particularly when material is moved to this phase too soon.

The curing phase is important and can take anywhere from 1 to 6 months. The smell of mature compost should not be unpleasant, while immature compost may have an unpleasant odour and become anaerobic when stockpiled. Compost should not be screened until the latter stages of curing, to maintain the compost porosity. Stockpiling of screened compost that is not fully cured can contribute to odour issues.

There are a number of ways to test the maturity of compost including the Solvita^{TM} test which can be performed on site and is considered an acceptable method in the Australian Standard AS4454 and several European guidelines.

2.4 Odour sources, measurement and management

The formation of odorous compounds is inherently associated with the decomposition of organic matter and odours *will* therefore form during composting even under “optimal conditions”. Nevertheless, the failure to develop these optimal conditions is a guaranteed recipe for making matters worse and the nature and noxiousness of the odours will be worse under sub-optimal conditions.

Composting facilities are typically characterised by multiple point and fugitive sources of odour (receival areas, open windrows, turning activities, maturation pads, leachate dams, biofilters), and are often sited in areas of relatively complex terrain.

The contribution that each part of the process makes to overall odour emissions will vary depending on the process and feedstocks. For example, studies have found that for highly putrescible, rapidly biodegradable feedstocks (such as food or household organics) the main composting phase accounts for most of the odour emissions. For slower degrading materials such as green waste, the odour emissions are more evenly spread across the entire process from receival to final product storage. In both cases, the curing phase was found to be a significant odour source and this is consistent with other studies which have shown in some cases, curing can be responsible for more odour release than the main composting stage. Odour inventory or odour balance studies can be an effective tool to identify and quantify the different sources of odour at a facility, which is then helpful to identify and implement additional control measures.

Understanding the relationships between feedstock characteristics and process conditions is critical to successful composting including how odours are generated and managed. As the composting process advances for each batch, different decomposition products are produced, resulting in changes to the character of odour generated over time (Coker 2012). Odorous compounds are interactive or synergistic, not additive, in their effect. In other words, a combination of odorous compounds is often perceived by the senses as one unique odour, rather than several odours acting independently.

Most composting odours are associated with a range of different volatile organic compounds that are released and it is noted that:

- Feedstocks which are high in nitrogen are prone to producing ammonia gas during composting which has a recognisable pungent odour. Although ammonia has been noted to have a high odour threshold (i.e. it takes relatively high concentrations to be detected) and to dissipate rapidly.
- Sulphur containing materials such as food, paper, gypsum, manure and biosolids can lead to release of mercaptans and other volatile organic sulphur compounds, while anaerobic conditions in a compost pile can lead to release of hydrogen sulphide gas with its characteristic rotten egg smell which is offensive even at low concentrations.
- Feedstocks high in proteins such as food waste, manures and animal processing wastes are particularly vulnerable to production of odorous compounds as they can release volatile organic, nitrogen and sulphur based compounds.
- Anaerobic conditions within a composting pile lead to formation and accumulation of particularly odorous compounds.

Weather has an impact on odour emissions and in Queensland’s warm climate the tipping or receival area can be a major source of odours due to waste significantly decomposing in the heat before it arrives on site, which is less of an issue in colder climates. Typically, poor dispersion of odour emissions from composting facilities occurs during light stable wind conditions, particularly during the evening and early morning when odour emissions can become entrained within slowly flowing air flows, travelling with little dilution along the path from source to receptor. On the other hand, moderate wind speeds may strip or draw out odorous compounds from a windrow resulting in a significant, well-defined and concentrated odour plume, which may be transported considerable distances downwind.

Meteorological data collected onsite at a composting facility can be extremely useful when responding to complaints, planning site operations to minimise odour impact or for use within an atmospheric dispersion model. Meteorological observations can be carefully analysed to help an operator understand the dispersion mechanisms governing their odour plume, which can provide useful odour mitigation insights.

The measurement and assessment of odour is complex. Composting releases a complex mix of many different odorous compounds at different stages of the process and depending on the composition of the feedstock and process conditions. The compounds all behave and change differently as they travel through the atmosphere. As such, there is often little benefit in trying to trace odours by measuring specific isolated compounds in air. The human nose is the most effective tool in measuring and characterising odours and there are established lab and field survey methods for quantifying odours.

Odour concentration is the most commonly used odour dimension to characterise an odour for regulatory purposes and is measurable by well-established olfactometry methods in a lab setting. However, other dimensions such as intensity, character, offensiveness and persistency are also important in assessing or describing a nuisance odour (together known as the CICOP dimensions of odour). When assessing the impact of that odour in a particular context, there are a number of factors which influence the extent to which communities may be adversely affected including frequency, intensity, duration, offensiveness and location of the odour events (together known as the FIDOL factors).

Odour dispersion modelling can be an effective tool to assess odour impact on receptors, taking into account the complexities around different odour sources (point and fugitive), local terrain and weather conditions; provided the right type of model is used. Models can help operators and regulators to understand the effects of these different variables. Odour emission measurements taken on site are a critical part of verifying and calibrating any odour dispersion modelling and impact assessment to maximise their accuracy. Field odour surveys can be a useful tool to quantify and delineate an odour plume but they require careful planning and analysis of the data to provide a comprehensive assessment of nuisance potential and extent.

For further detail on odour measurement and assessment, refer to the Phase 1 report.

The Phase 1 report also assessed different odour treatment approaches. There are a range of biological, chemical and physical treatments that can be applied to composting odours, but generally only where the odour is able to be captured, as in the case of an enclosed process. In that case, engineered biofilters have been shown to provide a high rate of odour removal efficiency for a moderate capital cost and low operating costs.

For open windrow composting, one option which has been found to be effective is to apply a ‘cap’ or blanket of unscreened matured compost (up to 150-200mm thick) on top of a newly formed windrow. The layer acts as a biofilter and can be very effective at reducing VOC emissions during the first few days of composting, when odour formation is typically highest. After the first turning, the mature compost gets mixed into the compost where it acts as an inoculum and continues to have a beneficial impact.

Chemical masking agents, often applied as a fog or mist over a site, have been used at composting facilities but their efficacy is debatable and they have been found to contribute to the odour nuisance.

Overall, treating the odours should be the last resort – operators should focus on controlling the process conditions as noted above to minimise the formation of noxious odours in the first place.

2.5 Compost end uses

Compost products and associated products such as soil conditioners, soil mixes and potting mixes, are used in a wide range of applications, each with differing degrees of exposure and risk to human health and the environment. Potential uses include:

- Residential gardens, either via bagged or bulk products, including mulches and soil mixes
- Gardens in schools, childcare centres and other similar institutions
- Public open spaces including parks and gardens, sporting fields
- Urban landscaping such as road verges and around other private and public building and infrastructure projects, particularly in revegetating disturbed surfaces
- Rehabilitation of poor soils and topsoil to facilitate revegetation on mine sites, contaminated sites and closed landfills
- Agriculture in various forms including broad-acre cropping, grazing, horticulture, tree cropping and turf farming

The level of contaminants that are permissible in compost products is currently not regulated in Queensland. Some EAs contain a requirement for compost products to meet AS 4454 specifications (all requirements, or only contaminant limits), but the legal status of this practice is unclear (see Section 3.2.1). The Australian Standard AS4454 – 2012 does contain maximum contaminant levels for unrestricted use of compost, but compliance and third party auditing are voluntary. Most if not all compost that is made from urban derived organic residues and sold in bulk is not third party audited; at best it complies with AS 4454 requirements by means of self-assessment (for more details see Section 3.2.1).

Consequently, there is a need to include end product contaminant levels into the regulatory framework in Queensland. This could be done by one of the following three options:

- Amending the ERA 53 schedule
- Changes to existing and new licenses to specify contaminant limits in end products rather than referring to AS 4454 specifications
- Developing an End of Waste code for composting of organic residues

One of the key questions in this context is whether different contaminant limits or quality standards should apply for different end uses of the compost products, particularly with respect to potential soil contamination and public health risks.

It is not within the scope of the current study to determine what those contaminant limits should be in Queensland. That is a significant undertaking in itself and one which could have significant and long lasting impact on the Queensland composting industry. While this study has reviewed approaches and standards set by other jurisdictions, both in Australia and overseas, it is also not appropriate to adopt limits from another jurisdiction without ensuring that they are appropriate in the Queensland context.

The interim Biosolids End of Waste code has adopted end use categories based on the NSW Biosolids guidelines which are quite comprehensive and cover most of the potential outlets identified above. The use categories are as follows:

- Unrestricted Use - Home lawns and gardens, Public contact sites, Urban landscaping, Agriculture, Forestry, Soil and site rehabilitation
- Restricted Use 1 - Public contact sites, Urban landscaping, Agriculture, Forestry, Soil and site rehabilitation
- Restricted Use 2 - Agriculture, Forestry, Soil and site rehabilitation
- Not Suitable for Use - Landfill, Land disposal at WWTP

AS4454-2012 does not define and differentiate end uses, as all compliant products are for unrestricted use. It does however define different categories of compost and mulch products (e.g. pasteurised product, compost product, mature compost, etc) which informs a knowledgeable consumer about the potential application of those products. Compost standards in several European countries differentiate product classes according to contaminant levels (e.g. Austria, Czech Republic, Spain, Ireland) or there are various standards that differentiate raw materials, quality and uses. The Compost Quality Assurance Association in Germany for example has established standards for a range of soil amendments including compost (pasteurised, mature, for growing media), digestate (liquid, solid), digestate from energy crops (liquid, solid), products containing biosolids (fully composted, partially composted, blended), as well as ash from wood and plant fired boilers.

As the Australian Standard AS 4454 – 2012 with a single tier of contaminant limits is well established, it would be preferential that future regulations also contain only limits for unrestricted use of compost products, unless there is strong evidence that many compost products are not able to achieve the stipulated limits. Having only one set of contaminant limits and one category of compost would also prevent potential confusion in the market place.

The use of compost products that meet end product contaminant limits for unrestricted use, as stipulated under a new regulatory framework, would be possible anywhere, and be governed only by supply and demand. A new regulatory framework that includes end product quality would also help to restore confidence in the market place.

The annual use of more than 400,000 tonne of biosolids on agricultural land in Queensland demonstrates that there is demand for organic soil amendments in the farming community. Biosolids are readily used by broadacre farmers although this product poses a considerably higher risk to the user with regard to pathogens and contaminants, than does compost that is fit for unrestricted use.

Therefore, the quality of compost would not be an impediment to agricultural use, while the costs associated with using compost might be. In fact, a classic experiment conducted in NSW showed that product costs easily override quality concerns. This is at least true for broadacre farmers, while horticultural growers are much more cautious when using urban derived compost, as risks from physical and chemical contaminants for them is much higher, due to stringent horticultural product quality management and assurance schemes.

Certified organic farmers are equally wary of using urban derived compost products, although acceptable heavy metal limits in compost under the organic farming standard were higher than requirements for biosolids or compost for unrestricted use (Neeson 2014). The reason for this was that animal manures can contain high heavy metal levels. A few years ago, heavy metal limits in compost as stipulated in organic farming standards were aligned with those contained in AS 4454 – 2012. However, organic farmers are not allowed to use biosolids products, regardless whether it is composted or not.

3 COMPOST REGULATION AND STANDARDS

3.1 Composting Regulation in Queensland

Composting in Queensland is an environmentally relevant activity (ERA) meaning that composting facilities are regulated by the state and require an Environmental Authority to operate. Composting falls under ERA 53 which previously focused on composting but has been recently updated to include anaerobic digestion and is now entitled ‘Organic material processing’. This is part of a broader suite of waste-related ERA reforms which are being implemented – the change to ERA 53 commenced in November 2018. Changes to other waste ERAs will follow in July 2019.

The activities which fall under ERA 53 are defined in Schedule 2 of the *Environmental Protection Regulation 2008* and relate to processing, by composting or anaerobic digestion, organic material defined as:

(a) animal matter, including, for example, dead animals, animal remains and animal excreta; or

(b) plant matter, including, for example, bark, lawn clippings, leaves, mulch, pruning waste, sawdust, shavings, woodchip and other waste from forest products; or

(c) organic waste which includes

- *a substance used for manufacturing fertiliser for agricultural, horticultural or garden use*;*
- *animal manure;*
- *biosolids;*
- *cardboard and paper waste;*
- *fish processing waste;*
- *food and food processing waste;*
- *grease trap waste;*
- *green waste;*
- *poultry processing waste;*
- *waste generated from an abattoir;*

[* this category permits processing of wastes and residues from the manufacture of chemical fertilisers, which are typically inorganic chemicals.]

However, organic waste in this context does not include:

- *clinical or related waste;*
- *contaminated soil;*
- *quarantine waste; or*
- *synthetic substances, other than synthetic substances used for manufacturing fertiliser for agricultural, horticultural or garden use;*

There are exemptions from the need to be licensed under ERA 53 including facilities that process less than 200 tonnes per annum; production of mushroom growing substrate; and on-farm composting of agricultural and livestock waste (using materials sourced from that farm or provided free of charge from other farms).

There are currently 96 facilities in Queensland licensed to undertake ERA 53 but a significant number of those are not actively engaged in composting operations. DES has identified 25 EAs which it believes are actively operating composting facilities. Arcadis has reviewed the key conditions within those licenses, particularly those pertaining to odour control, waste acceptance and contamination management.

There are no general constraints on blending or co-processing inorganic materials that are not defined as wastes, unless the EA conditions of a particular facility ban certain materials (see Section 3.1.1). Non-organic materials and regulated wastes cannot generally be processed under ERA 53 but may be permitted under a general 'End of Waste' provision approving the material as a resource and allowing its use under certain conditions. End of Waste codes are discussed further in 3.1.4 below.

A small number of Queensland composting facilities are also licensed under ERA 55 - Regulated Waste Recycling or Reprocessing, which allows them to receive a range of Regulated Waste streams for processing via composting.

Each composting facility operates under an Environmental Authority that sets conditions around how the facility can operate. Those conditions vary significantly, depending on the risk posed by the activities (e.g. facilities that also currently operate under ERA 55 - Regulated waste recycling or reprocessing, are considered higher risk and are more heavily conditioned). However, the age of the approval is also a significant factor - older approvals tend to have more lax conditions than newer EAs, reflecting the fact that the technical understanding of the regulator has evolved over time and approaches have changed to suit current regulatory needs, the state of knowledge, and site-specific risks at the time of issue. It is difficult to change the conditions of an existing EA unless the operator voluntarily agrees or there is a significant change in the approved activities.

In conditioning a new or substantially modified EA to undertake composting under ERA 53, the regulator will reference the ERA 53 *Model Operating Conditions*[1] as the basis for new conditions, which have been published since 2014. The regulator can still apply other conditions to address specific risks associated with a particular site or operation, but the model conditions provide a framework to improve consistency going forward.

The Department has also published a guideline for open windrow composting – the *Guideline for Open windrow composting under environmentally relevant activity 53(a), Organic material processing by composting* (Queensland Composting Guideline) which was first published in 2013. There has been no update of the technical content of the guidelines since they were first released[2]. The guidelines were developed to assist facility operators in assessing and managing environmental risks and to set clear expectations for operators, communities and local governments. The guideline also provides clear advice to DES assessment staff around acceptable solutions to achieve the outcomes-based conditions and to ensure consistency in approval conditions for new open windrow composting facilities.

Other waste related ERA's have been amended through the *Environmental Protection (Waste ERA Framework) Amendment Regulation 2018*[3]. From July 2019, ERA 55 which currently covers recycling and reprocessing of Regulated Wastes, is being broadened to cover '*Other waste reprocessing or treatment*'. It will encompass reprocessing and treatment operations of both general and regulated wastes, which are not already covered by ERA 53 or another waste reprocessing ERA such as ERA 54 for *Mechanical waste reprocessing*, or ERA 61 for *Thermal waste reprocessing and treatment*. Arcadis understands the changes will not impact on conditions within existing EAs.

3.1.1 Waste Acceptance

The waste acceptance conditions in each composting EA vary widely. Some EAs state no or very few specific waste acceptance conditions, which means that the operators rely on the materials identified in the definition of ERA 53 in Schedule 2 of the *Environmental Protection Regulation 2008* as noted above.

Most of the active composting EAs do specify a list of wastes that can be processed which is usually a subset of the list within the ERA 53 definition and may also include materials covered by a general

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[1] https://environment.des.qld.gov.au/assets/documents/regulation/pr-co-composting.pdf

[2] A minor amendment was made to the guideline in November 2018 to incorporate changes brought about by the ERA reform and ensure alignment with regard to the definition of 'allowed' and 'unsuitable' feedstock. There was no change to the technical content in that update.

[3] https://www.legislation.qld.gov.au/view/html/asmade/sl-2018-0198#sec.18

EoW code such as coal ash. A number of EA's specify materials which expressly cannot be processed.

The Queensland Composting Guideline suggests a shift to place the onus on the operator to determine which feedstocks are suitable, noting:

Various organic materials and some inorganic materials may be suitable for use in open windrow composting. The appropriateness of a waste stream for a composting facility is dependent on the capacity of a facility to manage risk factors embodied in the raw materials and to achieve acceptable environmental performance outcomes. It is the responsibility of the operator to ensure that waste materials received onsite for feedstock are suitable for use in composting. It is not suitable to impose conditions on an environmental authority for an open windrow compost operation to indicate acceptable waste inputs.

Eight of the operators licensed under ERA 53 are also licensed to process some Regulated Wastes via composting under ERA 55. Such facilities are generally considered higher risk and operate under additional conditions. For example, most of the ERA 53 + 55 licenses will specify the wastes that *cannot* be processed (e.g. asbestos, clinical waste, general municipal waste, persistent organic compounds).

The license may also specify that any regulated wastes be analysed and must comply with contaminant thresholds specified within the EA and the license may include a condition along the lines '*Regulated waste that is not organic must not be used as feedstock in a ratio of greater than 1 part regulated waste to every 3 parts other material (dry weight).*' Many will also include a statement such as:

> *Wastes can only be accepted and used as feedstock if a risk assessment demonstrates all of the following requirements:*
>
> *The waste is homogeneous.*
>
> *The waste has characteristics or constituents that provide an agronomic or soil conditioning benefit to the finished compost product and does not constitute mere dilution of the waste and its constituents into the product.*
>
> *The waste does not have any characteristics or constituents that adversely affect the composting process.*
>
> *Potential risks from receiving and handling the waste on the site and use of the final products that include the waste have been identified and determined not to present a risk of causing environmental harm.*

The Composting Guidelines state also that the department does not regulate product characteristics such as nutrient levels but the general environmental duty of composters requires that the end product does not contain pathogens or contaminant levels that when applied could cause harm to the environment and human health.

The key finding from the above analysis is there is substantial variation in the degree of conditioning and restrictions on waste acceptance between composting facilities across Queensland, which is a common theme for all EA conditions.

3.1.2 Conditions aimed at controlling odour emissions

The primary condition used in EAs to regulate odour emissions from a composting facility varies in form and wording, but is generally similar to:

Odours or airborne contaminants must not cause environmental nuisance to any sensitive or commercial place.

Or

The release of noxious or offensive odours or any other noxious or offensive airborne contaminants resulting from the activity must not cause a nuisance at any odour sensitive place.

An environmental nuisance is defined in the *Environmental Protection Act 1994* as:

unreasonable interference (or likely interference) with an environmental value caused by

- aerosols, fumes, light, noise, odour, particles or smoke;
- unhealthy, offensive or unsightly conditions caused by contamination; or
- another way prescribed by regulation

In some EAs the location where nuisance must be avoided is defined as any *'nuisance sensitive or commercial place'.* In other instances, nuisance cannot occur *'at or beyond the boundary of the approved place'*.

A sensitive place is typically defined within the EA as:

- a dwelling, residential allotment, mobile home or caravan park, residential marina or other residential
- a motel, hotel or hostel
- a kindergarten, school, university or other educational institution
- a medical centre or hospital
- a protected area under the *Nature Conservation Act 1992*, the *Marine Parks Act 2004* or a World Heritage Area

One EA emphasised the aspect of 'unreasonableness' and public safety, prohibiting release of odour that was *'unreasonably disruptive to public amenity or safety'*.

The likelihood of the activity causing a nuisance is also considered, with some licenses stating that the activity *'must not cause, or be likely to cause, a nuisance …'.*

The conditions noted above are generally outcome based – the expected outcome is stated (e.g. no environmental nuisance at a sensitive place) but it is up to the operator to determine how they will achieve that outcome. That approach is generally favoured by industry and works well where the outcome is measurable and can be readily linked back to that specific operation, but odour nuisance is often not in that category. Where there are multiple sources of odour within an area, it can be challenging to attribute an odour issue to a particular site and such conditions become very difficult to enforce, as has been the experience in the Swanbank precinct near Ipswich.

Licenses for some facilities may also include conditions which seek to mitigate the potential for odour emissions by specifying operational measures to minimise odour formation and release. Such conditions attempt to address the cause of odours in composting and while there is a fine balance between prescriptive conditioning of the operation and managing the environmental impacts, such approaches may be more effective in the specific case of odour nuisance.

An example condition of that type is:

The holder of this approval must undertake all reasonable and practicable measures to minimise odour emissions to the atmosphere from the composting operations. Such measures should include:

a) composting windrow forming and turning and compost windrow remixing operations in calm weather conditions where prevailing winds are not blowing in the direction of nuisance sensitive places;

b) maintenance of any composting windrows and raw material stockpiles in moist conditions;

c) minimisation of the storage time of odorous materials on the site;

d) not allowing composting windrows to turn anaerobic;

e) minimising the storage time of materials that may turn anaerobic;

f) ensuring raw materials and the finished compost product are kept at an oxidised state;

g) monitoring and maintaining the optimal Carbon to Nitrogen ratio and;

h) monitoring and maintaining the optimal temperature in the composting windrows."

Other conditions may require that compost additives with the potential to cause offensive odour must be immediately mixed with other composting materials and formed into windrows or covered with green waste or compost on the day they are received on site.

Such conditions should supplement and support the outcome-based, primary odour control conditions in an EA, rather than replace them. They would drive the operator to ensure that appropriate operational management procedures are in place and give the regulator an opportunity to take action when those procedures are not implemented, which may be easier to prove in some cases than linking an odour event to a particular operator.

Complaints management is also addressed in some EAs. A typical condition of this type states:

The person undertaking the activity to which this approval relates must investigate, or commission the investigation of, any complaints of nuisance caused by noxious or offensive odours upon receipt, or upon referral of a complaint received by the administering authority and, if those complaints are validated, make reasonable adjustments to processes or equipment to prevent a recurrence of odour nuisance."

The composting facility is normally required to record all complaints received.

In reviewing conditions within environmental authorities, it is clear that individual sites have very different odour related conditions, with even the wording of the standard nuisance condition varying across facilities.

3.1.3 Conditions on contamination management

Many of the existing EAs do not have specific conditions relating to management of contamination in compost and soil conditioner products. At least one EA requires application of the classification system within the 1997 NSW Biosolids Guidelines in determining the end use of the compost product.

The exceptions are those composting facilities that also process regulated wastes under ERA 55 and are therefore considered to be subject to greater risk of product contamination. In those cases, the EA tends to specify contaminant thresholds that apply to all compost products as well as requiring that all compost and soil conditioners products comply with the requirements of AS4454, AS4419 and AS3743. These Australian Standards are discussed further in 3.2, but they specify various contaminant thresholds (AS4454 only) as well as conditions around physical characteristics of the products. Products which do not comply with these conditions are considered waste and must be managed appropriately.

The model operating conditions are also silent on product quality and contamination levels. They include some conditions to control contamination issues on site, such as a requirement to provide an impervious barrier under areas used for receiving, mixing, storing and processing materials other than green waste and collecting and storing leachate.

All operators are responsible for complying with the general environmental duty which includes understanding and managing the potential for environmental risk and taking all reasonable and practical measures to prevent environmental harm. The Queensland Composting Guideline notes that:

The department does not regulate product characteristics such as nutrient levels but general environmental duty (GED) requires that the end product does not contain pathogens or contaminant levels that when applied could cause harm to the environment and human health. Producers that sell or distribute a composting product should consider the level of product pathogen or contaminant levels that are appropriate for product end use.

The Guideline does point out that some inorganic feedstock materials may negatively impact the manufacturing process and product quality, but concedes that appropriate risk assessment and analysis of the materials may enable safe incorporation and co-composting / blending in some circumstances, whilst still enabling the manufacture of products that are safe and beneficial for land application. Inorganic materials that were seen as acceptable for inclusion under tightly managed procedures were:

- crushed concrete,

- excavated natural materials such as sand, clay and calcium bentonite,
- some industrial by-products such as foundry sand,
- some coal combustion products such as fly ash,
- biodegradable plastics, and
- some drill wastes in the form of liquids and earthen materials from activities such as water boring, infrastructure drilling and coal seam gas drilling.

The Guideline also advises that the characteristics and risks (contaminants, human and eco-toxicity) of the waste materials and sources should be assessed by the operator before inclusion of these materials into the feedstock mix. As part of the risk assessment process, it is recommended that processors request a certified report or similar from the waste provider about the waste received, that details the employed sampling regime and test results that determine chemical, physical and biological properties of the waste material as well as the potential for human or eco-toxicity. It is acknowledged that industrial waste streams can be highly heterogeneous in composition and variable between loads and are often complex mixtures of compounds and contaminants, both organic and inorganic, which makes an assessment of associated risks much more difficult and resource intense by increasing not only the frequency of sampling and analysing but also the number of parameters that are analysed.

Anecdotally, Arcadis is aware that some compost operators who are not specifically required to analyse their feedstocks and products under their EA, take a rather lax approach to managing their general environmental duty around product contamination risks. Some will undertake only very limited and occasional analysis of incoming feedstocks and outgoing products, and do not routinely require certified analysis reports from their customers.

3.1.4 End of Waste Codes

The Queensland Government replaced the beneficial use approval framework with the new end of waste (EOW) framework in November 2016, which aims to recognise the value of wastes as resources by providing a process for acknowledging low risk materials and allowing them to be utilised outside the waste regulatory framework, leading to development of new markets for recovered waste materials (Department of Environment and Science 2016). The new framework aims to provide certainty about when, and under what circumstances, a waste ceases to be waste and is considered a resource and to increase business opportunities for waste generators, waste processors and business receiving recovered material from within Queensland. The Government’s EOW Guideline aims to remove impediments associated with the management of waste so that there will be a greater emphasis for waste producer's to ensure that their waste is a resource and suitable for being used in the market.

Since the new framework came into force, seven such end of waste codes have been published for the following materials which would allow their use in compost or blending with soils, under certain conditions:

- Biosolids (interim)
- Coal seam gas drilling muds
- Fertiliser wash water
- Sugar mill by-products (filter mud, boiler ash)
- Foundry sand
- Coal combustion products

Several others are still in the process of being developed. All resources covered by the above end of waste codes except for oyster shells can be utilised as feedstocks into composting or used as soil conditioners by direct land application. Therefore, relevant contaminant limit values that are stipulated in the various end of waste codes are presented and discussed below (over and above the statement that *the resource must not have any properties nor contain any other contaminants at concentrations which may cause environmental harm when used in accordance with the end of waste code*).

The **end of waste code for fertiliser wash water and slurry** (Department of Environment and Science 2018c) stipulates that these materials can be classified as a resource if they do not contain more than the following levels of Total Petroleum Hydrocarbons (TPH):

- (C6 – C9) – 100 mg/kg dm,
- (C10 – C15) – 100 mg/kg dm,
- (C16 – C34) – 300 mg/kg dm,
- (>C34 – C36) – 500 mg/kg dm.

The **end of waste code for sugar mill by-products** (Department of Environment and Science 2018d) stipulates maximum plant nutrient levels for nitrogen, phosphorous, potassium, sulphur, calcium and magnesium. The same plant nutrients are typically also found in composts, manures and mineral fertilisers, at similar or higher levels compared with those stipulated as maximum concentrations in sugar mill by-products.

The **end of waste code for foundry sand** (Department of Environment and Science 2018e) stipulates that foundry sands can be classified as a resource and used for the production of compost, mulch, soil conditioner or general purpose soil if they do not contain higher contaminant concentrations than those shown in Table 4 below.

Table 4: Maximum contaminant limits (mg/kg dm) for foundry sand to be classified as a resource (Source: Department of Environment and Science 2018e)

Contaminant	Unbound applications and manufacturing of compost, mulch and soil conditioner	Unrestricted use and manufacturing of general purpose soil
Arsenic (As)	40	20
Cadmium (Cd)	1	1
Chromium (Cr) III	100	100
Chromium (Cr) VI	1	1
Copper (Cu)	100	100
Lead (Pb)	150	30
Mercury (Hg)	1	1
Nickel (Ni)	60	60
Selenium (Se)	20	5
Silver (Ag)	40	10
Zinc (Zn)	200	200
Phenols (non-halogenated)	100	60
Phenols (halogenated)	1	1
Benzene	1	1
Fluoride	450	200
Formaldehyde	10	10
Triethylamine (TEA)*	1	1

Contaminant	Unbound applications and manufacturing of compost, mulch and soil conditioner	Unrestricted use and manufacturing of general purpose soil
Electrical conductivity	2,000 µS/m	1,000 µS/m
pH range	5 - 10 (pH units)	5 - 10 (pH units)

*Triethylamine (TEA) is to be monitored when TEA is used in the foundry process. It is not a requirement to monitor TEA for the resource produced from foundries that do not use TEA in their process.

The **end of waste code for coal combustion products** (Department of Environment and Science 2018f) stipulates that coal combustion products can be classified as a resource and utilised as a soil ameliorant if they do not contain higher contaminant concentrations than those shown in Table 5 below.

Table 5: Maximum contaminant limits (mg/kg dm) for coal combustion products to be classified as a resource (Source: Department of Environment and Science 2018f)*

Contaminant	Soil ameliorant and land applications
Arsenic (total)	20
Beryllium	60
Boron	10**
Cadmium	1
Chromium (total)	100
Chromium (III)	100
Chromium (VI)	1
Cobalt	100
Copper	100
Lead	50
Mercury	1
Molybdenum	10
Nickel	60
Selenium	5
Zinc	200
Electrical conductivity	10,000 (µS/cm)
pH	5 – 12.5 (pH units)

* measured using referenced test methods
** measured using hot $CaCl_2$ method

The **end of waste code for coal seam gas drilling mud** (Department of Environment and Science 2018g) stipulates that coal seam gas drilling mud can be classified as a resource and utilised as feedstock for composting, by blending it with finished compost or in the manufacturing of general purpose soils if they do not contain higher contaminant concentrations than those shown in Table 6 below.

Table 6: Maximum contaminant limits (mg/kg dm) for coal seam gas drilling mud to be classified as a resource (Source: Department of Environment and Science 2018g)

Contaminant	Manufacturing compost, mulch or soil conditioners		Manufacturing general purpose soil
	Use as feedstock in manufacturing compost	*Added to finished compost to create a final product*	
Arsenic (As)	80	80	20
Barium (Ba)	8,000	8,000	2,000
Boron (B)	20	20	5
Cadmium (Cd)	4	4	1
Chromium (Cr III)	400	400	100
Chromium (Cr VI)	4	4	1
Copper (Cu)	600	600	150
Lead (Pb)	600	600	150
Mercury (Hg)	4	4	1
Nickel (Ni)	240	240	60
Selenium (Se)	20	20	5
Silver (Ag)	40	40	10
Vanadium (Va)	400	400	100
Zinc (Zn)	1,200	1,200	300
Total Petroleum Hydrocarbons C6-C9	400	100	100
Total Petroleum Hydrocarbons C10-C36	4,000	1,000	1,000
Benzene	4	1	1
Phenols (non-halogenated)	240	60	60
Phenols (halogenated)	4	1	1

Comparison of maximum contaminant limits stipulated in the Australian Standard for Composts, soil conditioners and mulches with the various Queensland End of Waste Codes (Table 7) shows that, by and large, contaminant limits for unrestricted use are relatively well aligned to AS4454 and that, due to the alignment with the NSW Biosolids Guidelines, the contaminant monitoring regime in Queensland is comparatively comprehensive. The assumed contaminant reduction rate during composting / mixing ratio of coal seam gas drilling mud with mature compost of 1:4 seems very static. The establishment of maximum nutrient levels (nitrogen, phosphorous, potassium) for sugar mill by-products raises the question whether such limits might or should apply also to other recycled organic products in the future.

Table 7 Comparison of maximum contaminant limits (mg/kg dm) stipulated in Queensland End of Waste Codes and the Australian Standard for Composts, Soil Conditioners and Mulches (AS 4454-2012)

Contaminant	AS4454 - 2012 Compost Standard	Queensland End of Waste Codes											
		Biosolids			Fertiliser wash water and slurry	Sugar Mill By-products		Foundry Sand		Coal combustion products	Coal seam gas drilling mud		
		Grade A	Grade B	Grade C		Fliter mud and filter mud/boiler ash blend mixture (% as dry product)	Boiler ash (% as dry product)	Unbound applications and Manufacturing of compost, mulch and soil conditioner	Unrestricted use and Manufacturing of general purpose soil	Soil ameliorant and land applications	Use as feedstock in compost manufacturing	Added to finished compost to create a final product	Manufacturing general purpose soil
Aldrin	0.02	0.02	0.2	0.5									
Arsenic	20	20	20	20				40	20	20	80	80	20
Barium (Ba)											8000	8000	2000
Benzene								1	1		4	1	1
Beryllium										60			
BHC	0.02	0.02	0.2	0.5									
Boron	100									10	20	20	5
Cadmium	1.0	3	5	20				1	1	1	4	4	1
Chlordane	0.02	0.02	0.2	0.5									
Chromium	100	100	250	500				100	100	100	400	400	100
Cobalt										100			
Copper	150	100	375	2000				100	100	100	600	600	150

Contaminant	AS4454 - 2012 Compost Standard	Queensland End of Waste Codes											
		Biosolids			Fertiliser wash water and slurry	Sugar Mill By-products		Foundry Sand		Coal combustion products	Coal seam gas drilling mud		
		Grade A	Grade B	Grade C		Fliter mud and filter mud/boiler ash blend mixture (% as dry product)	Boiler ash (% as dry product)	Unbound applications and Manufacturing of compost, mulch and soil conditioner	Unrestricted use and Manufacturing of general purpose soil	Soil ameliorant and land applications	Use as feedstock in compost manufacturing	Added to finished compost to create a final product	Manufacturing general purpose soil
Cresols													
Cyanide (free)													
DDT/DDD/DDE	0.5	0.5	0.5	1									
Dieldrin		0.02	0.2	0.5									
Fluoride								450	200				
Formaldehyde								10	10				
HCB	0.02	0.02	0.2	0.5									
Heptachlor	0.02	0.02	0.2	0.5									
Lead	150	150	150	420				150	30	50	600	600	150
Lindane	0.02	0.02	0.2	0.5									
Manganese													
Mercury	1.0	1	4	15				1	1	1	4	4	1
Molybdenum										10			
Nickel	60	60	125	270				60	60	60	240	240	60
Nitrogen						1.7	0.15						

Contaminant	AS4454 - 2012 Compost Standard	Queensland End of Waste Codes											
		Biosolids			Fertiliser wash water and slurry	Sugar Mill By-products		Foundry Sand		Coal combustion products	Coal seam gas drilling mud		
		Grade A	Grade B	Grade C		Fliter mud and filter mud/boiler ash blend mixture (% as dry product)	Boiler ash (% as dry product)	Unbound applications and Manufacturing of compost, mulch and soil conditioner	Unrestricted use and Manufacturing of general purpose soil	Soil ameliorant and land applications	Use as feedstock in compost manufacturing	Added to finished compost to create a final product	Manufacturing general purpose soil
PAHs Total	ND	ND	0.3	1									
Pentachlorophenol													
Phenols (non-halogenated)								100	60		240	60	60
Phenols (halogenated)								1	1		4	1	1
Phosphorus						1.9	0.41						
Potassium						0.76	1.4						
Selenium	5	5	8	50				20	5	5	20	20	5
Silver (Ag)								40	10		40	40	10
Sulphur						0.15	0.19						
Triethylamine (TEA)								1	1				
TPH (C6-C9) (C10-C15) (C16-C34) (>C34-C36)					100 100 300 500						400 4000 (C10-C36)	100 1000 (C10-C36)	100 1000 (C10-C36)
Total Organic Fluorine		0.39	0.39	0.39									

Contaminant	AS4454 - 2012 Compost Standard	Queensland End of Waste Codes												
		Biosolids			Fertiliser wash water and slurry	Sugar Mill By-products		Foundry Sand		Coal combustion products	Coal seam gas drilling mud			
		Grade A	Grade B	Grade C		Fliter mud and filter mud/boiler ash blend mixture (% as dry product)	Boiler ash (% as dry product)	Unbound applications and Manufacturing of compost, mulch and soil conditioner	Unrestricted use and Manufacturing of general purpose soil	Soil ameliorant and land applications	Use as feedstock in compost manufacturing	Added to finished compost to create a final product	Manufacturing general purpose soil
Vanadium (Va)											400	400	100
Zinc	300	200	700	2500				200	200	200	1200	1200	300

Blank cells indicate no limit specified

3.1.5 Biosolids

Compost and biosolids are different products that are governed by different regulatory regimes, and while there are similarities, the products are not directly comparable in terms of their potential environmental risks. Biosolids have a long history of beneficial use via land application and well developed regulatory standards around their use. The following section provides an overview of biosolids guidelines as the principles and categories used for classifying biosolids and determining appropriate end use options might be informative for designing future regulations and guidelines regarding contamination and use of compost products.

In Queensland, biosolids are classified as 'trackable regulated waste' (Waste Code K130), which means transportation, processing and use via land application is governed by regulations and guidelines. A Beneficial Use Approval (BUA) was previously in place, allowing the use of biosolids via direct land application, under certain conditions. The 'General BUA for Biosolids' has been replaced with the interim 'End of Waste Code Biosolids' (Department of Environment and Science 2018a) as of 1 January 2019. However, the current version of the End of Waste Code is only an interim document to allow time for due consideration of submissions received during the public consultation period held at the end of 2018.

Both the previous BUA's and the new End of Waste Code outline the operational and regulatory structure specific to Queensland, while the detailed quality and end use requirements and specifications are generally derived from the NSW Environment Protection Authority's *Environmental Guidelines: Use and Disposal of Biosolids Products* (NSW EPA, 2000).

The overall biosolids classification is determined by two factors - the level of contamination and stabilisation:

- The contaminant grade (A – E) is determined by the concentration of elements (heavy metals) or chemicals that accumulate in the biosolids stream and can cause negative environmental and health impacts. The guidelines recognise only specific metals and halogenated organics (almost all pesticides). Other organic contaminants such as endocrine disrupters, polyaromatic hydrocarbons, detergents, and plasticisers are not recognised. The interim End of Waste Code Biosolids that is relevant for Queensland stipulates also maximum allowable total organic fluorine content, which has been set at 0.39 mg/kg dry mass across all quality grades.
- The stabilisation grade (A – C) is determined by the level of pathogen and vector attraction reduction achieved through sewage / biosolids processing. The pathogen reduction criteria is based both on approved processes, as well as an initial (Enteric viruses and Helminth ova) and long-term (E.coli, Faecal coliforms, and Salmonella) testing regime. "Vector attraction" actually determines biosolids stability, commonly measured via oxygen uptake rate, since it evaluates the degree to which the biosolids will further degrade in the environment. Grade A is pathogen free and will not degrade further; Grade B is stable, but may contain pathogens; Grade C is putrescible.

The biosolids classification system relates to the manner in which biosolids products may be used for land management purposes (Table 8).

Table 8: Biosolids classification and allowable land use (Source: NSW EPA 2000)

Biosolids Classification	Minimum Quality Grades Contamination	Stability	Allowable Land Application Use
Unrestricted Use	A	A	Home lawns and gardens, Public contact sites Urban landscaping, Agriculture, Forestry Soil and site rehabilitation
Restricted Use 1	B	A	Public contact sites, Urban landscaping, Agriculture Forestry, Soil and site rehabilitation
Restricted Use 2	C	B	Agriculture, Forestry, Soil and site rehabilitation
Restricted Use 2	D	B	Forestry, Soil and site rehabilitation

Biosolids Classification	Minimum Quality Grades		Allowable Land Application Use
	Contamination	Stability	
Not Suitable for Use	E	C	Landfill, Land disposal at WWTP

Table 9 overleaf also compares the Queensland End of Waste code limits for biosolids with those in other states and with AS4454. It shows relatively good alignment in most parameters, although some states allow higher limits for some applications (e.g. Victoria's grade C2).

Table 9: Comparison of maximum contaminant limits (mg/kg dm) stipulated in the Australian Standard for Composts, Soil Conditioners and Mulches (AS 4454-2012) compared to various state based biosolids thresholds

Contaminant	AS4454 - 2012 Compost Standard	QLD EoW Code			Other State Biosolids Guidelines										
		Biosolids			NSW EPA				EPA VIC		EPA WA		EPA SA		
		Grade A	Grade B	Grade C	Grade A	Grade B	Grade C	Grade D	Grade C1	Grade C2	Grade C1	Grade C2	Grade A	Grade B	Grade C
Aldrin	0.02	0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5					
Arsenic	20	20	20	20	20	20	20	30	20	60	20	30			
Barium (Ba)															
Benzene															
Beryllium															
BHC	0.02	0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5					
Boron	100														
Cadmium	1.0	3	5	20	3	5	20	32	1	10	1.0	20	1	11	20
Chlordane	0.02	0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5	0.02	0.5	0.02	0.2	0.5
Chromium	100	100	250	500	100	250	500	600	400	3000	1.0	1.0	1	1	1
Cobalt															
Copper	150	100	375	2000	100	375	2000	2000	100 (150)	2000	100 (150)	2500	100	750	2500
Cresols															
Cyanide (free)															
DDT/DDD/DDE	0.5	0.5	0.5	1	0.5	0.5	1.0	1.0	0.5	1.0					
Dieldrin		0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5	0.02	0.5	0.02	0.2	0.5
Fluoride															
Formaldehyde															

HCB	0.02	0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5		
Heptachlor	0.02	0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5		
Lead	150	150	150	420	150	150	420	500	300	500	200	420
Lindane	0.02	0.02	0.2	0.5	0.02	0.2	0.5	1.0	0.05	0.5		
Manganese												
Mercury	1.0	1	4	15	1	4	15	19	1	5	1.0	15
Molybdenum												
Nickel	60	60	125	270	60	125	270	300	60	270	60	270
Nitrogen												
PAHs Total	ND	ND	0.3	1	0.30	0.3	1.0	1.0	0.2	1.0		
Pentachlorophenol												
Phenols (**non**-halogenated)												
Phenols (halogenated)												
Phosphorus												
Potassium												
Selenium	5	5	8	50	5	8	50	90	3	50	3	50
Silver (Ag)												
Sulphur												
Triethylamine (TEA)												
TPH (C6-C9) (C10-C15) (C16-C34) (>C34-C36)												
Total Organic Fluorine		0.39	0.39	0.39								
Vanadium (Va)												

Zinc	300		200	700	2500	200	700	2500	3500	200 (300)	2500	200 (300)	2500	200	1400	2500

Blank cells indicate no limit specified

3.2 Compost Standards

3.2.1 Australia

Most State Governments in Australia have published composting guidelines. Composting guidelines published in Queensland (Department of Environment and Heritage Protection 2013) and NSW (NSW Department of Environment and Conservation 2004) primarily address siting, operational and regulatory matters. These guidelines deal with feedstock quality aspects to some extent but do not stipulate contaminant quality requirements of finished products. This however is done in the Victorian (EPA Victoria 2017) and South Australian Composting Guidelines (EPA South Australia 2013) by including contaminant limits for compost products, which in fact are aligned with limits stipulated in the *Australian Standard for Composts, Soil Conditioners and Mulches (AS 4454 - 2012).*

The Australian Standard is the benchmark standard for compost quality in Australia and specifies minimum processing standards for the elimination of pathogens and weeds, as well as reporting requirements on a range of analytical tests for both composted and pasteurised products. It is the key reference for industry when assessing and classifying compost quality.

AS4454 – 2012 is a voluntary quality standard, as are the associated standards for *Soils for Landscaping and Garden Use* (AS 4419 – 2018) and *Potting Mixes* (AS 3743 – 2003). The testing of compost products against some or all quality requirements stipulated in AS 4454 - 2012 is entirely at the discretion of individual composting companies, as there is no legal requirement to do so (unless an operators EA directly references the standard, as some do). In fact, in Section 2 General Requirements – Containment of Disease, the AS 4454 – 2012 document states that *it is not appropriate for regulators to specify compliance with this Standard as a mandatory requirement for facility operations, licensing or application to land of production outputs*. Nevertheless, numerous state regulators (including Queensland) do reference the standard in license conditions for composting facilities.

AS4454 – 2012 presents minimum requirements for physical, chemical and biological product properties, which provide assurance for users that certified products are free of viable plant propagules and will not cause adverse effects if used appropriately. In addition, products certified to AS4454 – 2012 quality requirements must also comply with State or Federal chemical and organic contaminant guidelines for products suitable for unrestricted use in land application of products derived from organic wastes, compostable organic materials or biosolids, whichever is the more stringent.

AS4454 specifications regarding contaminant limits and pathogen reduction requirements are aligned with guidelines for use and disposal of Grade A biosolids products for unrestricted use in the NSW Biosolids Guidelines (Section 3.1.5) but allow higher copper and zinc concentrations (Table 10) where this can be justified by agronomic considerations and where none of the other metal limits are exceeded. The interim Queensland End of Waste Code Biosolids, did not follow this lead but maintained lower limits for copper and zinc as stipulated in the NSW Biosolids Guidelines.

AS4454 – 2012 differentiates products and minimum quality requirements according to product maturity (pasteurised product – composted product – mature compost) and particle size distribution (soil conditioner – fine mulch – coarse mulch). It defines nine broad product types, three of which are of particular relevance for this report: pasteurised soil conditioner, composted soil conditioner, and mature composted soil conditioner.

Unlike biosolids quality and end-use guidelines and codes, the compost standards do not differentiate between various contaminant classes and allowable uses, but stipulate only one class of allowed contamination through impurities, pathogens, heavy metals and organic contaminants for composted products, and that is for unrestricted use. Impurity and contaminant limits for unrestricted use as specified for AS4454 – 2012 are shown in Table 10. This implies that, if an EA does not stipulate end product contaminant criteria, and if the allowable land use criteria for biosolids (Table 8) are assumed to apply, compost that exceeds AS4454 – 2012 contaminant requirements for unrestricted use, could still be utilised in line with biosolids restricted use 1, 2 or 3 specifications, which essentially means everywhere except for home lawns and gardens. The fact is that only a small proportion of compost products made from urban derived residues is utilised on home lawns and gardens. Following this line of argument, most compost products would not have to comply with AS4454 – 2012 contaminant requirements for unrestricted use.

Table 10: Impurity, pathogen, heavy metal and organic contaminant limits for compost products for unrestricted use according to AS 4454 – 2012

Product Characteristic	Unit	Compost Quality Criteria AS 4454
Impurities		
Glass, metal and rigid plastic	% dm	≤ 0.5
Plastic – light, flexible or film	% dm	≤ 0.05
Stones and lumps of clay	% dm	≤ 5
Pathogens#		
Faecal coliforms	MPN/g	< 1000
Salmonella spp		absent in 50 g dry weight equivalent
Heavy Metals#		
Arsenic	mg / kg dm	20
Boron*	mg / kg dm	100
Cadmium	mg / kg dm	3
Chromium (Total)	mg / kg dm	100
Copper	mg / kg dm	100 (150)**
Lead	mg / kg dm	150
Mercury	mg / kg dm	1
Nickel	mg / kg dm	60
Selenium	mg / kg dm	5
Zinc	mg / kg dm	200 (300)**
Organic Contaminants#		
DDT/DDE/DDD	mg / kg dm	0.5
Aldrin	mg / kg dm	0.02
Dieldrin	mg / kg dm	0.02
Chlordane	mg / kg dm	0.02
Heptachlor	mg / kg dm	0.02

Product Characteristic	Unit	Compost Quality Criteria AS 4454
HCB	mg / kg dm	0.02
Lindane	mg / kg dm	0.02
BHC	mg / kg dm	0.02
PCBs^	mg / kg dm	Not detected

[#] Pathogen, heavy metal and organic contaminant limits are largely aligned with NSW Biosolids Guideline values for Grade A product

* Testing for boron is generally only necessary for products that are based on seaweed, seagrass or unseparated solid waste that have a component of cardboard packaging.
** A product that contains levels of copper between 100 mg/kg and 150 mg/kg and/or zinc between 200 mg/kg and 300 mg/kg whilst not exceeding the limit values for all other contaminants, shall provide a warning label in accordance with labelling requirements.
^ The detection limit for PCBs shall be 0.2 mg/kg

As noted above, AS4454 is a voluntary standard. Most composters will follow selected elements of AS4454 and may claim to comply with the standards, but actually achieving third party certification against the standards imposes significant additional costs which are not considered viable for most operators. Most compost, soil and potting mix manufacturers base their decision whether to certify or not certify their products against Australian Standard requirements, on commercial considerations, i.e. whether the Standards Mark is recognised and valued in the market place and whether or not a price premium can be achieved for certified products.

For the majority of composters, this is not worth their while unless they are selling bagged products for retail sale and niche markets. There are very few third-party certified bulk compost, mulch and soil products.

Wilkinson *et al*. (2002) described four methods which compost manufacturers can use to demonstrate compliance to the Australian Standard, namely

- *Product Certification (Third Party Assessment)*
  The manufacturer's capability to produce a product consistently to the Standard is assessed on an ongoing basis by an independent third party certification body.
- *Quality System Certification (Third Party Assessment)*
  The manufacturer's quality management system is assessed against one of the international standards that describe models for quality assurance (AS/NZS ISO 9001 to 9003).
- *Customer - Supplier Assessment (Second Party Assessment)*
  A purchaser of a product may wish to assess a supplier to ensure that the product they buy meets their particular requirements. This would be a commercial arrangement between purchaser and supplier.
- *Self-Declaration (First Party Assessment)*
  The manufacturer declares that the products and/or production methods meet recognised standards. The manufacturer can state on labels and brochures that a product complies with the relevant standard, but since it is not a 'third party assessment', no recognisable symbol such as the Standards logo can be applied.

It is generally recognised that quality assurance schemes incorporating regular independent third party assessment and product or system certification provide the highest level of credibility. At present, the vast majority of bulk compost producers in Queensland and indeed the whole of Australia only offer the weakest form of guarantee, ‘Self Declaration’, or none at all, and certainly not third party auditing and certification (Hazeldine 2019). The acceptability to customers of this approach depends on the reputation and past performance of the manufacturer. However, as compost suppliers increasingly target commercial agricultural and horticultural markets where food safety and biosecurity requirements become ever tighter, it is expected that the pressure will grow for compost production systems and compost products to be independently audited and certified by a third party.

The Australian Standard for composts, soil conditioners and mulches (AS 4454 – 2012) is often criticised by a range of stakeholders, including composting businesses themselves. However, it must not be forgotten that it provides only minimum requirements for properties of composts, soil conditioners and mulches in order to facilitate the beneficial recycling and use of compostable materials with minimal adverse impact on environment and public health, and that it does not prevent individual composters or the composting industry as a whole from producing superior products with low contaminant and impurity levels that are fit for purpose and deliver the outcomes promised to users.

3.2.2 Overseas

In order to provide a comparison to AS 4454 – 2012 end product quality requirements, Annexe H in Appendix B provides information about compost quality assurance schemes in various European countries and Annex F about compost use regulations in these countries. Compost quality standards in several European countries differentiate product classes (e.g. A+, A, B) according to contaminant levels (e.g. Austria, Czech Republic, Spain and Ireland) or there are a range of different standards with sub-categories that are differentiated depending on raw materials used, product type and end-uses. The Compost Quality Assurance Association in Germany for example has established the following quality standards and administers associated quality assurance programs:

1. compost (pasteurised, mature, component in growing media),
2. digestate from organic residues (liquid, solid),
3. digestate from energy crops (liquid, solid),
4. products containing biosolids (fully composted, partially composted, blend containing raw biosolids),
5. biosolids for direct land application, and
6. ash from wood and plant fired boilers.

Table 11 provides a comparison of impurity, pathogen, heavy metal and organic contaminant limits according to compost quality standards or regulatory requirements in Australia and several other countries where organics recycling activities are widespread. The comparison shows that AS 4454 compost quality requirements concerning impurities, pathogens and heavy metals are similar to overseas requirements, except for the very stringent requirements the Austrian regulation demands for grade A+ compost, which is for organically certified farms. However, it can be also seen that AS 4454 heavy metal limits are significantly lower than those for Canadian B grade compost (restricted use) and those that are required in the USA. Biosolids quality requirements for land application were used both in the USA and Australia to establish contaminant limits for compost products. Probably the only difference is that the risks posed by contaminants in organic soil amendments are seen differently in the USA and Australia. It is worth noting that the 2012 version of the Australian Compost Standard stipulated for the first time contaminant limits, which reflected more or less limits contained in the NSW Biosolids Guidelines for unrestricted use. Previous AS 4454 versions just referred to Federal or State regulations, which generally were biosolids guidelines or regulations.

When it comes to organic contaminant limits, the comparison in Table 11 shows that overseas compost standards and regulations (for regular compost) tend to not stipulate limits for organic contaminants or only very sparsely. The Italian standards for example contain a limit for PCB when biosolids are co-composted. The German standard for regular compost (no 1 in the above list) contains limits for PFOA + PFOS, and also for total dioxine and dl-PCB, while standards for biosolids based compost require testing for various other contaminants (Bundesgütegemeinschaft Kompost, undated).

The US EPA Part 503 Rule does not contain limits for organic contaminants. Limits were considered when the regulation was developed (before 1992) but in the end no limits were included because the results of the sewage sludge survey in combination with the risk assessment to determine what limits would be required showed that none of the biosolids generated at the time would fall above those limits (Brown, 2019). A contributing factor to this decision was the fact that most of the compounds that were being considered were banned by that time. In the 1990’s, after the US EPA Part 503 Rule was passed, a risk assessment of biosolids contamination with dioxins came to the same conclusion, i.e. not to establish limits and not to monitor this contaminant.

Table 11: Impurity, pathogen, heavy metal and organic contaminant limits for compost products in Australia and selected countries

Product Characteristic	Country & Compost Quality Standard / Ordinance						
	Australia AS 4454	**Europe** Quality Assurance Scheme a)	**Austria** Compost Ordinance b)	**Italy** CIC c)	**UK** PAS 100 d)	**USA** EPA Part 503 Rule e)	**Canada** Guide Compost Quality f)
Impurities g)							
Glass, metal and rigid plastic [% dm]	≤ 0.5	≤ 0.5 (all impurities)		≤ 0.5 (plastic, glass metals > 5mm)	≤ 0.25 with ≤ 0.12 plastic		≤ 1/2 pieces foreign matter > 25 mm in 500 ml
Plastic – light, flexible or film [% dm]	≤ 0.05						
Stones and lumps of clay [% dm]	≤ 5			≤ 5	≤ 8 h) (non-mulch) ≤ 10 h) (mulch)		
Pathogens							
Faecal coliforms [MPN/g]	< 1000			< 1000 (*E. coli*)	< 1000 (*E. coli*)		< 1000
Salmonella spp	absent in 50 g dry weight equiv.	absent in 25 g dry mass		absent in 25 g	absent in 25 g fresh mass		absent in 4 g dry mass
Heavy Metals [mg/kg dm]							
Arsenic	20					41	75 (B) 13 (A)
Boron	100						

Product Characteristic	Country & Compost Quality Standard / Ordinance						
	Australia AS 4454	**Europe** Quality Assurance Scheme [a]	**Austria** Compost Ordinance [b]	**Italy** CIC [c]	**UK** PAS 100 [d]	**USA** EPA Part 503 Rule [e]	**Canada** Guide Compost Quality [f]
Cadmium	3	1.3	3.0 (B) 1.0 (A) 0.7 (A+)	1.5	1.5	39	20 (B) 3 (A)
Chromium (Total)	100	60	250 (B) 70 (A) 70 (A+)	0.5 (Cr VI)	100		1060 (B) 210 (A)
Copper	100 (150) [i]	110 (300) [j]	500 (B) 150 (A) 70 (A+)	230	200	1500	750 (B) 400 (A)
Lead	150	130	200 (B) 120 (A) 45 (A+)	140	200	300	500 (B) 150 (A)
Mercury	1	0.45	3.0 (B) 0.7 (A) 0.4 (A+)	1.5	1	17	5 (B) 0.8 (A)
Nickel	60	40	100 (B) 60 (A) 25 (A+)	100	50	420	180 (B) 62 (A)
Selenium	5					100	14 (B) 2 (A)
Zinc	200 (300) [i]	400 (600) [j]	1800 (B) 500 (A) 200 (A+)	500	400	2800	1850 (B) 700 (A)

Product Characteristic	Country & Compost Quality Standard / Ordinance						
	Australia AS 4454	**Europe** Quality Assurance Scheme a)	**Austria** Compost Ordinance b)	**Italy** CIC c)	**UK** PAS 100 d)	**USA** EPA Part 503 Rule e)	**Canada** Guide Compost Quality f)
Organic Contaminants [mg/kg dm]							
DDT/DDE/DDD	0.5						
Aldrin	0.02						
Dieldrin	0.02						
Chlordane	0.02						
Heptachlor	0.02						
HCB	0.02						
Lindane	0.02						
BHC	0.02						
PCBs	Not detected			0.2 k)			

a) European Compost Network, 2018
b) Austrian Ministry for Agriculture and Forestry, 2010
c) Italian Compost and Biogas Association, 2018
d) BIS, 2011
e) US EPA, 1994
f) Canadian Council of Ministers of the Environment, 2005
g) see Appendix B, Annex B for impurity limits in compost in various European countries
h) stones > 4mm
i) see Table 10
j) Values exceeding 110 mg Cu kg^{-1} and 400 mg Zn kg^{-1} must be declared
k) For compost made from feedstock that contains up to 30% biosolids

Several of the European compost standards and regulations are very comprehensive and go well beyond the stipulation of end product quality requirements, and could be easily seen and used as End-of-Waste codes. This is made very clear in the European Compost Network's quality assurance framework which specifically references End of Waste Criteria. The Compost Quality Protocol for England, Wales and Northern Ireland represents in fact *end of waste criteria for the production and use of quality compost from source-segregated biodegradable waste* (WRAP 2012).

Chapter 3 – key findings and recommendations

- Compost products and associated products such as soil conditioners, soil mixes and potting mixes, are used in a wide range of applications, each with differing degrees of exposure and risk to human health and the environment.
- Waste acceptance conditions in existing EAs vary widely with some licences having no or very few specific waste acceptance conditions stated, which limits the control over feedstock contaminants. There is a general need for tighter regulation of feedstocks and inconsistency in regulation between otherwise similar sites creates an un-level playing field commercially (real or perceived) which may be a barrier to investment in upgrades and improvements.
- Contaminant limits in the Australian Standard for composts (AS 4454 – 2012) and international (European) standards for composts and digestates do not vary markedly. Yet the legal / regulatory status of compost quality criteria specified in overseas standards is often very different to the situation in Australia, as is the organisational structure. In Australia, very little or no bulk compost / soil conditioning / mulch product is independently audited and accredited against AS 4454 – 2012 quality requirements, with bagged products typically only subjected to this. In that respect, the self-assessment option for composters has detrimental effects, as it undermines production of good quality compost, and trust in the market place.
- The Australian Standard for composts, soil conditioners and mulches (AS 4454 – 2012) provides minimum requirements for the physical, chemical and biological properties of composts, soil conditioners and mulches in order to facilitate the beneficial recycling and use of compostable materials with minimal adverse impact on environmental and public health, by avoiding biosecurity and phytotoxicity risks associated with inappropriate product manufacture or selection. AS 4454 does not prevent any composter from producing superior compost free of contaminants and impurities that smells earthy as it should and delivers crop yields significantly higher than without use of compost. The standard is not the problem, the lack of clear regulations and the current business model of many composters (making most of the profit on processing liquid and regulated wastes) are the issue.
- At present, the vast majority of bulk compost producers in Queensland and indeed Australia, only offer the weakest form of guarantee under AS 4454 - 'Self Declaration', or none at all, and certainly not third party auditing and certification. The acceptability to customers of this approach depends on the reputation and past performance of the manufacturer, and requires the customer to be informed of the risks which they often are not. However, as compost suppliers increasingly target high value commercial agricultural and horticultural markets where food safety and biosecurity requirements become ever tighter, it is expected that the pressure will grow for compost production systems and compost products to be independently audited and certified by a third party.
- The End of Waste codes, although currently limited in number, provide good guidance and control over contaminants within defined waste streams that may be used in composting. This suggests that EoW codes could be an effective (existing) tool to better regulate high risk feedstocks.

Recommendations – Standards and Regulations

- If the government were to consider differentiating and categorising compost products and/or end uses, it would be beneficial to align with existing definitions and categories within standards or guidelines that are well known to industry such as AS4454, the Soil Health Investigation Levels or biosolids standards
- Further work is needed to establish the suitability of the AS4454/ Biosolids organic contaminant limits to the current situation with respect to organic waste recycling. Most of these chemicals have been phased out for many years and studies overseas show that they are usually virtually absent in

Chapter 3 – key findings and recommendations

compost products. There are numerous contaminants not included in these standards which could be relevant.

- Further work is also needed to collate data on organic contaminants (and other characteristics) in compost products from a wide variety of sources to establish what proportion of products exceed the AS4454/ Biosolids limits, and which compounds are causing issues. Without sufficient data, it is impossible to have an informed discussion and to make informed decisions.
- End of Waste codes may provide a powerful tool, with minimal regulatory change, to better regulate the contaminant risks associated with specific feedstocks or for compost products themselves, by allowing contaminant thresholds to be universally applied.

4 COMPOST FEEDSTOCKS

A key focus of this study has been identifying and assessing the feedstocks which are currently going into Queensland composting facilities or could potentially be used in composting under existing regulations and approvals. Feedstocks and their characteristics have a significant impact on both odour generation at composting facilities and contamination of compost products.

As noted above, a wide range of different feedstocks are used in composting and anecdotally, the list has significantly expanded over the past decade well beyond the conventional segregated clean organic and agricultural residues that were previously the mainstay of compost production inputs.

Arcadis has reviewed data from a number of different sources to gain an understanding of the feedstocks that are currently processed by composters across Queensland, including:

- Feedstock data provided by DES,
- Waste acceptance criteria stated in licenses (relevant to composting) and in ERA 53 definition (see Section 2.5 above), and
- A feedstock list kindly provided to Arcadis by a major Queensland composter.

Based on these datasets, Arcadis has compiled a list of feedstocks known to be used or allowed to be used in composting, which is summarised in Table 13 overleaf. The list is long with 109 feedstocks identified.

Some of the feedstocks are obvious from the nomenclature, but many of the descriptions were very broad and the likely source or composition of the feedstock could not be easily inferred from the description (e.g. ‘Ground water’, ‘Leachate waste’, ‘Soil’, ‘Process water’, etc). This highlights the potential need for a standardised nomenclature to define more descriptive names for feedstocks, which provides more insight into their source and nature.

The list of allowed input material for quality assured compost and digestate products developed by the German Compost Quality Assurance Association is also long – it contains 140 entries (Bundesgütegemeinschaft Kompost, 2018). However, it is extensive because the list aims to describe and differentiate various input materials as much as possible and also includes products that can be used for enhancing the production process or end-product. In addition, the list also provides specifications regarding allowable origins of certain residues. The list covers the following categories:

- Organic residues from residential and commercial properties (4 sub-categories)
- Organic residues originating from food processing and animal feed production facilities (39 sub-categories)
- Residues from on-site wastewater treatment plants at food processing and animal feed production facilities (4 sub-categories)
- Agricultural manures and plant residues (17 sub-categories)
- Organic residues from processing agricultural plant matter (5 sub-categories)
- Residues from technical processes (7 sub-categories)
- Forestry and wood processing residues (3 sub-categories)
- Other residues (plant matter) (17 sub-categories)
- Other residues (animal and animal processing matter) (16 sub-categories)
- Mineral materials (7 sub-categories)
- Processing (composting / anaerobic digestion) aids and end-product enhancing compounds (24 sub-categories)

Section 2.1 described the decomposition that occurs during composting as a series of chemical reactions in which complex organic compounds (mainly proteins, carbohydrates and fats) are broken down into their constituent parts. As the same processes do not occur with mineral materials such as sand, clay or concrete dust, they generally do not aid the composting process as such. As mineral materials usually have small particle size and high bulk density, incorporating them into the compost feedstock mix increases bulk density and reduces porosity of the mix, possibly pushing some characteristics of the feedstock mix outside of what is considered desirable. However, adding mineral or waste materials that are not directly benefitting the composting process (e.g. cement slurry) may not necessarily show negative effects on feedstock quality and the composting process if only small quantities (individual and total) are added to the feedstock mix. Composting is a very robust and resilient process that works for a wide range of feedstock materials, mixes and characteristics, although processing conditions and time frames, and end product qualities might vary markedly.

Table 12 Desirable characteristics for composting feedstock (Source: modified from NRAES 1992)

Characteristic	Optimum	Reasonable range
Carbon to nitrogen ratio (C:N)	25:1 – 30:1	20:1 – 40:1
Moisture content (wet basis)	50% - 60%	40% - 60%
Porosity	35% - 45%	30% - 50%
Oxygen concentration	> 10%	> 5%
Bulk density (kg/m^3)		< 640
pH	6.5 – 8.0	5.5 – 9.0

Some mineral materials however, such as nitrogen-based chemical fertiliser, can aid the composting process when feedstock with high carbon to nitrogen (C:N) ratio (e.g. bark, straw, land clearing residues) is composted. It should be mentioned that one school of thought (MidWestBiosystems, http://midwestbiosystems.com/) advocates (mainly on-farm) co-composting with clay soil, as this enhances the formation of clay humus complexes and therefore enhances compost product quality, mainly carbon stability and carbon sequestration. However, mineral materials are commonly used for blending with finished compost products in order to modify certain compost characteristics (e.g. pH) or to generate specific products in which compost is only one of several components, such as blended soils or growing media.

Table 13: Current and potentially allowed composting feedstocks identified

Animal Matter
- Abattoir waste
- Animal manures, including livestock manure
- Animal processing waste
- Animal waste, including egg waste and milk waste
- Hide curing effluent
- Paunch material
- Tallow waste

Chemical fertiliser residues
- Ammonium nitrate
- Dewatered fertiliser sludge
- Fertiliser water and fertiliser washings
- Pot ash

Earthworks & mining waste
- Acid Sulphate Sludge
- Bentonite
- Crusher dust
- Drilling Mud / Slurry (Coal Seam Gas)
- Gypsum
- Lime
- Lime slurry
- Mud and dirt waste
- Sand
- Soil
- Soil treated by indirect thermal desorption

Food & Food processing waste
- Food Organics
- Organics extracted from mixed household waste / MSW
- Quarantine waste treated by an AQIS approved facility
- Beer
- Brewery effluent
- Food processing effluent and solids
- Food processing treatment tank or treatment pit liquids, solids or sludges
- Grain waste
- Grease trap - treated grease trap waters and dewatered grease trap sludge
- Grease trap waste
- Molasses Waste
- Soft drink waste
- Starch water waste
- Sugar and sugar solutions
- Vegetable oil wastes and starches
- Vegetable waste
- Yeast waste

Industrial residues
- Abrasive blasting sand (excluding heavy metal contaminated sands)
- Amorphous silica sludge
- Ash
- Bauxite sludge
- Carbon pellets
- Cement slurry
- Coal ash
- Compostable PLA plastics
- Coolant waste
- Dye waste (water based)
- Filter cake and presses
- Filter/ion exchange resin backwash waters
- Fly ash
- Foundry sands
- Paint wash
- Paper mulch
- Paper pulp effluent
- Paper sludge dewatered
- Plaster board
- Polymer water
- Process fluid
- Treated timber
- Total Petroleum Hydrocarbon water
- Water based inks
- Water based paints
- Water blasting washwaters
- Waterbased glue
- Waterbased lacquer waste
- Wood molasses

Plant matter
- Cane residues
- Cypress chip
- Forest mulch
- Gross pollutant trap (GPT) Waste
- Green waste
- Mushroom compost (substrate)
- Natural textiles
- Pine bark
- Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)
- Tub ground mulch
- Wood chip
- Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs
- Worm castings suitable for unrestricted use

Sewage & STP residues
- Activated sludge and lime sludge from wastewater treatment plants
- Biosolids
- Nightsoil
- Septic wastes

Sewage sludge
Sewage treatment tank or treatment pit liquids, solids or sludges
Wastewater & washwaters
Bilge waters
Boiler blow down water
Brine water
Calcium water
Car Wash Mud & Sludge
Carpet cleaning washwaters
Effluent waste
Forecourt water
Groundwater
Latex Washing
Leachate waste
Low level organically contaminated stormwaters or groundwaters
Muddy water
Oily water
Soapy water
Stormwater waste
Sullage waste (greywater)
Treatment tank sludges and residues
Vehicle wash down waters
Wash Bay water
Waste water

4.1 Categorisation of Feedstocks

The feedstocks have been broadly categorised by Arcadis into types, within which the feedstocks are expected to have similar characteristics and risk profiles (although there are variations and exceptions), as summarised below. The feedstock risk management frameworks discussed in Section 6 assume that feedstocks can be grouped under these categories, with specific management processes applicable to each category, as well as to specific materials. While the lower risk categories (plant and animal matter) will be easier to manage and will have simpler management processes, feedstocks with higher potential for contamination (or higher uncertainty around potential contamination) require more thorough assessment and management. The categories adopted are summarised and described below.

Table 14: Summary of feedstock categories and general risks

Category	Description
Animal matter	Animal / livestock processing wastes including all residues from abattoirs and subsequent processing of tallow and hides; egg and milk waste, manures from intensive farming. High odour risk but assumed to be low contamination risk (no chemical residues), although question on chemicals used in hide curing effluent.
Plant matter	Predominantly clean plant material with minimal contamination. Includes green waste, gross pollutant trap (GPT) waste and clean (untreated) timber which may contain physical impurities, but otherwise includes mostly crop and forestry residues. Potential for trace pesticides and herbicides, but generally low contamination risk. Low odour risk and many of these materials can be used as bulking agents to balance / mitigate the odour risk of other materials.
Food and food processing waste	Wastes predominantly containing food and residues from food processing (predominantly crop / vegetable sources). Household and commercial food organics may contain physical impurities. Food processing wastes are assumed to contain minimal chemical contaminants. Grease trap waste is included in this group as it is primarily a by-product of food preparation in a commercial setting. All materials present a high odour risk and low chemical contamination risk with the exception of organics extracted from MSW, which is predominantly food (plus garden organics and paper) but can potentially be highly contaminated.
Sewage and sewage treatment plant (STP) residues	Sludges and solids arising from the collection and treatment of human waste (sewage), most of which is processed so that the material is classified as biosolids. Potential for varying degrees of chemical contamination (including metals and PFAS) and pathogens, depending on the degree of prior processing. High potential for odour issues.
Chemical fertiliser residues	Chemical residues and effluents from the manufacture of chemical fertilisers including wash waters and non-conforming product. Highly concentrated nutrients and risk of ammonia odours.
Industrial residues	A broad catch-all category for a range of solid, liquid and slurry wastes from industrial manufacturing processes or otherwise highly processed / treated materials. Contamination risk varies widely but is generally high, particularly for those materials that are poorly described. Odour risk is generally low although they may contain sulphur and nitrogen compounds that increase the odour risk.

Category	Description
Wastewater and wash waters	Another broad catch-all category for liquid effluent streams, contaminated stormwaters and washdown waters, mostly from commercial activities. Contamination risk varies but is generally high, particularly for the many materials in this category that are poorly described. Odour risk is generally low although they may contain sulphur and nitrogen compounds that increase the odour risk.
Earthworks & mining waste	Includes inert soils and slurries from earthworks and mining activities, as well as drilling mud from coal seam gas activities and mineral additives that can be beneficial soil conditioner additives (limes, gypsum). Contamination risk is generally low with the exception of chemical additives in drilling mud and residual contamination in treated soils. Other streams may contain naturally occurring contaminants (e.g. sulphate in acid sulphate sludge; heavy metals in earthen material; natural salts in drilling muds). Potential for extreme pH levels (lime, acid sulphate sludge).

Further, to aid analysis, Arcadis has broadly categorised each material by:

- Whether it is likely to be in solid, liquid or slurry form
- Whether it is organic or inorganic (according to the definition in ERA 53, see section 2.5 – note ERA 53 permits processing of wastes and residues from the manufacture of chemical fertilisers as ‘organic’ even though most are typically inorganic chemicals). In some cases, there is insufficient information in the feedstock name to categorise, in which case it has been marked ‘unknown’.

Further information on each feedstock is presented in Appendix A but generally, there is very limited analytical data available to characterise the feedstocks and quantify their potential chemical composition. In some cases where the description is particularly vague, it is impossible to speculate about the potential composition and associated risks.

4.2 Revising Feedstock Descriptions

In addition to classification of feedstocks into the categories proposed above, it is also necessary to name and define feedstocks in a way that is accurate and descriptive. The current nomenclature for feedstocks used by operators or quoted in various documents, is often vague and / or potentially inaccurate, with a number of current feedstock descriptors being insufficient to enable an assessment of potential contamination risk.

It would be beneficial if there was a single, consistent nomenclature defined to describe feedstock materials, which could then be linked with typical properties. Further, the current list of feedstocks should be updated to provide not just a more accurate and descriptive feedstock name, but also a short statement regarding source and composition of each feedstock. This is an important piece of information to record as it will assist in guiding management decisions on the assessment of new feedstocks, and will aid in ensuring that incoming feedstocks are classified in a consistent manner upon receipt at composting facilities.

In addition, the current feedstock list could be significantly reduced in number by consolidating feedstocks of similar composition and risk profile together (e.g. cypress chip, wood chip, pine bark, and forest mulch could be a single ‘forestry residues’ feedstock).

Some examples of re-named feedstocks and the associated description are provided below, however this process cannot be completed for all feedstocks at this time as the information regarding source and composition for many of the feedstocks is not generally available.

Table 15: Examples of Potential Updates to Feedstock Names and Descriptions

Proposed Feedstocks	Feedstock Description	Previous Feedstock Names	Key Potential Contaminants
Forestry Residues	Forestry by-products such as mulch, bark, or wood chips that have not been treated (including by pesticides or other chemicals prior to harvesting)	Cypress chip, wood chip, pine bark, and forest mulch	None
Animal and Abattoir Waste	Meat, manures, or animal waste products that have not been treated or come in significant contact with industrial chemicals such as cleaning products or agricultural chemicals.	Abattoir waste, Animal manures including livestock manure, Animal processing waste, Animal Waste including egg waste and milk waste, Paunch material.	Pathogens, nutrients
Oily waters	Water collected off hardstand or other oily surfaces such as roads, forecourts, and vehicle wash down areas, likely contains low level hydrocarbons. Water collected at large industrial facilities *not* included in this feedstock.	Oily water, Forecourt Water, Total Petroleum Hydrocarbon Water, Vehicle wash down waters,	TRH, BTEXN, VOCs, PAHs, metals.

4.3 Alternative management options

In considering whether certain feedstocks are appropriate for composting, this study has focused on two aspects – odour potential and contamination. However, there are other factors to consider, not the least of which is whether there are alternative treatment or disposal pathways available for those materials, if they are deemed to be not suitable for composting. This is particularly important to understand when proposing recommendations around regulating the use of certain feedstocks in composting and the potential for adverse or perverse outcomes if tighter regulation leads to those materials being inappropriately managed by industry.

Potential alternative management pathways for different feedstocks, if composting were not an option, include:

- For nutrient-rich animal and human wastes such as manures and biosolids, these are often directly applied to farm land which can have benefits for soil but also carries risks, including biosecurity risks.
- For solid wastes such as green waste, food organics, quarantine wastes and gross pollutant trap (GPT) wastes – the most likely alternative option in most parts of Queensland is landfill, which has its own adverse impacts on the environment and communities. Anaerobic digestion might become a processing option in the future, but will require significant new infrastructure development.
- For industrial solid wastes such as foundry sands, blasting sand and filter cake – the most likely alternative is a landfill that is appropriately engineered and licensed to receive these materials.
- For large volume mineral processing residues such as coal ash, fly ash and bauxite sludge – the most common alternative is on-site disposal to large tailings dams, which are effectively landfills and present their own environmental risks.
- For highly putrescible liquids and sludges, such as from food processing and abattoirs, the most likely alternative management option is on-site treatment in facultative ponds or more advanced processing and treatment systems (e.g. anaerobic digestion, wastewater treatment plants) which would need to be developed. This would push treatment back to the site of waste generation, and likely increase the operating costs for those waste generators, potentially increasing the risk of illegal disposal. There would need to be significant new treatment infrastructure developed in most areas.
- Some of the liquids currently received would either need to go to sewage treatment plants (if acceptable) or specialised industrial wastewater treatment facilities, which may be an appropriate alternative but there needs to sufficient capacity available to cater for the volume of these liquids generated. Industrial wastewater treatment facilities are expensive and so increase the risk of liquids being illegally dumped to land, waterways or sewer.
- Grease trap waste can be, and is, treated through various processes which separate out the grease and food solids, so that the clarified water can then be discharged to sewer. The remaining residues / sludges still need treatment and at present, there are few alternative options available for this other than composting. Pre-processing of grease trap waste in this way at least reduces the water content and volume of material requiring processing.
- For clean biomass streams such as woodchips, bark, sawmill residues, forest mulch or cane residues - there are a limited number of existing bioenergy facilities that can use some of these materials as fuel but otherwise significant volumes go directly into unpasteurised mulch markets (landscaping) or are left in the field. In the future, it is expected that more of this material will be captured as a renewable bioenergy feedstock.

This is not an exhaustive list, but it demonstrates that while other management pathways are available for some materials, they may not necessarily be preferable from an environmental perspective. In particular, landfilling of organic materials and regulated wastes presents a number of potential risks, and government policy is to reduce and avoid landfilling of waste where possible.

Other preferred processing options may exist but the infrastructure is not yet available in Queensland (e.g. AD plants for industrial / commercial organics), which suggests a transition period is needed if there is to be a shift away from composting of some feedstocks.

In some cases, the alternative options may be considerably more expensive than composting which leads to an increased risk of the materials being illegally dumped or otherwise inappropriately disposed, which could have significant environmental consequences. This in itself is not a reason not to take stronger regulatory action to protect the environment, but such risks need to be acknowledged and planned for.

Chapter 4 – key findings and recommendations

- This study has identified a long and varied list of over 100 different feedstock materials that are thought to be, or are permitted to be, used as composting feedstocks in Queensland. The feedstocks have been broadly categorised by type, into groupings that have similar risk profiles and management requirements.
- The current nomenclature for feedstocks used by operators or quoted in various documents, is often vague and / or potentially inaccurate, with the majority of current feedstock descriptors insufficient to enable an assessment of potential contamination risk.
- In considering potential restrictions on some feedstocks, it is necessary to understand the alternative disposal and processing options available in the market and assess the potential for perverse outcomes. While other management pathways are available for many composting feedstocks, they may not necessarily be preferable from an environmental perspective. In particular, landfilling of organic materials and regulated wastes presents a number of potential risks, and government policy is to reduce and avoid landfilling of waste where possible.
- In some cases, the alternative options may be considerably more expensive than composting which leads to an increased risk of the materials being illegally dumped or otherwise inappropriately disposed, which could have significant environmental consequences. This in itself is not a reason not to take stronger regulatory action to protect the environment, but such risks need to be acknowledged and planned for.
- Other preferred processing solutions may exist but the infrastructure is not yet available in Queensland (e.g. AD plants for industrial / commercial organics), which suggests a transition period is needed if there is to be a shift away from composting some feedstocks.

Recommendations – Feedstocks

- It would be beneficial to have a standard list of feedstock names which provide a more accurate and descriptive picture of the material, accompanied by a short statement regarding source and composition of each feedstock. This is an important piece of information to record as it will assist in guiding management decisions on the assessment of new feedstocks, and consistency in terminology used across industry will aid in ensuring that incoming feedstocks are classified in a consistent manner upon receipt at composting facilities and that risks are better understood.
- Allow an adequate transition period for any regulatory changes which will divert materials away from composting, where there may be a need for industry to develop new infrastructure.

5 POTENTIAL CONTAMINANTS

Phase 2 of the study was particularly focused on understanding the contamination risks associated with compost products, developing methods to assess those risks and exploring options to better regulate the risks.

Contaminants in recycled organic products can be broadly categorised:

- Physical contaminants (impurities)
- Chemical contaminants (e.g. heavy metals, organic pollutants), and
- Biological contaminants (pathogens)

This report focuses on potential chemical contamination of recycled organic products through heavy metals and organic pollutants and addresses physical contamination (impurities), whilst acknowledging the need to manage biological pathogens through existing standard practices.

Overwhelmingly, contaminants are introduced via the feedstock materials that are processed, including any liquids that are used in the process. It might be possible that air-borne contaminants are deposited by dust or rain on the composted material, that metal abrasion from shredding equipment add to the heavy metal load, or that wind-blown impurities end up in the compost, but these sources are negligible compared to contaminant loads in feedstock materials.

The way organic residues are processed can modify contaminant levels in finished products to some extent. Factors such as blending, particle size reduction, screening, addition of additives (before / after composting) and the duration of the composting process, more precisely the maturity or degree of organic matter degradation that has been achieved; all affect contaminant levels in finished products and provide opportunities for manipulating contaminant concentrations.

Physical contaminants can be reduced to a certain degree by removing them mechanically or by manual picking as part of processing operations, but in the majority of cases this cannot be achieved for chemical contaminants and the focus should be on understanding and controlling the feedstock risks.

There are a large number of potential contaminants that may be present in feedstocks, ranging from naturally occurring compounds such as metals in clays, through to emerging contaminants and known toxins in industrial waste streams. For the purposes of assessing potential contamination risk from feedstocks, the following key types of contaminants have been considered as potentially relevant for one or more feedstocks.

Table 16: Summary of Potential Contaminants Types and Sources as Applied to the Risk Assessment

Contaminant Type	Potential Sources	Specific Chemicals of Concern
Physical Impurities	Impurities can affect amenity value of product but also soil quality. Microplastics are an emerging contaminant of concern. Potential toxic effects are poorly understood and they are commonly found in effluent streams. Fragments of glass, metal and stone can have an impact on visual amenity and market value of products.	Microplastics
Heavy Metals	Naturally occurring in soils, may be elevated in clays or by-products of mining, drilling, or earthworks. Common contaminant from anthropogenic processes, including run-off from paved areas, process waters, wood treatment (e.g. CCA	Arsenic, lead, chromium, copper, zinc, etc.

Contaminant Type		Potential Sources	Specific Chemicals of Concern
		(chromated copper arsenate)), effluent streams, etc.	
Organic Chemicals / Contaminants	Polycyclic Aromatic Hydrocarbons (PAHs)	Generally associated with fuel sources, particularly fuel combustion and waste products from combustion. Common contaminant from anthropogenic processes, including asphalt and ash based wastes, run-off from paved areas, process waters, spent carbon based products, effluent streams, etc.	Benzo(a)pyrene, carcinogenic PAHs, non-carcinogenic PAHs
	Total Recoverable Hydrocarbons (TRH)	Generally associated with fuel sources, including fuel combustion. Common contaminant from anthropogenic processes, including ash based wastes, run-off from paved areas, process waters, spent carbon based products, effluent streams, etc. Can be naturally occurring in organic materials.	BTEXN (benzene, toluene, ethylbenzene, xylenes, naphthalene), TRH C6-C40
	Volatile organic compounds (VOCs)	Generally associated with manufactured chemicals and fuel sources. Common contaminant from anthropogenic processes, including solvents, detergents, fuel combustion, ash based wastes, run-off from paved areas, process waters, spent carbon based products, plastics, effluent streams, etc.	Complex mix of varied chemicals, includes chlorinated compounds and other volatiles.
	Herbicides and Pesticides	Potential contaminant in green waste residues, treated wood products, or from some agricultural waste streams. Modern products are generally less persistent and toxic than historical products such as dioxins or DDT.	Various
Per- and poly-fluoroalkyl substances (PFAS)		Highly persistent surfactants used in fire fighting foams, manufactured household goods, and a range of other products. Commonly found in effluent streams, sewage sludges, leachates and contaminated soils and waters.	PFOS, PFOA, other PFAS
Emerging Contaminants including Pharmaceuticals		As new chemicals are manufactured and used, or as the understanding of the toxicity or persistence of chemicals currently in use progresses, new groups of emerging contaminants are likely to be identified over time. While commonly found in effluent streams, it should be assumed that any feedstock that has been in contact with industrial chemicals or been subject to processing / treatment / anthropogenic interventions may contain unknown chemicals. Emerging pharmaceutical contaminants are a particular group of concern, and likely concentrations or compositions are largely unknown. Commonly found in sewage effluent streams.	Unknown

Contaminant Type	Potential Sources	Specific Chemicals of Concern
Pathogens	Associated with animal, food and effluent wastes. It is expected that current pasteurisation and standard composting techniques have been developed to manage pathogens in feedstocks.	E.coli, Salmonella, etc.

5.1 Physical Impurities

Impurities is used to describe physical contaminants in compost and other recycled organic products which are undesirable materials that impair the purity, potential use and market value of these products. Impurities in recycled organic products generally encompass general waste materials that have been wrongly placed in the stream, such as glass, metal, plastic (rigid and soft / flexible), but may also include rocks.

Glass, plastic and metal generally originate from household organics, such as food and/or green waste collected from households via a kerbside service or green waste collected through transfer stations. Other streams such as waste cleared from gross pollutant traps may also contain such materials. As shown in Table 10, the Australian Standard for compost, soil conditioners and mulches stipulates maximum contents for three classes of impurities, namely (i) glass, metal and rigid plastics at 0.5%, (ii) light-weight plastics at 0.05% and (iii) stones and lumps of clay limited to 5% (dry matter).

Impurities in recycled organic products can have visual (amenity), practical (compost spreading etc) and health and safety (as in the case of sharp glass) implications, which in turn can reduce the value and marketability of the end product. Different markets and applications accept different levels of physical / visible impurities. For example, small, yet highly visible pieces of plastic pose a major problem with the marketing and use of recycled organic products in horticultural and retail markets, while higher levels of impurities are usually tolerated when material is used in bulk landscaping or for remediation and rehabilitation projects.

This was clearly demonstrated in a 2009 study that sought to gain insight into the market acceptability of different physical contamination levels in recycled organic materials utilised for various land management purposes, utilising mulch derived from source separated garden organics and two grades of MSW compost (equivalent to AWT compost, AWT DORF, MBT compost) (Hyder & ROU 2009).

In that study, for all end-use sectors, price was the overriding factor in determining the acceptable level of impurities although there were instances where products were deemed unacceptable regardless of the price. In applications requiring large amounts of organic soil amendments, such as land rehabilitation, users were prepared to accept higher levels of physical contamination. In general terms, users were not prepared to pay extra to get cleaner products while the cleanest products were generally seen as too expensive and not competitive. The study concluded that acceptable impurity levels depend upon the application and use of the material, and that rather than imposing a “one size fits all” specification for impurities, it would be more appropriate to tailor product quality requirements to the application.

A literature review regarding guidelines for physical contamination in recycled organic products (Hyder 2008) that assessed a wide range of regulations and quality standards regarding impurity limits concluded that there was no scientific basis for determining physical contamination limits and that most limits, including those contained in the Australian Standard AS4454, overall appeared to be the dictate of aesthetic considerations which are subjective and as such extremely difficult to quantify.

The report argued also that the cost of achieving AS4454 impurity limits can be prohibitive and potentially exclude otherwise appropriate materials from beneficial use in land application should the standard’s limits become part of the approval conditions for a facility.

There is no question that removal of impurities from compost is costly and has its limits. Information from Germany suggests that 95% of impurities contained in compost can be removed through screening and wind sifting, which means that, if collected organics (in that case household food and garden organics) contains 1% impurities, the screened and cleaned compost will contain around 0.15% (by weight) of impurities (Bundesgütegemeinschaft Kompost 2016). If the feedstock has higher impurity levels, so will the generated compost.

The level of impurities in raw materials can also be an indication of other chemical contaminants. Work in Spain with household food and garden organics (FOGO) that contained between 0.13% and 30.2% impurities (average 10.7%) has shown a significant positive relationship between non-compostable materials entering the processing facility and the quantity of heavy metals zinc, copper, and lead found in the produced compost (Lopez et al. 2016). Reduction of high impurity levels in raw materials will not only reduce the proportion of physical contaminants in the finished compost, but will also likely result in lower concentrations of some chemical contaminants (particularly metals).

In terms of feedstocks, a report by consultants Rawtec in 2018 for the NSW EPA (Rawtec 2018) assessed data from various council kerbside FOGO collection systems and found that impurity rates in the FOGO as collected averaged 2.6% but varied across a wide range of 0.04% to 17.8%, and the bin configuration had a significant impact on this. The most frequently encountered impurities in FOGO were plastic, metal, containerised food (including glass and plastic containers), other organics (e.g. leather, rubber, oils) and miscellaneous bagged materials and household goods.

For the products however, there is no publicly available data that provides information concerning impurity levels contained in various recycled organic products generated in Australia. The proportion of products made from garden organics, FOGO or municipal waste derived organics that meet or exceed maximum AS4454 – 2012 limits is not known. Therefore, it is impossible to ascertain if there are particular problems with impurities in recycled organic products in Australia, let alone Queensland, and if certain impurities pose a problem across a range of products.

Data from Europe can shed some light on impurity levels in different types of recycled organic products. Impurity levels (> 2mm) in quality assured compost in Germany showed a median value of 0.04% (excluding rocks) in 2018 (Bundesgütegemeinschaft Kompost 2019). Work published by the European Commission (Saveyn and Eder 2014) which reflected the development of technical proposals for end-of-waste (EoW) criteria for biodegradable waste subjected to biological treatment, i.e. compost and digestate, showed impurity levels of a limited number of samples (16) representing a range of composts made from different raw materials (Figure 2). In addition, the work undertaken by the EU assessed also thousands of existing test results from country specific datasets to gain an understanding of the extent of impurities that are found in various recycled organic products.

Results obtained from 16 samples showed that all composts derived from source separated FOGO and green waste, as well as two out of three sewage sludge composts, easily met the proposed limit for impurities of 0.5% dry matter (Figure 2). However, none of the samples representing MBT (mechanical biological treatment of MSW) compost registered values below the proposed limit.

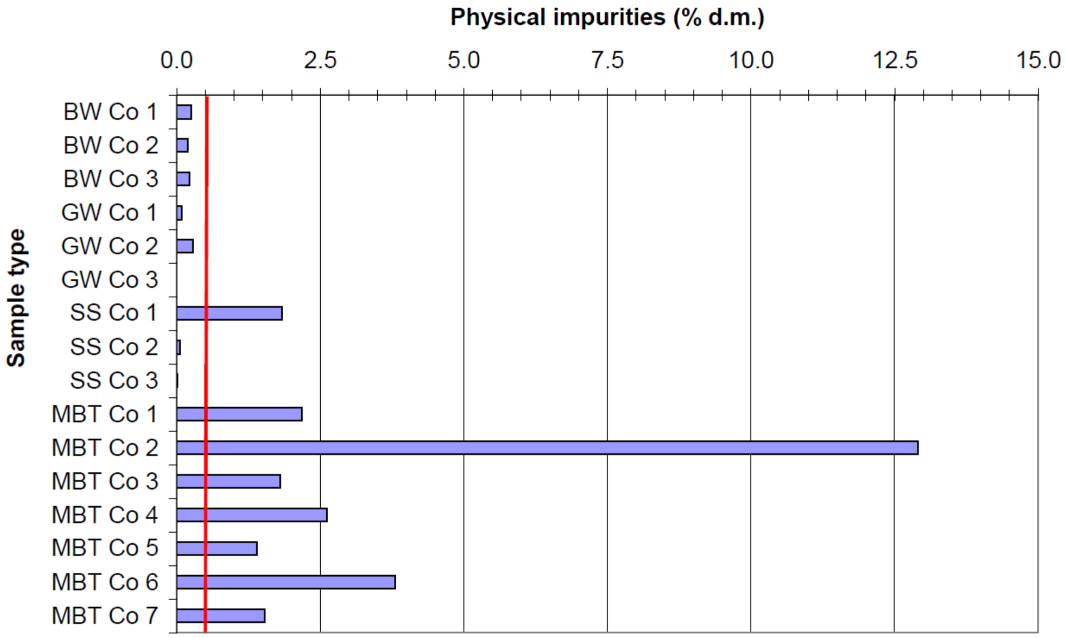


Figure 2:Physical impurities (glass, metal and plastic > 2 mm) in compost samples collected in Europe. The red bar represents the proposed maximum values for EU EoW product quality criteria (Co=compost; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment of MSW; Man=manure; ECr=agricultural energy crops) [Source: Saveyn and Eder 2014]

In addition to the small number of compost samples that were assessed for impurities as part of the EU study, existing data sets with large sample numbers acquired over extended periods, provided mainly by National quality assurance organisations, were also used to gain better understanding of impurities in different recycled organic products. The collated information represents more than 10,000 compost and digestate samples made from different raw materials and sourced from different locations. About 2,700 samples represented 'raw' data, i.e. samples of materials applying for a quality label, but before being awarded the label, while almost 8,000 samples represented products that were awarded a National quality label after meeting National product quality requirements.

The EU study noted that impurity levels need to be viewed with care as:

- different methods were used for the determining impurities (e.g. bleach destruction method or optical sieving method);
- different types of impurities were determined in the different National quality assurance frameworks: glass, metals, plastics, plastic films, stones, etc.;
- particle size fractions for determining impurities did not always represent particles >2mm, but were >5mm in some cases. Figure 2 represents impurities that best reflect all impurities > 2 mm, excluding stones;
- some datasets had low sample numbers. The proportion of samples exceeding the proposed limit was only reported where the sample size was more than 100.

The EU study drew the following conclusions from data contained in large National datasets and showed that:

- Source separated FOGO and green waste compost generally met the proposed limit values at 90-percentile level. Levels in France, Spain and Portugal were found to be somewhat elevated compared to those in Italy, the Netherlands and Belgium. The difference might have been due to different measurement methodologies being used, varying National limits and differences in how well source separation organics recycling schemes functioned. The difference in impurities found in

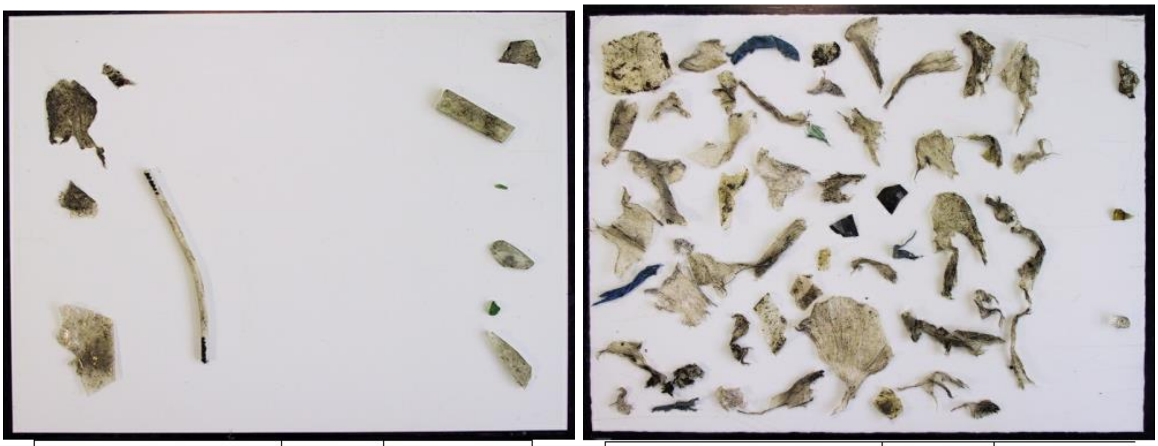
Dutch and French compost made from source separated materials is noteworthy, with only 6 % of Dutch samples failing the proposed impurity limit, whereas 26% of the French samples contained impurities that exceeded the proposed limit.

- Data on sewage sludge compost were scarce and restricted to France but suggested that most samples (> 80 %) met the proposed limit values.
- Both the extensive French data and limited Spanish data indicate that most (> 90%) MBT composts did not meet the proposed limit values. This may be partially due to the measurement methodology employed in France, yet the fact that glass made up a large proportion of impurities in French MBT compost suggested that glass entered the mixed waste stream rather than being recycled, and that the employed mechanical glass separation technologies were unable to adequately remove the glass. Significant differences between impurity levels in different MBT facilities were observed.

5.1.1 Area based measurement of impurities

Virtually all compost quality requirements related to impurities, including the Australian Standard AS4454, quantify physical contamination based on the mass of impurities in relation to total (dry) mass of product (Hyder 2008). One of the main limitations of mass based methods is that products contaminated with large quantities of low density plastic (e.g. plastic bag pieces) will show very low impurity levels if expressed as percentage of total mass, as is shown in Figure 3. Impurities dominated by heavy particles have relatively low surface area, while impurities dominated by lightweight materials have a relatively high surface area.

These circumstances prompted the German Compost Quality Assurance Association to establish an area-based limit for impurities in addition to the existing weight-based limit (0.5% dm). The new threshold was introduced in 2007 and set at a surface area of 25 cm^2 per litre of compost (Thelen-Jüngling 2008). The limit was tightened to 15 cm^2 per litre in July 2018 in a bid to further reduce plastic contamination in compost products (Bundesgütegemeinschaft Kompost 2016).



Fraction	weight-% DM	surface area [cm²/l]
Impurities > 2 mm [total] in 1 L	0,47	8,60
light weight fraction [plastics] on the left	0,03	5,51
heavy fraction [glas, metal] on the rigth	0,44	3,09

Fraction	weight-% DM	surface area [cm²/l]
Impurities > 2 mm [total] in 1 L	0,17	68,91
light weight fraction [plastics] on the left	0,13	67,53
heavy fraction [glas, metal] on the right	0,04	1,38

Figure 3 Physical impurities (> 2 mm) in compost expressed on the basis of weight and surface area, dominated by heavy particles (left) or lightweight particles (right) [Source: Thelen-Jüngling 2008]

5.1.2 Microplastics

Microplastics are very small plastic fragments that measure less than 5mm in length and can enter ecosystems from a variety of sources. Primary microplastics are any plastic fragments purposely made to be that size (≤ 5.0 mm) before entering the environment and include for example microbeads used in cosmetic products and plastic pellets. Secondary microplastics are created from the degradation of larger plastic products once they enter the environment through natural weathering and degradation processes. A third group is emerging which comes from the human use of an object that gives off microplastics, for example from the road wear of synthetic tyres, washing synthetic clothes, or synthetic grass pitches and sports grounds. Plastics degrade very slowly, which increases the probability of microplastics being ingested and incorporated into, and accumulated in, the bodies and tissues of many organisms.

Nizzetto et al. (2016) have outlined why the presence of microplastics in soil can be problematic, stressing that these materials can potentially impact soil ecosystems, crops and livestock either directly or through the toxic and endocrine-disrupting substances added during plastics manufacturing. These substances include short/medium-chain chlorinated paraffins (candidates for inclusion in the Stockholm Convention) and plasticizers, which can represent up to 70% of the weight of plastics. Endocrinologically active alkylphenols, such as bisphenols, and flame retardants including several banned brominated compounds comprise up to 3% by weight of some plastics. The same authors also claim that, during use, plastic polymers efficiently accumulate other harmful pollutants from the surrounding environment, including a number of persistent, bioaccumulative and toxic substances, such as PCBs, dioxins, DDTs and PAHs.

Concerns about plastics and microplastics in the environment have undoubtedly focused on the marine environment in the past, although in 2012 Rillig already saw the occurrence of microplastics in soil as eminently plausible and called for a systematic examination of soil as well as increased attention of policy makers and regulatory bodies to this matter. In that regard, use of biosolids products on agricultural land came under scrutiny first, as over 90% of microplastics contained in sewerage are retained in the sludge (Nizzetto et al. 2016).

Based on high level estimates, Nizzetto et al. (2016) suggested that between 125 and 850 tons of microplastics per one million inhabitants are added annually to European agricultural soils through land application of sewage sludge or as processed biosolids. They estimated furthermore that these quantities equate to average and maximum areal per-capita microplastic loading rates of 0.2 and 8 mg/ha/yr, respectively. However, He et al. (2018) pointed out that pollution of farmland with microplastic can also originate to a large degree from use of plastic mulch (and other plastic products) in agricultural practice. Yet, there is still a significant lack of data regarding concentrations, volumes, types and composition of microplastics in soil environments to allow analysis of the current pollution status of microplastics in the soil on a regional, National or global scale (He et al. 2018).

Work has been published recently that looked at the presence of microplastics in farmland soils. For example, the abundance of microplastics in twenty vegetable fields on the outskirts of Shanghai amounted to 78 ± 12.91 and 62.50 ± 12.97 pieces per kg in shallow and deep soils, respectively (He et al. 2018). The majority of microplastics found were made of polypropylene (50.5%) and polyethylene (43.4%), indicating that plastic mulch was the main contributor to microplastic contamination in soil. In another study that was conducted in China (Zhang et al. 2018), all fifty samples of arable soils contained plastic particles (10 - 0.05 mm), numbering between 7,100 and 42,960 particles per kg of soil, with 95% of plastic particles found being categorised as microplastics (1.00 - 0.05 mm).

Contamination levels found in Germany were significantly lower, yet still present. Piehl et al (2018) found 206 pieces of macroplastic per hectare and 0.34 ± 0.36 particles of microplastic per kilogram dry weight in arable soil where microplastic-containing fertilizers and agricultural plastic applications were never used previously. They saw polyethylene as the most common polymer type, followed by polystyrene and polypropylene, and noted that microplastics were dominated by plastic films and fragments, whereas macroplastics were comprised predominantly of plastic film. The authors did point out that contamination levels are probably higher in fields where agricultural plastic is used (e.g. greenhouses, mulch, or silage films) or where organic soil amendments that contain plastic fragments such as biosolids or urban derived composts are applied.

In France, Watteau et al. (2018) developed and applied novel analytical methods to determine the level of microplastics in a long-term experimental field, where municipal solid waste (MSW) composts were applied every other year over 10 years. Their results showed that plastics and microplastics were present in the soil that was amended for 10 years with MSW compost, while not in the control soil.

Microplastics were mostly observed as individual particles, present in the coarsest fractions as well as some of the fine soil fractions, but they were little associated with the soil matrix. Most plastic particles did not show any signs of degradation (e.g. microbial lysis), which suggests that fragmentation is the main pathway of particle size reduction.

It should be understood that microplastics in soil is a new field of scientific investigation where much has yet to be learned. Bläsing and Amelung (2018) for example stated that "nearly nothing is known about plastic pollution of soil; presumably, because awareness is either not existent or because no standardised methods are available for plastic quantification in soil" and Scalenghe (2018) pointed out that plastic polymers found in the soil are not made of a homogeneous material but are different from each other and hence degrade differently in soil over different time spans.

Researchers in Germany investigated the content of microplastics > 1 mm in a range of products generated from various source separated organic residues that were processed either via composting or anaerobic digestion (Weithmann et al. 2018). Both the composting and the anaerobic digestion facilities processed FOGO material blended with vegetation residues, yet there were some important operational differences that affect impurity levels in the finished product.

All analysed product samples contained plastic particles, but quantities differed significantly depending on feedstock type and mix and efforts to remove impurities before processing. Composted FOGO contained markedly less plastic particles than digested FOGO, but this has nothing to do with the processing technology as such, but rather with differences in the feedstock mix (higher proportion of vegetation residues used in composting (

Table 17) and the lack of pre-treatment (removal of packaging) in the anaerobic digestion facility. The level of degradation of the organic material, which affects particle size distribution and the mesh size chosen for screening also affects the content of plastic particles in the finished product.

Unfortunately the authors did not report if the feedstock material (FOGO and vegetation residues) processed in the two facilities had similar impurity levels or not. Liquid digestate from an AD facility that processes primarily commercial residues from the food and beverage industry contained by far the highest number of plastic particles. No information was provided about measures to remove impurities in this operation. As a comparison, the authors also assessed digestates generated at facilities that process agricultural residues and energy crops and found very few plastic particles in those products.

Table 17: Comparison of microplastic particles >1mm in products generated from source segregated organics in Germany (Source: modified from Weithmann et al. 2018)

Parameter	Composting	Dry anaerobic digestion	Wet anaerobic digestion
Feedstock	FOGO + vegetation residues	FOGO + vegetation residues	Commercial organic residues (food and beverage industry)
Proportion vegetation residues	High (more than 50%)	Low (about 20%)	Unknown, probably none
Removal of impurities from feedstocks	Screening (80mm), material < 80mm => ferrous metal separation, material > 80mm => manual sorting, shredding	None	Unknown
Removal of impurities from finished product	Compost is screened to < 8mm and < 15mm	After digestion (28 days) the material is screened (20mm) and subsequently composted and matured	Unknown

Parameter	Composting	Dry anaerobic digestion	Wet anaerobic digestion
Products assessed and microplastic particles (> 1mm) found per kg of product	Compost < 8mm: 20 Compost < 15mm: 24	Mature digestate A: 70 Mature digestate B: 122 Immature digestate C: 146 Percolate D: 14	Liquid digestate: 895

5.2 Heavy metals

The earth's crust contains small quantities of trace elements, some of which are essential to plants, animals and humans (micronutrients), while others may be toxic or have no effect, and many are essential at low levels, but are toxic at high concentrations. Trace elements comprise, among others, around 40 heavy metals (density >5 g/cm^3), some of which can accumulate in specific body organs.

As a result, the term 'heavy metal' has become synonymous with an element that can be harmful to the environment, plants, animals, and humans, and usually refers to cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn).

The presence and variation of trace elements in the environment (i.e. soil, water, plants, animal and humans) is the result of the natural occurrence of elements, mainly depending on geological processes underlying soil formation, and human activities. The use of fertilisers, pesticides, herbicides and waste materials, including animal manures have resulted in increased trace elements in many soils. Since soils contain various amounts of trace elements, plants growing on different soils will contain different levels of trace elements, and plant species vary in their capability of absorbing different trace elements.

Compost products contain trace elements, some of which are heavy metals, and the concentration of which depend on the feedstocks processed and the level of degradation that is achieved during composting. However, soils in their natural state also contain trace elements and heavy metals, concentrations of which depend primarily on geological formations and soil formation processes at any given location. The risk emanating from heavy metals contained in compost depends on the following criteria:

- Concentration of heavy metals in compost
- Load of heavy metals applied to land, determined by concentration, application rate and frequency of application
- Characteristics of receiving soil (e.g. texture, pH, soil organic carbon), and existing heavy metal concentration in receiving soil, combined with plant availability of metals
- Type of crop grown (root or non-root crop, capacity to take up metals) and subsequent use for human consumption or alternative uses.

The following section, which provides information on essentiality and toxicity of heavy metals commonly found in compost products, their occurrence in the environment, environmental consequences of composting and compost use, and the soil plant interaction in relation to heavy metal uptake, is adapted from Epstein (1997).

5.2.1 Arsenic (As)

The two most common forms of arsenic (As) are arsenate and arsenite, the latter of which is more soluble and more toxic. Arsenic is not essential for plants and is not readily taken up. Rice is the most sensitive crop to soil As since it is grown in flooded fields, where arsenite is formed. If very high concentrations of As are applied to soils, most crops including peas, potatoes, cotton and soybeans can suffer from As phytotoxicity. The level of As in compost is generally low; therefore, uptake is very low and does not result in phytotoxic effects.

Hunter (2008) suggests that even arsenic is now close to qualifying as a micronutrient in animals, based on it's suggested role in the metabolism of the amino acid methionine and in gene silencing (Uthus, 2003, cited in Hunter 2008) a positive interaction with the more important micronutrient selenium (Zeng et al, 2005, cited in Hunter 2008).

5.2.2 Cadmium (Cd)

Cadmium is not essential for plants or animals. Although Cd is phytotoxic when added to acidic soils, it has not been found to be toxic to plants under natural conditions. Plant uptake differs among species and cultivars and accumulation varies in different plant organics (leaves > storage roots > fruits and grain). It has been shown that when the ratio of zinc to cadmium is larger than 100:1, zinc (Zn) phytotoxicity occurs before the concentration of Cd in the crop becomes toxic to humans.

Cadmium can be toxic to animals and humans if ingested, initially affecting primarily kidney functions. However, when Japanese farming families consumed rice grown in paddies that were contaminated by mine waste and smelter emissions containing Cd, Cd-induced osteomalacia resulted in multiple bone fractures in women. The rice grain, grown in flooded soils, was highly enriched with Cd but contained average Zn levels, although the soil contained 100 times more Zn than Cd. The gastrointestinal uptake of Cd is reduced by normal or increased dietary levels of calcium, zinc and iron.

5.2.3 Copper (Cu)

Copper is essential for both plants and animals. Copper concentrations in plants are usually in the range of 2 – 25 µg/g dry matter (dm) with levels of less than 2 – 5 µg/g dm indicating deficiency and concentrations above 25 – 40 µg/g dm having the potential to result in toxicity symptoms. Copper toxicity in plants has been reported near copper deposits, smelters and where excessive amounts of Cu-based fungicides and fertilisers were applied to strongly acidic sandy soils. When biosolids and composts with normal copper concentrations have been land applied, even at high cumulative loading rates, no evidence of copper phytotoxicity was observed. Only when biosolids with very high copper concentrations (>2000 mg/kg) were applied to strongly acidic soils did Copper phytotoxicity occur in sensitive crops.

Ruminant animals are the most sensitive class of livestock for Copper deficiency and toxicity. Prolonged consumption of low copper, high molybdenum, high sulphate, high zinc or high iron diets can induce Copper deficiency. Copper toxicity to animals has been reported for Cu-fertilised pastures where sheep consumed the Copper fertiliser, but no Copper toxicity has been reported for ruminants consuming field-grown Cu-rich forages. Testing of sheep tolerance of ingested Cu-rich biosolids and pig manure showed that copper toxicity did not occur even though dietary copper far exceeded toxic levels of soluble copper salts. Bioavailability of diet copper varies widely for ruminants, and biosolid, manure and compost copper has low bioavailability. Copper toxicity to humans and animals occurs very infrequently.

5.2.4 Lead (Pb)

Lead is not essential for plants or animals, and it can be toxic to both. Plant tolerance to soil lead is very high because lead is strongly adsorbed by soil particles. Very high lead levels, 3,200 kg /ha, applied as Pb salts, did not reduce corn yields. Except in highly contaminated soils, plants accumulate little soil lead when the soil fertility is appropriate for crop production, because phosphate inhibits lead transport to the plant leaves and other edible plant tissues. Absorbed lead remains predominantly in the fibrous roots. Lead content in edible portions of crops is low and crops provide very low amounts of lead in human diets. The potential risk from lead in compost is not through plant uptake of compost applied lead, but rather through direct soil ingestion of lead by children or livestock or as the result of deposition on edible plant portions.

5.2.5 Mercury (Hg)

Mercury is not essential for plants or animals. Uptake of mercury by plants is low, especially in the above-ground portions of plants. There is little evidence that mercury in compost can cause excessive mercury in either food crops or liver of livestock grazing on compost amended pastures, although there are accounts of mercury accumulation in vegetables when green waste compost was applied to soil. Mercury poisoning of humans was mainly linked to fish and contaminated seed.

5.2.6 Nickel (Ni)

Nickel is essential for plants and animals, yet nickel deficiency has rarely or ever been observed in in normal agriculture. Nickel can be phytotoxic, with the possibility of significant yield reduction occurring in all economic plant species grown in strongly acidic soils when leaves exceed 25 – 50 ppm Ni. However, nickel toxicity to plants occurs before nickel levels in plants become toxic to livestock or humans.

5.2.7 Selenium (Se)

Selenium is essential for animals and humans, but is considered non-essential for plants. It is toxic to animals, and the range between toxicity and deficiency is very narrow, with all livestock and humans being susceptible to selenium poisoning. Selenium deficiency in herbivores, usually caused by low levels in soil and forage, can cause muscular degeneration. Selenium poisoning of animals and humans is well documented. Selenium is readily taken up by plants and ingestion of plants that accumulate the element is often the cause of selenium poisoning in animals, which causes ‘blind staggers’ in animals, and can lead to anorexia, emaciation and eventual collapse of animals.

5.2.8 Zinc (Zn)

Zinc is essential for plants or animals. In a wide variety of plants, a concentration of less than 15 – 12 ppm Zn in dry tissue indicates deficiency, while levels above 400 ppm indicate possible phytotoxicity. Zinc phytotoxicity was observed in sensitive crops when biosolids with high zinc concentrations were applied to acidic soils (pH < 5.5.). Zinc toxicity to plants occurs before levels in plants reach levels that could be harmful to humans. Zinc requirements and tolerance in animals are affected by several nutrients, vitamins and elements, including copper, manganese, iron, lead and cadmium.

5.2.9 Metal Soil-Plant Interactions

Trace elements in raw or composted organic residues form various compounds or associations when applied to soil which can affect their uptake by plants and their mobility through soils. They can be complexed by organic compounds, co-precipitated in metal oxides, be in a water-soluble state, or bound on soil or organic matter colloids in an exchangeable form. Hence, measuring total trace element content in soil or organic amendments does not predict soil-plant interactions, i.e. bioavailability and plant uptake.

Understanding the soil-plant relationship regarding trace elements is important in ensuring low uptake of trace elements by plants and minimal movement to water resources. When organic soil amendments are applied to soil, there are many potential pathways for the trace elements: uptake by plants, movement with water to ground or surface water sources, volatilisation from surface applied products, and immobilisation in the soil matrix. Trace elements applied to soil may pass through the soil unchanged, react with organic and inorganic compounds to form soluble or insoluble compounds, be adsorbed on the soil colloids, volatilise from the soil, or be taken up by plants. The potential pathways are primarily affected by

- type of trace element and chemical state,
- soil acidity,
- organic matter,
- cation exchange capacity,
- reversion to unavailable forms.

5.2.9.1 Type of trace element and chemical state

The availability of trace elements to plants and their mobility in soil often depends on their chemical state and interaction with other elements. The elements Cu, Ni, Cd, Pb and Zn behave similarly in soil. They could for example exist as divalent cations (Cu^{2+}, Zn^{2+}) in acid soils or be combined with a hydroxyl ion [$Zn(OH)^+$] in neutral or alkaline soils. The importance of the chemical form on plant uptake is well documented, as it has been shown that trace elements that are applied as salts are more soluble and result in greater uptake than the same element applied in an organic matrix such as biosolids or compost.

5.2.9.2 Soil acidity

Generally, as soil acidity increases, the solubility of trace elements increases, and so does the potential for uptake by plants. However, this paradigm is not universally applicable as factors such as compost feedstock, soil type and plant species may affect uptake.

5.2.9.3 Organic matter

Organic matter, both from the soil and from organic amendments has a high cation exchange capacity compared to mineral soil, and therefore tends to bind or chelate metal ions such as Cu, Ni, Zn and Cd. Organic matter binds metals more strongly at a soil pH below 7.5, which is why metal availability in acidic soil is lower when organic matter content is high compared to the same soil with low organic matter content.

Metal-organic matter complexes play an important role in the micronutrient cycles in the soil, and are relevant here as (i) soluble organic compounds that otherwise would precipitate, (ii) metal ion concentrations may be reduced to non-toxic levels through complexion, and (iii) trace element availability to plants may be enhanced by various organic-metal-organic complexes.

5.2.9.4 Other aspects

Other factors such as the amount of phosphorous, soil temperature, soil moisture, and aeration can affect the solubility and availability of a trace element to plants. For example, phosphate is well known for reducing zinc availability to plants, and for decreasing the stunting injury caused by excessive amounts of phytotoxic elements. Trace elements can ‘revert’ with time to chemical forms less available to plants, for example this is possible for zinc. This process can be quite rapid and is influenced by factors such as pH and the extent of reductive soil conditions.

5.2.10 Effect of compost on trace element uptake

Numerous studies have been conducted on the uptake of trace elements from different types of organic soil amendments, with work in the Americas focusing on composted and non-composted biosolids, and work in Europe focusing on compost made from mixed solid waste and source segregated organic residues (e.g. Riedel and Marb 2008).

Uptake of metals differ among plant species and among cultivars within species, and accumulation varies in different plant organs (leaves > storage roots > fruits and grain). Plant availability and plant uptake of metals (Cd and Zn) is lower from composted than from uncomposted organic soil amendments (shown for biosolids / MSW compost at equivalent Cd application rate). Different types of organic matter and the stage of decomposition play roles in plant uptake of metals. Most likely, as a result of decomposition, compost contains elevated levels of humic substances that chelate heavy metals and result in reduced heavy metal uptake.

The readily available water soluble faction of trace elements is small in compost products, if the process is carried out properly. The pH of most composts is near neutral (pH 7) and when compost is applied to soil, can increase the pH and therefore reduce plant availability and uptake of heavy metals.

5.2.11 Concentrations of heavy metals found in compost products

When it comes to the concentrations of contaminants in compost generated in Queensland, or in fact across Australia, there is virtually no publicly available data that provides information about average heavy metal contents, the range of metal levels detected, and the proportion of compost samples and products that exceed maximum limits stipulated in AS 4454 – 2012 or in State / Federal regulations. Therefore, it is impossible to ascertain whether and to what degree recycled organic products exceed stipulated contaminant limits, and if problems exist with certain products and/or certain metals.

In December 2017, DES undertook a limited sampling round of compost products at six Queensland composting facilities as part of a general industry investigation, and tested for a range of contaminants (unpublished). In terms of metals, all samples returned low metal concentrations below relevant thresholds, with the exception of one site which returned copper and zinc levels above the AS4454 product thresholds but well below the HIL A soil thresholds for residential use. The results are discussed further below.

The only publicly available data for Australia in that respect dates back to 2002, when Wilkinson *et al*. published heavy metal concentrations found in green waste composts generated in Australia, and compared them to Victorian EPA limits applicable at the time. The data showed that, in those days, green waste composts frequently exceeded the Victorian State EPA limits for copper, chromium and zinc. Up to 70 test results for various metals were reviewed and 38%, 41% and 26% of tested product samples exceeded copper, zinc and chromium limits, respectively (Table 18).

A study on the quality of waste derived compost in Ireland, undertaken at the same time when the Australian data were published, found that nearly half of the samples of FOGO (N=24) and garden organics (N=8) compost were classified as Class I and the other half as Class II compost according to the EU Biowaste Directive requirements, and that there was no major concern regarding heavy metal content of FOGO and garden organics compost (Herity 2003). Compost made from commercial organic residues (N=7) contained the highest concentration of heavy metals, with one of the samples being classified as Class I compost, three samples as Class II compost, two samples were classified as stabilised biowaste and one was nonconforming. Elevated mean copper, lead and zinc levels in compost derived from commercial organics (Table 19) was primarily caused by one sample that contained excessive levels of these metals, while metal levels in the remaining samples were in the same range as FOGO and garden organics composts.

Table 18: Concentration (mg/kg dm) of heavy metals in green waste composts and the proportion exceeding Victorian EPA limits valid in 2002 [Wilkinson et al. 2002]

Metal	No samples	Mean	Min	Max	EPA VIC limit	Proportion above limit
Arsenic	48	4.7	0.1	35	20	2.1
Cadmium	53	0.8	0.1	1.7	3	0.0
Chromium	50	34	0.1	160	50	26.0
Copper	68	54	<1	165	60	38.2
Mercury	49	1.5	0.05	25	1	6.1
Nickel	47	13	<1	62	60	2.1
Lead	58	74	74	308	150	6.9
Selenium	23	2	2	17	5	8.7
Zinc	70	220	220	969	200	41.4

Table 19: Concentration (mg/kg dm) of heavy metals in different composts in Ireland [modified from Herity 2003]

Metal	FOGO Compost (N = 12 - 29)		Garden Organics Compost (N = 8)		Commercial Organics Compost (N = 7)	
	Min - Max	Mean	Min - Max	Mean	Min - Max	Mean
Arsenic	0.2 – 8.3	3.1	n.d.	n.d	n.d.	n.d.
Cadmium	0.2 – 1.02	0.6	0.5 – 1.2	0.9	0.2 – 1.6	0.8
Chromium	2.0 - 135	18.7	1.0 - 148	31	0.1 - 116	19.8
Copper	2.5 - 124	47.5	1.0 – 62.7	33.3	20.8 – 2,476	392.1
Mercury	0.0 – 2.7	0.4	0.1 – 0.3	0.2	0.1 – 0.3	0.1
Nickel	1.9 - 68	18.7	1.0 – 53.1	15.5	2.7 - 49	15.4
Lead	7.0 - 122	39.5	1.0 - 129	64	16 - 342	111.2
Selenium	0.5 – 1.0	0.7	n.d.	n.d.	n.d.	n.d.
Zinc	5.2 - 361	147.8	12 - 301	140.1	10.9 – 2,707	476.3

n.d. = no data

The analysis of six compost samples by the Department of Environment and Science (unpublished) in December 2017 showed that zinc and copper levels can still be elevated and surpass AS 4454 – 2012 limits (Table 20). Compared to data presented by Wilkinson et al. (2002) some 15 years earlier (Table 18), it appears that heavy metal levels in compost have decreased, particularly chromium. However, the sample size of Queensland test results is very small and can therefore not support such a general statement.

Table 20: Concentration (mg/kg dm, average of duplicate analysis) of heavy metals in six compost products sampled in Queensland in December 2017 [Department of Environment and Science, unpublished]

Metal	AS 4454 Limit	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
Arsenic	20	17.5	< 5	< 5	< 5	< 5	8.5
Boron	100	< 50	< 50	< 50	< 50	< 50	< 50
Cadmium	1	< 1	< 1	< 1	< 1	< 1	< 1
Chromium	100	28	13	6.5	5.5	12.5	13.5
Copper	100 (150)	61.5	40	179.5	35	90.5	25.5
Lead	150	31.5	13	< 5	< 5	< 5	21.5
Mercury	1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Nickel	60	11.5	6	7	3	8.5	4

Metal	AS 4454 Limit	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
Selenium	5	< 5	< 5	< 5	< 5	< 5	< 5
Zinc	200 (300)	258.5	137.5	528	32.5	200	74

The lack of centrally collated data and information regarding the quality of generated recycled organic products prevents a well-informed discussion and decision making process, which was apparent for example during the last revision of AS 4454, which took around five years to accomplish, in part due to lack of data.

In contrast, the German Compost Quality Assurance Association for example, which is an independent body that is authorised to manage quality assurance systems and programs for a range of recycled organic products in that country, holds all test results for products certified under its schemes, and publishes annual average product characteristics, i.e. not only contaminants. If necessary, these data are available and can be subjected to detailed analysis. The on-line presentation of median compost characteristics for 2018, based on 3,636 compost test results (Bundesgütegemeinschaft Kompost 2019), showed the following median heavy metal concentrations

- 0.39 mg/kg dm for cadmium,
- 21.0 mg/kg dm for chromium,
- 36.5 mg/kg dm for copper,
- 27.0 mg/kg dm for lead,
- 0.09 mg/kg dm for mercury,
- 12.8 mg/kg dm for nickel,
- 157.0 mg/kg dm for zinc.

Presented median values are well below German and Australian compost standard quality requirements, and are also lower than mean metal values for Australian compost detected in 2002 (Table 18).

When the European Union developed end-of-waste (EoW) criteria for biodegrable waste subjected to biological treatment (compost & digestate) it commissioned the development of technical proposals. This work was extensive, and involved both standardised sampling and testing of 120 samples representing a range of composted and digested recycled organic products (Figure 4) from 15 EU member states and Switzerland, as well as the assessment of thousands of existing test results from country specific datasets to gain an understanding of the possible range of heavy metal concentrations in these products (Saveyn and Eder 2014).

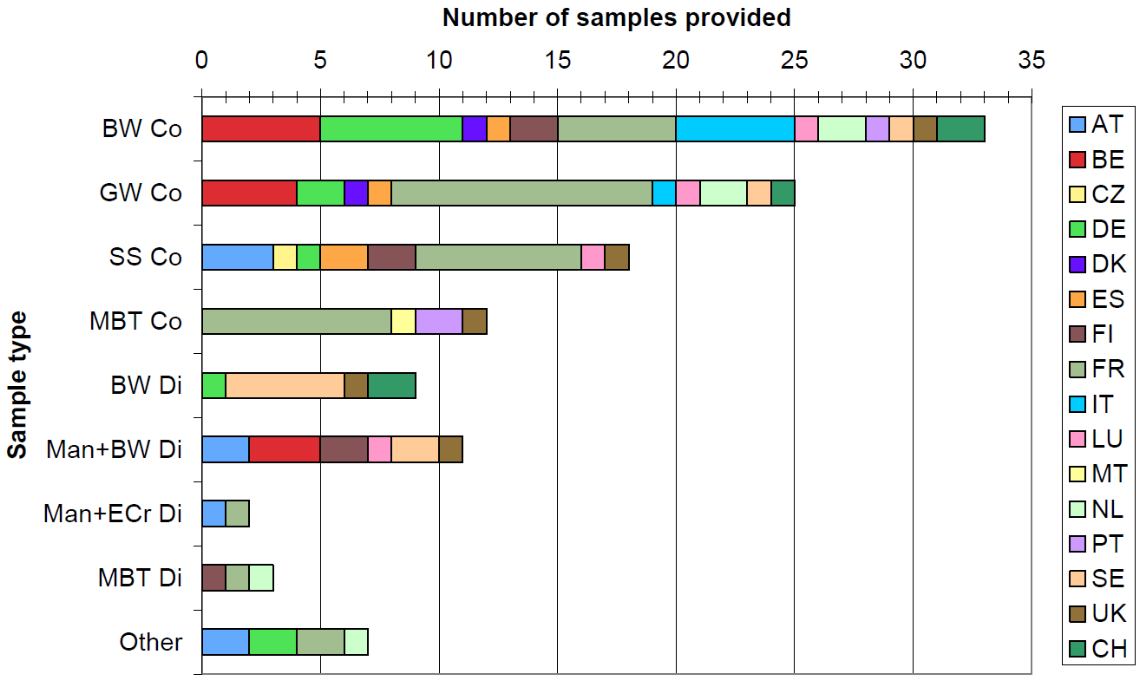


Figure 4: Distribution of samples according to type of product (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment of MSW; Man=manure; ECr=agricultural energy crops) [Saveyn and Eder 2014]

The results of the heavy metal analyses carried out as part of this work are depicted in Figure 5. The results are displayed as cumulative graphs scaled from 0 to 100% of the total sample population for a material type, with every concentration data point representing an actual sample measurement. This representation helps to visualise the spread of data and allows also seeing how many samples of a type of compost or digestate exceed a certain threshold concentration. Some samples, especially digestates, could not be analysed for various reasons and are therefore not represented in the graph.

In order to have a minimum number of valuable samples for evaluation and discussion, the results of source separated bio-waste (FOGO), manure and energy crop digestates were grouped. For the category of MBT digestate (MBT = mechanical biological treatment of MSW) only two samples were available, hence these have illustrative value only.

The graphs also contain red bars, indicating the proposed EU end-of-waste limit values, which are based on an earlier pilot study on compost/digestate and discussions at the time.

The analytical results displayed in Figure 5 allowed the authors of the EU study to summarise and conclude the following:

Cadmium: many samples meet the proposed 1.5 mg/kg limit value, except one green waste, one sewage sludge and four MBT compost samples and one digestate sample. MBT compost generally displays the highest cadmium levels;

Chromium: nearly all samples meet the proposed limit of 100 mg/kg, except one sewage sludge compost sample and one MBT compost sample. MBT compost generally displays the highest chromium levels;

Copper: compost from source separated FOGO or green waste generally meets the proposed limit value of 200 mg/kg, with most of these products having a concentration below 100 mg/kg. Sewage sludge compost, MBT compost and digestate display generally higher copper concentrations, with respectively three, two and five samples failing to meet the proposed limit value. It was noted that digestates with (3 samples) and without manure (2 samples) exceeded the proposed copper limit values, suggesting that manure seems not to be the only possible cause for elevated copper concentrations in digestate;

Mercury: all samples meet and most are well below the proposed limit of 1 mg/kg. Sewage sludge compost and MBT compost generally have higher mercury concentrations than compost and digestate made from source separated organic residues;

Nickel: most samples meet the proposed 50 mg/kg limit value, except for four FOGO compost samples, one green waste compost sample, one sewage sludge compost sample and one MBT compost sample. Although high natural soil nickel background concentrations can result in elevated nickel levels in compost originating from such areas, only one of the four concerned FOGO compost samples that exceeded the nickel limit appeared to originate from such a region in Italy, indicating that other types of contamination may have played a role in the analysed FOGO compost samples;

Lead: MBT compost samples show generally higher lead concentrations than the other materials, with four samples failing to meet the proposed limit of 120 mg/kg. All other products meet the proposed limit with digestate samples generally showing the lowest lead levels;

Zinc: FOGO and green waste composts generally display the lowest zinc concentrations, with only one green waste compost sample failing the 600 mg/kg limit. Sewage sludge compost, MBT compost and digestate display generally higher zinc concentrations, with one MBT compost and one digestate sample failing the proposed limit value.

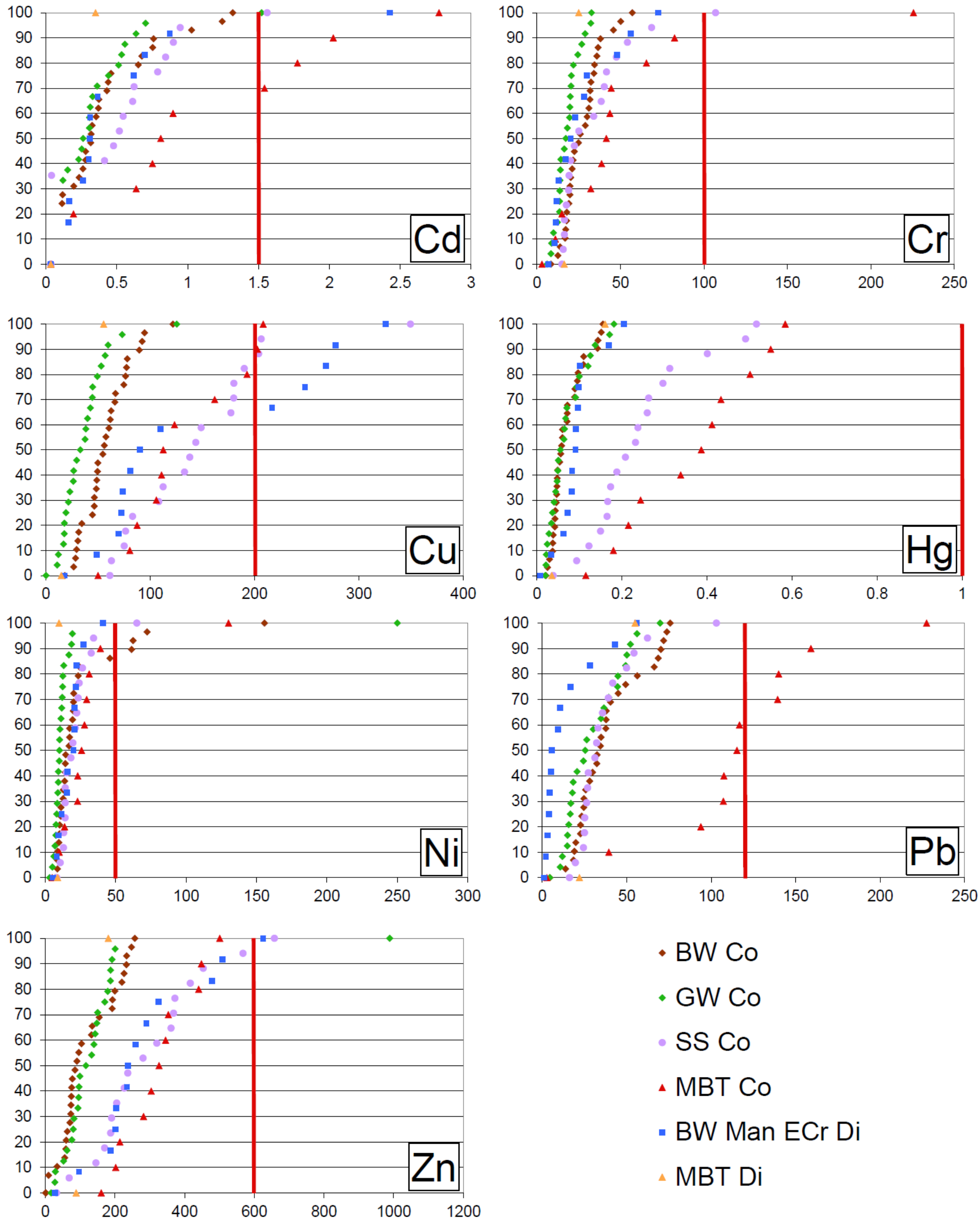


Figure 5 Heavy metals in compost and digestate samples collected in Europe. The horizontal axis represents the concentration (mg/kg d.m.) and the vertical axis the cumulative percentage of samples. The red bar represents the proposed maximum values for EU EoW product quality criteria (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment of MSW; Man=manure; ECr=agricultural energy crops) [Saveyn and Eder 2014]

Furthermore, the authors of the EU study also inferred from their own dataset that:

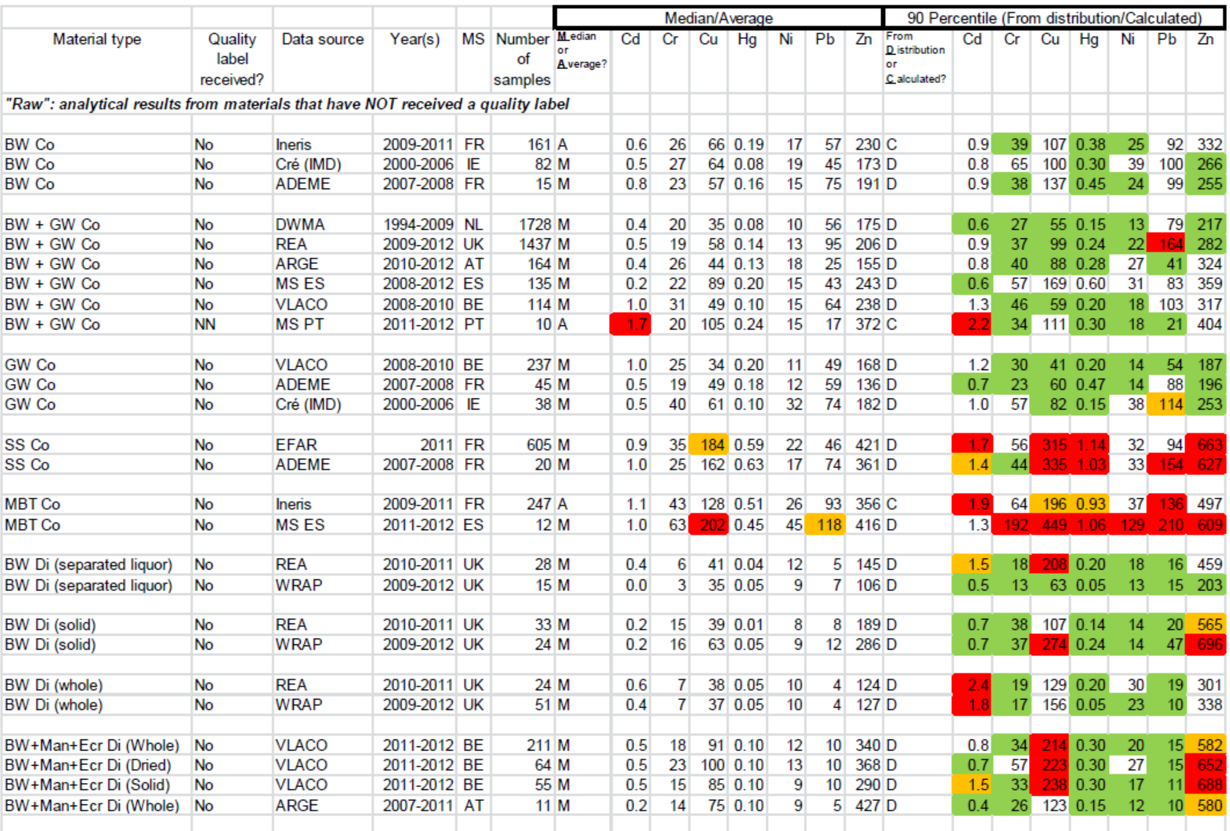
- In general, compost products from source separated collection of FOGO and green waste display the lowest overall heavy metal concentrations, except for lead. Composts produced from source separated garden organics nearly always meet the proposed limit values for individual heavy metals, but several FOGO composts exceeded the proposed nickel limits. Contaminant levels that exceed proposed limit values also demonstrate that analysis of the output material is necessary to track potential problems to contaminated input materials;

- Sewage sludge compost generally meets the proposed limit values for cadmium, chromium, mercury, nickel, lead and zinc (mostly) but tends to have problems in meeting the proposed copper limits;
- MBT compost generally meets the proposed limit values for copper, chromium, mercury, nickel and zinc (mostly) but tends to have problems in meeting the proposed limit values for cadmium and lead;
- Digestate generally meets the proposed limit values for cadmium, chromium, mercury, nickel, lead and zinc (mostly), displaying the generally lowest lead levels of all materials, but tends to have problems in meeting the proposed copper limits.

The EU study compared their own data, based on a relatively small sample size of 120, with existing data sources that had large sample numbers and were acquired over longer time periods to level possible seasonal variations. The collated information represents more than 14,000 compost and digestate samples made from different raw materials and sourced from different locations. The majority of data originated from National quality assurance organisations. About 5,500 samples represented ‘raw’ data, i.e. samples of materials applying for a quality label, but before being awarded the label. These datasets are shown in Table 21 while data representing 9,000 samples of products that were awarded a National quality label were omitted in the table below as they are less informative.

Table 21 Overview of heavy metal concentrations (mg/kg) in compost/digestate made from different raw materials. Information sourced from various European databases.

Note: Data are ranked per material type according to the number of samples (N) in the population. Cell colour filters: RED = proposed EU EoW limit exceeded, ORANGE = 90% of proposed EU EoW limit exceeded, GREEN = value below 50% of proposed EU EoW limit (green filter only applied on 90-percentile data) (NN= no information available; Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment; Man=manure; ECr=energy crops) [Saveyn and Eder 2014]



						Median/Average								90 Percentile (From distribution/Calculated)							
Material type	Quality label received?	Data source	Year(s)	MS	Number of samples	Median or Average?	Cd	Cr	Cu	Hg	Ni	Pb	Zn	From Distribution or Calculated?	Cd	Cr	Cu	Hg	Ni	Pb	Zn
"Raw": analytical results from materials that have NOT received a quality label																					
BW Co	No	Ineris	2009-2011	FR	161	A	0.6	26	66	0.19	17	57	230	C	0.9	39	107	0.38	25	92	332
BW Co	No	Cré (IMD)	2000-2006	IE	82	M	0.5	27	64	0.08	19	45	173	D	0.8	65	100	0.30	39	100	266
BW Co	No	ADEME	2007-2008	FR	15	M	0.8	23	57	0.16	15	75	191	D	0.9	38	137	0.45	24	99	255
BW + GW Co	No	DWMA	1994-2009	NL	1728	M	0.4	20	35	0.08	10	56	175	D	0.6	27	55	0.15	13	79	217
BW + GW Co	No	REA	2009-2012	UK	1437	M	0.5	19	58	0.14	13	95	206	D	0.9	37	99	0.24	22	164	282
BW + GW Co	No	ARGE	2010-2012	AT	164	M	0.4	26	44	0.13	18	25	155	D	0.8	40	88	0.28	27	41	324
BW + GW Co	No	MS ES	2008-2012	ES	135	M	0.2	22	89	0.20	15	43	243	D	0.6	57	169	0.60	31	83	359
BW + GW Co	No	VLACO	2008-2010	BE	114	M	1.0	31	49	0.10	15	64	238	D	1.3	46	59	0.20	18	103	317
BW + GW Co	NN	MS PT	2011-2012	PT	10	A	1.7	20	105	0.24	15	17	372	C	2.2	34	111	0.30	18	21	404
GW Co	No	VLACO	2008-2010	BE	237	M	1.0	25	34	0.20	11	49	168	D	1.2	30	41	0.20	14	54	187
GW Co	No	ADEME	2007-2008	FR	45	M	0.5	19	49	0.18	12	59	136	D	0.7	23	60	0.47	14	88	196
GW Co	No	Cré (IMD)	2000-2006	IE	38	M	0.5	40	61	0.10	32	74	182	D	1.0	57	82	0.15	38	114	253
SS Co	No	EFAR	2011	FR	605	M	0.9	35	184	0.59	22	46	421	D	1.7	56	315	1.14	32	94	663
SS Co	No	ADEME	2007-2008	FR	20	M	1.0	25	162	0.63	17	74	361	D	1.4	44	335	1.03	33	154	627
MBT Co	No	Ineris	2009-2011	FR	247	A	1.1	43	128	0.51	26	93	356	C	1.9	64	196	0.93	37	136	497
MBT Co	No	MS ES	2011-2012	ES	12	M	1.0	63	202	0.45	45	118	416	D	1.3	192	449	1.06	129	210	609
BW Di (separated liquor)	No	REA	2010-2011	UK	28	M	0.4	6	41	0.04	12	5	145	D	1.5	18	208	0.20	18	16	459
BW Di (separated liquor)	No	WRAP	2009-2012	UK	15	M	0.0	3	35	0.05	9	7	106	D	0.5	13	63	0.05	13	15	203
BW Di (solid)	No	REA	2010-2011	UK	33	M	0.2	15	39	0.01	8	8	189	D	0.7	38	107	0.14	14	20	565
BW Di (solid)	No	WRAP	2009-2012	UK	24	M	0.2	16	63	0.05	9	12	286	D	0.7	37	274	0.24	14	47	696
BW Di (whole)	No	REA	2010-2011	UK	24	M	0.6	7	38	0.05	10	4	124	D	2.4	19	129	0.20	30	19	301
BW Di (whole)	No	WRAP	2009-2012	UK	51	M	0.4	7	37	0.05	10	4	127	D	1.8	17	156	0.05	23	10	338
BW+Man+Ecr Di (Whole)	No	VLACO	2011-2012	BE	211	M	0.5	18	91	0.10	12	10	340	D	0.8	34	214	0.30	20	15	582
BW+Man+Ecr Di (Dried)	No	VLACO	2011-2012	BE	64	M	0.5	23	100	0.10	13	10	368	D	0.7	57	223	0.30	27	15	652
BW+Man+Ecr Di (Solid)	No	VLACO	2011-2012	BE	55	M	0.5	15	85	0.10	9	10	290	D	1.5	33	238	0.30	17	11	688
BW+Man+Ecr Di (Whole)	No	ARGE	2007-2011	AT	11	M	0.2	14	75	0.10	9	5	427	D	0.4	26	123	0.15	12	10	580

Interrogation of the large dataset fundamentally supported most findings reported above for the studies own sampling and testing regime. In short, the following conclusions were drawn from the extended database:

- Compost made from source segregated FOGO and garden organics generally meet all proposed heavy metal limit values at the 90-percentile level. Nonetheless, the extensive UK dataset (REA) indicated that 27.5 % of the samples fail the proposed EU end-of-waste limit for lead, which might be due to historical pollution from the extended use of leaded fuels. Conversely, compost made from FOGO and garden organics in Ireland did not show elevated lead levels (Herity 2003). The extensive Dutch DWMA database shows that 97.4% of the more than 1700 samples measured in the period 1994-2009 would meet the proposed limit values for all 7 heavy metals. The Spanish database also shows that more than 90% of the samples would meet the proposed limit values for all 7 heavy metals.
- Sewage sludge compost data from the extensive French EFAR database confirm higher median copper, mercury and zinc concentrations compared to FOGO and garden organics composts from source separate collection. In total, only slightly more than half of the 605 samples (52.2%) would meet all proposed 7 heavy metal limits, with failures noted particularly for cadmium, copper, mercury and zinc. Sludge compost data from Italy show that sewage sludge composts can meet most requirements if a strict input material controls are in place.
- The large French Ineris database (247 samples) shows that MBT compost generally meets chromium, nickel and zinc limits, but 8.0%, 12.4 % and 19.4% of the samples exceeded proposed maximum copper, cadmium and lead levels, respectively. None of the samples contained in the much smaller Spanish MBT data would meet all heavy metal limits.
- Data for pasteurised and mature composts were remarkably similar in median and 90-percentile values for all heavy metals. However, judgment as to what extent the maturity level influences the concentration of metals was not possible as the available database did not provide adequate information about the actual difference in the extent of organic matter decomposition

(mineralisation) that had occurred in pasteurised and mature compost ones. Nevertheless, the data did at least not support the hypothesis that maturation of composts systematically drives up heavy metal concentrations, expressed on dry weight basis, due to decomposition of organic matter.

- Digestate data were much less abundant compared to compost data, which is why they were interpreted with extreme care. Nonetheless, the limited UK datasets for FOGO digestates seem to suggest that median heavy metal concentrations are similar or lower than for composts, although in some cases problems were noted with cadmium, copper and zinc at 90-percentile level. Data from Belgium (VLACO) indicate that it may be difficult for digestate containing manure to meet zinc and especially copper limits. Various databases indicated that physical properties (liquid – solid – dried) of digestate have relatively little influence on metal concentrations, when expressed on dry matter basis.
- The data from across Europe showed that end product quality depends much more on the type of material processed and the processing technology employed rather than the geographical location where the raw material is sourced from.

Comparison of the proposed maximum heavy metal values for EU EoW product quality criteria with AS 4454 – 2012 limits shows that proposed EU levels are lower (Cd, Ni, Pb), equal to (Cr, Hg) or higher (Cu, Zn) than limits set for unrestricted use in the Australian compost standard. Contaminant limits (heavy metals and organic contaminants) proposed for the EU end-of-waste code for compost & digestate, were not implemented as an end-of-waste code, but were primarily integrated into European fertiliser regulations, plus some sub-ordinate regulations (Siebert 2019b).

Review of international compost quality data is interesting and potentially useful in assessing Australian compost products in lieu of available data, where the feedstocks are comparable. However, composting facilities in the EU are tightly regulated and rarely allowed to process the range of feedstocks that are accepted in some Queensland composting facilities.

5.3 Organic Contaminants

This section covers organic contaminants, which in this context, are compounds based on carbon including a range of hydrocarbons and organic chemicals.

5.3.1 AS4454 and the Stockholm Convention

Organic contaminant limits in AS4454 – 2012 are largely aligned with the NSW Biosolids Guideline values for Grade A products (see Table 10 above). The 9 compound groups listed in Table 10, and other organic contaminants are frequently termed 'persistent organic pollutants'. Persistent organic pollutants (POPs) resist photolytic, biological and chemical degradation (Ritter et al. 2007). They are often halogenated and are characterised by high lipid solubility, leading to their bioaccumulation in fatty tissues. They are also semi-volatile, enabling them to move long distances in the atmosphere before deposition occurs (Ritter et al. 2007).

Australia is a signatory to the Stockholm Convention on Persistent Organic Pollutants which came into force in 2004. The Convention is a global treaty that aims to protect human health and the environment from the effects of POPs. The Convention has a range of control measures to reduce and, where feasible, eliminate the release of POPs.

Persistent organic pollutants listed in AS4454 - 2012 include many of the first generation organochlorine insecticides such as dieldrin, DDT and chlordane and several industrial chemical products or byproducts such as polychlorinated biphenyls (PCBs) (Table 22).

Table 22: Organic contaminants listed in AS4454 – 2012 and their classification in the Stockholm Convention on Persistent Organic Pollutants

Chemical	Chemical class	Uses	Stockholm Convention classification*
DDT/DDE/DDD Dichlorodiphenyltrichloroethane and derivatives	Organochloride	Insecticide	Annex B
Aldrin	Organochloride	Insecticide	Annex A
Dieldrin	Organochloride	Insecticide	Annex A
Chlordane	Organochloride	Insecticide	Annex A
Heptachlor	Organochloride	Insecticide	Annex A
HCB Hexachlorobenzine	Organochloride	Fungicide	Annex A, C
Lindane	Organochloride	Insecticide	Annex A
BHC Isomers of hexachlorocyclohexane	Organochloride	Insecticide/by-product of Lindane production	Annex A

Chemical	Chemical class	Uses	Stockholm Convention classification*
PCBs Polychlorinated biphenyls	Organochloride	Various uses	Annex A, C

* Annex A: Parties must take measures to eliminate the production and use of these chemicals. Specific exemptions for use or production are listed in the Annex and apply only to Parties that register for them; Annex B: Parties must take measures to restrict the production and use of these chemicals in light of any applicable acceptable purposes and/or specific exemptions listed in the Annex; Annex C: Parties must take measures to reduce the unintentional releases of these chemicals with the goal of continuing minimisation and, where feasible, ultimate elimination.

Most of these chemicals have been targeted for complete elimination (Annex A), some have approved but restricted uses (Annex B), whilst the release of other chemicals to the environment may be the result of unintended consequences which nevertheless still need to be minimised (Annex C).

A brief summary of some of these chemicals from Table 22 is included below. This information has largely been adapted from the Stockholm Convention website (undated).

DDT (and its derivatives DDE and DDD) is an organochlorine insecticide that was widely used during World War II to protect soldiers and civilians from malaria, typhus, and other diseases spread by insects. Subsequently, DDT was widely used on a variety of agricultural crops, especially cotton. DDT continues to be applied against mosquitoes in several countries to control malaria. Its stability, persistence in the soil and its widespread use mean that DDT residues can be found everywhere, even in the Arctic. The best-known toxic effect of DDT is egg-shell thinning among birds, especially birds of prey. As a result, it was banned in many countries during the 1970s, but residues can still sometimes be detected in food. The short-term acute effects of DDT on humans are limited, but long-term exposures have been associated with chronic health effects. It has also been detected in breast milk, raising serious concerns about infant health.

Aldrin is an organochlorine insecticide that was widely used until the 1990s, when it was banned in most countries. Before the ban, it was heavily used as a pesticide to treat seed and soil to kill termites, grasshoppers, corn rootworm, and other insect pests. But it can also kill birds, fish, and humans. Aldrin is not toxic to insects; it is oxidized in the insect to form **dieldrin**, which is the active compound. In one incident in Texas, aldrin-treated rice is believed to have killed hundreds of shorebirds, waterfowl, and passerines. The fatal dose for an adult male human is estimated to be about 5 g, with exposure most likely to occur through dairy and meat products. Studies in India indicate that the average daily intake of aldrin and its by-product dieldrin is about 19 micrograms per person.

Another insecticide that was used to control termites is **chlordane**. Chlordane remains in the soil for a long time and has a reported half-life of one year. The lethal effects of chlordane on fish and birds vary according to the species, but tests have shown that it can kill mallard ducks, bobwhite quail, and pink shrimp. Chlordane may affect the human immune system and is classified as a possible human carcinogen. It is believed that human exposure occurs mainly through the air, and chlordane has been detected in the indoor air of residences in the US and Japan.

As mentioned previously, some chemicals in Annex A are approved for use under specific exemptions. For example, **lindane** had in the past been used as a broad-spectrum insecticide for a variety of applications but parties to the Convention now limit it use to controlling head lice and scabies.

Hexachlorobenzene (HCB) and **polychlorinated byphenyls (PCBs)** are two examples of chemicals that have two sources of origin – direct, intended manufacture or as by-products in the manufacture of other target chemicals. HCB was first introduced in 1945 as a fungicide seed treatment. But it is also a by-product of the manufacture of other industrial chemicals and exists as an impurity in several pesticide formulations. When people in eastern Turkey ate HCB-treated seed grain between 1954 and

1959, they developed a variety of symptoms, including photosensitive skin lesions, colic, and debilitation; several thousand developed a metabolic disorder called porphyria turcica, and 14% died. Mothers also passed HCB to their infants through the placenta and through breast milk. In high doses, HCB is lethal to some animals and, at lower levels, adversely affects their reproductive success. HCB has been found in food of all types. A study of Spanish meat found HCB present in all samples. In India, the estimated average daily intake of HCB is 0.13 micrograms per kilogram of body weight.

PCBs are used in industry as heat exchange fluids, in electric transformers and capacitors, and as additives in paint, carbonless copy paper, and plastics. Their persistence in the environment corresponds to the degree of chlorination, and half-lives can vary from 10 days to one-and-a-half years. PCBs are toxic to fish, killing them at higher doses and causing spawning failures at lower doses. Research also links PCBs to reproductive failure and suppression of the immune system in various wild animals, such as seals and mink.

Large numbers of people have been exposed to PCBs through food contamination. Consumption of PCB-contaminated rice oil in Japan in 1968 and in Taiwan in 1979 caused pigmentation of nails and mucous membranes and swelling of the eyelids, along with fatigue, nausea, and vomiting. Due to the persistence of PCBs in their mothers' bodies, children born up to seven years after the Taiwan incident showed developmental delays and behavioural problems. Similarly, children of mothers who ate large amounts of contaminated fish from Lake Michigan showed poorer short-term memory function. PCBs also suppress the human immune system and are listed as probable human carcinogens.

Production and importation of PCBs are not permitted in Australia, with the phase-out of existing PCBs being managed under the National Strategy for the Management of Scheduled Waste (Department of the Environment and Energy undated). This strategy also addresses how Australia will manage HCB waste and organochlorine pesticides.

Halogenated POPs can be classified as **AOX** (adsorbable organic halogens). AOX is a measure of the total organic halogen load in soil, water or biosolids measured by extraction with activated carbon. The procedure measures chlorine, bromine, and iodine (not fluorine) on an equivalency basis. It follows the general principle that increasing halogenation is associated with reduced biodegradability and toxicity.

5.3.2 Other chemical groups of concern

Many studies refer to PCBs exhibiting **dioxin-like** toxicity in that they demonstrate the same specific toxic mode of action relative to the most toxic **dioxin**, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Of the 209 different types of PCBs, thirteen exhibit a dioxin-like toxicity. The toxicity of PCB and other dioxin-like chemicals like the **furans** (the polychlorinated dibenzo-p-furans) comprises carcinogenic and endocrine disruptive effects and neurotoxicity.

Dioxins and furans are often grouped together under the acronym, **PCDD/F (polychlorinated dibenzo-p-dioxins/furans)**. PCDD/Fs are not made for any specific purpose; they mostly exist as by-products of industrial processes such as bleaching paper pulp, pesticide manufacture, and combustion processes such as waste incineration (Environment Australia 1999). Composting was also investigated as a potential source of dioxins, but this was not supported by science (Fricke et al. 1996, Brändli et al. 2007b, Conesa et al. 2009) The most infamous examples of dioxin-containing chemicals and their devastating effects are probably the defoliant Agent Orange and the release of dioxin (TCDD) in an industrial accident in Seveso (Italy) in 1976.

The **polycyclic aromatic hydrocarbons (PAH)** also originate from combustion processes and are of concern because of their carcinogenic and mutagenic character (Saveyn and Eder 2014). PAHs are hydrocarbons — organic compounds containing only carbon and hydrogen in multiple aromatic rings. PAHs are uncharged, non-polar molecules found in coal and in tar deposits. They are also produced by the thermal decomposition of organic matter. They are considered ubiquitous in the environment and can be formed from either natural or manmade combustion processes (Ramesh et al. 2011).

The measurement of PAHs is usually determined as the sum of the US EPA's 16 "priority" chemicals (ΣPAH_{16}). These range from naphthalene (C10, molecular weight 128) to more complex chemicals such as indeno[1,2,3-cd]pyrene (C22, molecular weight 276). PAHs like naphthalene, phenanthrene and pyrene are major constituents of diesel fuel (De Souza and Correa 2016), but they can also be released into the atmosphere from the incomplete combustion of both petroleum products and other organic biomass.

There is therefore some commonality between analysis of PAHs and **TPA/TRH (total petroleum hydrocarbons/total recoverable hydrocarbons).** TRH (rather than TPH) has become the standard term to describe the total quantity of hydrocarbons in a sample, including but not limited to, petroleum hydrocarbons (i.e. some PAHs will also be measured in TRH). TRH quantifies a mixture of compounds falling into various carbon number ranges or fractions (e.g. C10-C14, C15-C28 and C29-C36) without identification of the individual compounds. The individual compounds can be identified by further analysis, for example by GC-MS (gas chromatography-mass spectrometry).

Perfluorooctanesulfonic acid (PFOS) is an anthropogenic fluorosurfactant. It was the key ingredient in Scotchgard, a fabric protector made by 3M, and numerous stain repellents. PFOS was added to Annex B of the Stockholm Convention in May 2009. Historically, PFOS has been used for a variety of products due to its surface-active properties, surface resistance/repellence to oil, water, grease or soil (UNEP, 2018). PFOS is both intentionally produced and formed by degradation from a large group of related substances, referred to as PFOS-related substances.

PFOS is widely used in electric and electronic parts, fire fighting foam, photo imaging, hydraulic fluids, leather, paper and textiles. High bioaccumulation of PFOS have been found in notable concentrations in Arctic animals, such as polar bears, seals, bald eagles and mink, tropical biota, birds and fish. A risk assessment conducted for the Stockholm Convention claimed that PFOS has the potential to affect the liver, kidney, thyroid, fecundity, and could lead to cancer formation (UNEP, 2018). It should be noted that there has been considerable debate about the economic impact of phasing out PFOS, especially in developing countries (Wang et al. 2009). The UNEP concedes that alternatives to PFOS for some applications are not always available in developing countries. Furthermore, for some applications like photo imaging, semi-conductor or aviation hydraulic fluids, technically feasible alternatives to PFOS are not available to date.

Australia has yet establish safe threshold criteria for PFOS in agricultural soils, but the PFAS National Environmental Management Plan (HEPA, 2019) has developed interim soil screening values for residential areas of between 10 and 2,000 µg PFOS or PFHxS/kg, depending on accessibility of soil by residents / the public to protect humans from food chain exposure, 10 µg PFOS/kg for ecological indirect exposure (to protect from soil ingestion by a secondary consumer) and 200 µg PFOS or PFHxS/kg to protect against exposure for birds.

Other surfactants include the **alkylbenzene sulfonates,** which are anionic chemicals found in personal-care products such as soaps, shampoos and toothpaste, as well as other household products (e.g. laundry detergent, dishwashing liquid, spray cleaner etc.). They were first introduced in the form of branched alkylbenzene sulfonates (BAS) but have since been replaced by linear **alkylbenzene sulfonates (LAS)** due to environmental concerns. Some European countries have set limits for LAS compounds in compost and compost-like products (see Table 23 below), although it is thought that these chemicals are generally degradable under aerobic conditions (Amlinger et al. 2004). They may be present in anaerobically digested biosolids, but are quickly degraded once the material is exposed to aerobic conditions (Jensen 1999).

Other chemicals used in personal care products include the **nonylphenols and nonylphenol ethoxylates (NP/NPEs)**. These are nonionic surfactants, or detergent-like substances, with uses that lead to widespread release into aquatic environments. NP/NPEs are highly toxic to aquatic life (US EPA 2016). NP/NPEs are produced in large volumes, and are used for industrial processes and in consumer laundry detergents, personal hygiene, automotive, latex paints, and lawn care products.

Tributyltin (TBT) is an umbrella term for a class of "**organotin**" compounds containing an organic complex with tin ($(C_4H_9)_3Sn$). A prominent example is tributyltin oxide as it was used for decades as a biofouling agent in marine paint (Antizar-Ladislao, 2008). The International Maritime Organization has banned the use of TBT since 2008. TBT is also used in other industrial applications such as slime control in paper mills, disinfection of circulating industrial cooling waters, and in the preservation of wood. TBT compounds are known for their toxic, persistent, bioaccumulative and endocrine disruptive characteristics.

Brominated flame-retardants are organobromine compounds that have an inhibitory effect on combustion chemistry and therefore reduce the flammability of products that contain them. They are used extensively in plastics and textile applications like electronics, clothes and furniture. Some of these are listed in Annex A of the Stockholm Convention. There are many types of brominated flame-retardants including **polybrominated diphenyl ethers (PBDEs)**, polybrominated biphenyls (PBB), brominated cyclohydrocarbons, hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA). PBDEs have caused neurotoxic health effects in both animal and human studies (NSW EPA 2018). PBDEs have also been identified in dust from Australian households (Stasinska et al. 2013).

Some of the chemicals listed in the Stockholm Convention are used as plasticisers. They are particularly useful in reducing brittleness in plastics such as PVC. For example, the **phthalates** are semi-volatile plasticisers. They are considered to have harmful effects on the reproductive and endocrine systems (Heudorf et al. 2007). Phthalates are used in a wide variety of products including building materials, food packaging, baby care products, children's toys and cosmetics. The most common class of phthalate are the **di-(2-ethylhexyl)-phthalates (DEHP)**.

Other chemicals used in the manufacture of plastics are also of concern to public and environmental health. For example, **bisphenol A (BPA)** is an important component in the synthesis of plastics, particularly some polycarbonates and epoxy resins. BPA-based plastic is clear and strong, making it quite common in plastic water bottles and other hard plastics like those found in CD and DVD covers.

Epoxy resins containing BPA are used to line water pipes, as coatings on the inside of many food and beverage cans and in thermal paper such as that used in sales receipts (Pivnenko et al. 2015). There is some debate about the human health risks associated with exposure to BPA. In 2015, the European Food Safety Authority (EFSA, undated) concluded "BPA poses no health risk to consumers of any age group (including unborn children, infants and adolescents) at current exposure levels". This assessment, however, is now under review by an EFSA-appointed scientific expert committee. In contrast, the European Chemicals Agency (undated) concluded that BPA should be listed as a substance of very high concern due to its properties as an endocrine disruptor.

Authorities in the US and Canada have also acknowledged that whilst there is insufficient data to conclude that likely exposure levels will have negative health effects, a precautionary approach should be taken by banning the use of BPA in infant bottles. In addition, in a survey conducted by Food Standards Australia New Zealand (FSANZ), the levels of intake of BPA were found to be "very low and do not pose a significant human health risk for any age group" (FSANZ, 2010). But FSANZ also acknowledged that there are "some unresolved uncertainties in the data on BPA, and notes that further studies are currently being conducted in the US to address these uncertainties". FSANZ will review these studies as they become available.

The **polychlorinated alkanes (PCAs)**, often referred to as chlorinated paraffins (CPs), are a class of industrial chemicals comprising of chlorinated straight-chain hydrocarbons. They have been produced since the 1930s for use as extreme pressure lubricant additives, plasticizers, flame-retardants, and paint additives (Clarke and Smith, 2011). Because of their widespread and unrestricted use, Clarke and Smith (2011) reported that PCAs are found in a range of environments such as in human milk, environmental samples and in air over the UK, including remote regions. The International Agency for Research into Cancer (IARC) has classified PCAs as Class 2B, meaning that they are possibly carcinogenic to humans (IARC, 1998).

The historical use of **polychlorinated naphthalenes (PCNs)** preceded PCBs, though their applications are similar (Clarke and Smith, 2011). PCNs are structurally similar and have similar physico-chemical properties to the PCBs. PCNs have been widely used since the early 1900s as dielectric fluids, engine oil additives, electroplating masking compounds, wood preservatives, lubricants, and for dye production (Falandysz, 1998). PCNs were phased out in the USA from the 1970s but by the 1990s, global production of PCN mixtures was estimated to still be about 150,000 t (Falandysz, 1998). PCNs are ubiquitous environmental contaminants sharing many of the characteristics of other POPs, and several congeners exhibit dioxin-like toxicity (Clarke and Smith, 2011).

5.3.3 Organic contaminant limits in other countries

Very few countries have set limits for organic contaminants in compost and related products.

Since the presence or absence of organic contaminants in compost is mainly related to the characteristics of the processed feedstock material, most European countries identify which feedstocks can and cannot be composted (Bernal et al. 2017). Other countries like the Netherlands, Austria and Germany do not require the measurement of organic contaminants in compost and digestate when they are derived from source-separated materials (Saveyn and Eder, 2014). In the UK, the PAS 100 compost quality standard and the PAS 110 standard for digestate and related products do not require analysis of organic contaminants, but again, strict feedstock controls apply. The PAS Standards can only be applied to products derived from source-separated “biowaste (FOGO) and biodegradable” materials (BIS 2010, 2011).

Biosolids (and derivatives) and treated/painted timber waste are specifically excluded from the Standard. Food and catering residual, and other types of organic residues containing animal by-products can only be fed into the composting process if they comply with the composter’s HACCP (hazard analysis and critical control point) plan. Composters must take care “to avoid any potentially polluting wastes, products or materials from becoming included with the input materials”.

Organic contaminant limits for composts and related products do apply in some European countries (Table 23; Saveyn and Eder, 2014). In several EU member countries, legislation is specific to the feedstock being processed. For example, the German Sewage Sludge Regulation prescribes limits for biosolids products/composts, *viz*: 0.2 mg/kg dm for every of the PCB_6 congeners and 100 ng I-TEQ/kg dm for 17 priority PCDD/Fs. Austria also has a different set of limits for MBT compost that are only approved for use in landfill capping and biofilter applications: 1 mg/kg dm for PCB_6, 50 ng I-TEQ/ kg dm for PCDD/F and 6 mg/ kg dm for PAH_6 (Saveyn and Eder, 2014).

Table 23: Organic contaminant concentration limits for compost and related products in selected EU countries [adapted from Saveyn and Eder 2014]

Chemical	Austria	Belgium/ Wallonia[a]	Germany	Denmark	France	Luxembourg[b]	Slovenia	Switzerland[b]
PAH (mg/kg)	6[c]	5 (PAH_{16})		3[d]	Note[e]	10 (PAH_{16})	3	4 (PAH_{16})
PCBs (mg/kg)	0.2 (PCB_6)	0.15 (PCB_7)	Note[f]	0.08 (PCB_7)	0.8 (PCB_7)[g]	0.1 (PCB_6)	0.4 (PCB_6)	
PCDD/F[h]	20	100	Note[f]			20		20
PFC (mg/kg) (PFOS + PFAS)	0.1		0.1					
AOX (mg/kg)	500	250						
LAS (mg/kg)		1500[i]		1300				
NPE (mg/kg)		25[i]		10				
DEHP (mg/kg)		50[i]		50				

[a] For digestate in the state of Wallonia; [b] Guide values for Luxembourg and Switzerland; [c] sum of benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, fluoranthene and indeno[1,2,3-cd]pyrene; [d] sum of acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene and indeno[1,2,3-cd]pyrene; [e] individual limits for 3 cogeners; [f] Maximum sum of PCDD/F and dl-PCB: 30 ng WHO-TEQ/kg dm, in some cases additional restrictions for PCDD/F only of maximum 5 ng WHO-TEQ/kg dm; [g] Only for biosolids compost; [h] PCDD/F= sum of 17 polychlorinated dibenzo-p-dioxins/furans expressed in International Toxicity Equivalents; [i] Guide value; PAH_{16}= sum of US EPA 16 priority listed PAHs; PCB_6= sum of PCBs 28, 52, 101, 138, 153 and 180; PCB_7= sum of PCBs 28, 52, 101, 118, 138, 153 and 180;

The long-standing position of the UK, USA and Canada and many other countries is that there is no conclusive evidence that the levels of organic contaminants typically found in recycled organic materials is hazardous to soil quality, human health or the environment. This may be partly due to the large number of potential contaminants, the relatively low levels of contaminants, and the gap in knowledge about the chronic effects of contaminants on human health and the environment (Tremblay et al. 2014). Nevertheless, a degree of vigilance is always recommended to monitor and determine the significance and implications of ‘emerging’ organic contaminants that may be present in land-applied organic materials (e.g. see Clarke and Smith, 2011 with respect to biosolids).

It is also possible that many of these other jurisdictions do not allow as wide a range of wastes, including regulated wastes, to be used as compost feedstocks so there may be less need to be concerned about the presence organic contaminants.

The Canadian Guidelines for Compost Quality (PN 130) recognises that “trace amounts” of persistent or bio-accumulating organic contaminants can be present in some compost feedstocks, and recommends that special attention should be given to avoiding feedstocks with “high contents” of these contaminants (Canadian Council of Ministers for the Environment 2005). However, they consider that, given the low content of dioxin and furans in compost feedstock in Canada, routine analysis under the Guidelines for Compost Quality is not necessary. The same also applies to PCB and PAH, though readers are encouraged to seek specific advice from their provincial or territorial authority that has jurisdiction.

The same general situation appears to apply in the United States. There is not one compost quality standard enforced in the US, though there has been a significant effort to harmonise testing standards through the development of the Testing Methods for the Evaluation of Composting and Compost (TMECC). The TMECC was a joint initiative of the US Composting Council and the US Department of Agriculture (TMECC, undated). Whilst the TMECC outlines standardised testing methods, including for some organic contaminants, it does not specify limits. In addition, the US EPA biosolids “Part 503” rule does not include any limits for organic contaminants, only heavy metals. However, recent developments in the US may suggest that the position of the US EPA could be changing. A review of a variety of studies from 1989 to 2015 identified 352 pollutants of concern, including 61 as “acutely hazardous, hazardous or priority pollutants”, but the Agency currently lacks the ”data or risk assessment tools needed to make a determination” on their safety (US EPA, 2018).

Appendix B contains a summary of various regulatory standards and thresholds used in other jurisdictions internationally.

5.3.4 Organic contaminants found in compost feedstock and compost products

Studies conducted within Australia and overseas have sometimes concluded that particular organic contaminants should be monitored in specific cases, depending on the type of feedstock being treated.

The Queensland Department of Environment and Science analysed six compost samples in 2017 for a total of 147 potentially hazardous compounds in order to gain understanding of the types and levels of contaminants that might be contained in compost products generated and supplied in Queensland. The chemical compounds analysed for represented the following contaminant groups:

- Methylene blue active substances (MBAS)
- Polychlorinated biphenyls (PCBs)
- Organochlorine pesticides
- Organophosphorous pesticides
- Phenolic compounds
- Polynuclear aromatic hydrocarbons (PAHs)
- Total petroleum hydrocarbons (TPHs)
- Total recoverable hydrocarbons (TRHs)
- Benzene, toluene, ethylbenzene and xylene (BTEXN)
- Perfluoroalkyl Sulfonic Acids
- Perfluoroalkyl Carboxylic Acids
- Perfluoroalkyl Sulfonamides
- FSAs
- PFAS Sums

A summary of the test results is provided in Table 24. It can be seen that no maximum concentration limits exist within seven of the assessed contaminant groups, and that where limits for soil are referenced (Health Investigation Levels, PFAS NEMP - residential with garden accessible soil (Jan 2018)) one of the six tested composts exceeds the PFOS soil limit for residential soil with garden access by a factor of more than 20. None of the other referenced limits were exceeded by any of the tested compost products. Reported test results for organochlorine pesticides suggest that all samples exceeded AS 4454 – 2012 limits for of 0.02 mg/kg dm for eight organochlorine pesticides, but that is highly unlikely.

Table 24 Range of concentrations (mg/kg dm) of 147 contaminants in various contaminant groups found in six compost products sampled in Queensland in December 2017 [adapted from Department of Environment and Science, unpublished]

Chemical	Limits	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
MBAS	none	22	23	135	<14	55	22.5
PCBs	1.0**	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3
Organochlorine pesticides	0.02* for 8 of 21 chemicals 6 – 300** for some of 21 chemicals	< 0.14 - < 0.2	< 0.14 - < 0.2	< 0.3 - < 0.31	< 0.29 - < 0.3	< 0.29 - < 0.3	< 0.28 - < 0.31
Organo-phosphorous pesticides	none	< 0.5					
Phenolic compounds	100 – 3,000** for two of 12 chemicals	< 0.5 - 10	< 0.5 - 2	< 0.5 - 29	< 0.5 - 3.7	< 0.5 - 3.8	< 0.5 - < 2

Chemical	Limits	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6
PAHs	1 – 300** for three of 18 chemicals	0.5 or < 0.5					
TPHs C6 - C9 Sum C10 – C36	none	< 10 4,690	< 10 3,900	< 10 11,800	< 10 3,630	< 10 3,045	< 10 2,830
TRHs C6 - C10 Sum C10 – C40	none	< 10 5,335	< 10 4,355	< 10 12,350	< 10 4,535	< 10 3,395	< 10 3,125
BTEXN	3 – 160** for four of 8 chemicals	< 0.2 - < 1					
Perfluoroalkyl sulfonic acid	PFOS 0.009^ none for other 5 chemicals	0.0012 < 0.0002 – 0.006	**0.218** < 0.0005 – 0.081	< 0.0002	< 0.0002	< 0.0002	0.0015 < 0.0002
Perfluoroalkyl carboxylic acid	0.1^ for one of 11 chemicals	< 0.0002 – 0.053	< 0.0005 – 0.036	< 0.0002 – < 0.001	< 0.0002 – < 0.001	< 0.0002 – < 0.001	< 0.0002 – 0.0012
Perfluoroalkyl sulfonamides	none	< 0.0002 – < 0.0005	< 0.0002 – < 0.0005	< 0.0002 – < 0.0005	< 0.0002 – < 0.0005	< 0.0002 – < 0.0005	< 0.0002 – < 0.0005
FSAs	none	< 0.0005 – 0.0077	< 0.0005 – 0.141	< 0.0005	< 0.0005	< 0.0005	< 0.0005 – 0.0006
Sums PFAS PFHxS + PFOS	none	0.0153 0.0018	0.594 0.298	< 0.0002	< 0.0002	< 0.0002	0.036 0.0016

* Australian Standard for Compost, soil conditioner and mulches, AS 4454 - 2012
** NEPM schedule B1 (HIL_A)
^ PFAS NEMP Residential with garden accessible soil (Jan 2018)

It is worth noting that TPHs (C10 – C36) and TRHs (C10 – C40) levels range between approximately 3,000 and 5,000 mg/kg dm for five of the six tested products. This is relatively high considering that maximum levels of 4,000 and 1,000 mg/kg dm for TPH (C10 – C36) were set for composting feedstock and finished product respectively, in licensing conditions for a composting operation in Queensland. The source of elevated TPHs in feedstock and finished compost products is not clear.

The tests for TPH and TRH are inherently non-specific in identifying the particular hydrocarbons that are present so it is difficult to hypothesise on their source.

Analysis of unprocessed green waste samples provided to Arcadis by one composter showed low levels of TPH and TRH (up to a maximum of around 1400 mg/kg total). Similarly, analysis of a single grease trap waste sample showed total TRH levels around 1900 mg/litre. These elevated levels within two of the most common composting feedstocks are interesting, but cannot fully account for the TRH / TPH levels detected in finished compost products. Either other feedstocks are contributing to the TRH / TPH levels, which is unusual because the levels were consistent across six different sites, or they could be the result of secondary metabolites from the decomposition of organic matter.

Otherwise, there is very little data or research in the literature about expected TPH/TRH levels in either green waste or compost and the potential for secondary decomposition products to contribute to these parameters. Focus tends to be on PAH analysis, which is more specific to known toxic compounds. It may be worth further investigating the speciation of the hydrocarbons that comprise the TPH/TRH results to help identify the real source.

5.3.4.1 Municipal solid waste-like products

There is only facility in Queensland which extracts organics from mixed municipal waste (household waste) and subjects them to composting. The facility in Cairns has been in operation since around 2006 and uses a variant of mechanical-biological treatment technology (MBT), which combines mechanical processing of the mixed waste to separate the organic fraction, with biological processing of the organic fraction to produce a compost product. The compost from MBT processes tends to be quite contaminated, both with physical impurities (glass, plastic and metal fragments) and chemical contaminants (lead is a particular concern, sourced from batteries).

There are a number of MBT plants installed across New South Wales and Western Australia. The NSW EPA recently announced a snap ban on the application of MBT composts, or Mixed Waste Organic Outputs (MWOO), by rescinding a Resource Recovery Exemption (similar to an End of Waste code in Queensland) which allowed their use on land under tight conditions. The ban was prompted by new independent research which indicated unacceptable risks to the environment from the physical and chemical contaminants in the product, and questioned the benefits to soil quality from its application. Investigations are ongoing to assess whether some outlets, such as mine rehabilitation and forestry, will be allowed in the future with added controls. However its use in agriculture will not be allowed.

NSW EPA come under significant criticism for its handling of the MWOO ban, given it was introduced with immediate effect and no transition plan for the five facilities that were producing it. The EPA promoted MBT as a viable solution to divert MSW from landfill for many years, resulting in significant capital investment in processing infrastructure and commitments by many councils to use the facilities. It is yet to be seen whether the Government will soften its stance in the face of significant industry pressure.

Internationally, MBT has been used for decades in North America producing compost products that are spread to agricultural land and other uses. In the UK, it went out of favour when composting regulations were significantly tightened in the wake of the mad cow disease outbreak. In the EU, there are many MBT plants but very few produce a compost product for land application – rather they are used as a pre-treatment to energy-from-waste facilities or landfill. In fact, MBT facilities were used in some countries (Germany, Austria, Italy) to stabilise residual waste prior to landfilling in MBT landfills and hence to reduce greenhouse gas emissions. It is assumed that landfilling of MBT waste that meets maximum respiration index and gas production potential values results in approximately 80–90% lower gas emissions than when untreated residual waste is landfilled (Heyer et al 2013).

The research commissioned by NSW EPA of the risks associated with the application to land of composts derived from MWOO (NSW EPA 2018) included a summary of a “systematic evaluation” of organic contaminants in MWOO composts, but limited detail on analytical methods, sampling strategy and the numbers of samples taken was provided. Nevertheless, the results of this study suggested that the main chemicals of concern included PBDEs, phenols, phthalates, PAHs, and tributyltin (TBT).

The phenols were included as chemicals of concern by the NSW EPA because although they appear not to be particularly toxic to humans, their ecological threshold values are apparently low (about 0.13 mg/kg).

PBDEs were identified in MWOO at concentrations of up to 720 mg/kg (Table 10). A risk assessment identified that such high concentrations of PBDEs occurring in MWOO could be of concern for human health, though it stated that the long-term effects of these compounds are not clear. However, a risk assessment for the European Commission proposed critical levels for application to soil of 50 mg/kg for PBDE congener groups and 500 µg/kg for PentaBDE (ESWI 2011).

With respect to phthalates, dibuytl phthalate (DBP), bis-2-ethylhexyl adipate (DEHA) and bis-2-ethylhexyl phthalate (DEHP) were the main chemicals found in MWOO, with concentrations of up to 2,600 mg/kg measured for DEHP (Table 10). As with many of these chemicals of interest, concentrations in MWOO were found to be highly variable and high concentrations were common in some batches, probably due to periodic failures in the source separation of plastics. NSW EPA noted that previous work had shown that phthalates are not persistent in soils and will degrade over time (Cartwright et al. 2000 cited by NSW EPA 2018). The EPA had also commissioned other work in this program that confirmed DEHP concentrations declined over the course of a 3-year experimental field trial (Whatmuff et al. 2017 cited by NSW EPA 2018). However, concentrations of up to 1 mg/kg were still measured in soil 3 years after application of 10 t/ha.

Bisphenol A was detected in all MWOO sampled with concentrations ranging from 4 to 100 mg/kg (Table 25), with a fraction of the compound being leachable. In the hazard ranking undertaken by the researchers, BPA was regarded as a lower hazard than PBDEs and phenols; it was deemed to be primarily a threat to soil ecological health based on the ecological threshold value adopted for it by the European Chemicals Agency. They further state, however, that there is “limited information on the attenuation of BPA and impacts on soil toxicity over time”; and furthermore, that it “is also unclear whether on areas where food is grown BPA could be taken up in plants or adhere to plants which may be consumed”.

Table 25: Concentrations (mg/kg dm) of chemical contaminants found in MWOO [NSW EPA 2018]

Chemical compound	Facility A	Facility B
Phenols	4.8-85	<0.42-98
Phthalates	0.48-2,600	<0.29-180
Chlorobenzenes	Below LOD*	Below LOD*
Nitrobenzenes	Below LOD*	Below LOD*
Pesticides	Few detected, very low	Few detected, very low
Herbicides	Few detected, very low	Few detected, very low
PCBs	Below LOD*	Below LOD*
Bisphenol A	14-27	4-100
Tributyltin (TBT)	<0.0005 – 0.058	<0.0005-0.0011
PBDEs Total	3.8-720	0.096-0.970

* LOD = limit of detection

The NSW EPA program screened for over 100 pesticides in MWOO, with most compounds being undetectable. Of those detected, thiabendazole, dicamba, 2-methyl-4- chlorophenoxyacetic acid (MCPA) and methylchlorophenoxypropionic acid (MCPP) were the most frequent, with MCPA having the highest concentrations in the solid material (1.8 mg/kg). MCPA was also the most frequently detected pesticide in soil leachates. In fact, no pesticides were ranked as posing a particular concern in the associated risk assessment conducted by the program researchers. A similar conclusion (low risk) was also attributed to TBT since concentrations in MWOO compost were found to be very low (Table 25).

This study also investigated PFOS/PFAS concentrations in MWOO-derived composts and compared them to analyses collected from biosolids samples. They found that, in general, concentrations of PFAS were lower in MWOO than in biosolids. The dominant compounds detected in MWOO were PFOS (up to 6.2 µg/kg), PFHxA (up to 26 µg/kg) and N-MeFOSE (up to 11.0 µg/kg). Concentrations of the ∑PFAS varied from non-detectable to 47.4 µg/kg. Leachable concentrations of PFAS varied from non-detectable to 0.68 µg/L, with the highest values found for PFHxA. Maximum concentrations of leachable PFOS and PFOA were 0.07 and 0.10 µg/L, respectively. These compared favorably to freshwater guideline values of 0.13 and 220 µg/L for PFOS and PFOA in slightly-to-moderately-disturbed systems (NSW EPA 2018). Their conclusion was that, even allowing for no dilution in the landscape, the use of MWOO would not lead to the interim freshwater guideline values being exceeded.

After the completion of this research program, the NSW EPA concluded that limit values for PBDEs, phenol and phthalates (DEHP) should be developed to ensure safe use of these materials in agriculture to protect the environment and human health.

Earlier, Hyder Consulting (Hyder, 2008) conducted a project for the Waste Management Association of Australia on “chemicals of concern” in mechanical-biological treatment (MBT) processes that produce a compost-like organic fraction called “alternative waste technology derived organic rich fraction”, or AWT DORF. At that time, with increasing Australian interest in MBT technologies, there was concern that the NSW Biosolids Guidelines and the Australian Standard (AS4454) do not cover all potential contaminants that may be found in AWT DORF as a result of its mixed waste origin.

A literature review investigated 49 chemicals of concern to determine their likelihood of being present in MSW, and an assessment was made of the environmental hazard associated with each chemical when applied to land. Three temporally distinct samples were then collected from four AWT facilities and two green waste composting facilities in order to test for these chemicals

Most of the chemicals of concern were either absent in AWT DORF or their levels were very low and close to the limits of detection (Table 26). Indicative statistical analysis also demonstrated that for the vast majority of chemicals, concentrations were not significantly higher in AWT DORF than in samples representing compost made from source separated organics.

Table 26: Risk levels and test results for 'chemicals of concern' in AWT DORF [Hyder 2008]

Chemical	Application	Risk of presence in MSW	Environ hazard rank	Eco Threshold Value (mg/kg)	Detection in compost & AWT DORF (range mg/kg)
Cypermethrin	Insecticide	HIGH RISK	4	0.86	ND
Chlorpyrifos	Pesticide		7	0.3	AWT DORF - 1 sample (0.14)
Simazine	Herbicide		35	105	AWT DORF - 1 sample (0.17)
Permethrin	Medication/insecticide		--	5.2	AWT DORF - 12 samples (0.25-0.43)
Brodifacoum	Pesticide	MEDIUM RISK	1	0.01	Not Analysed
Tebuconazole	Fungicide		5	45	ND
Dichlofluanid	Fungicide		28		Not Analysed
DEHP	Plasticiser		33	57	8 samples (2.2-870)
Dibutyl phthalate (DBP)	Plasticiser		40	0.72	AWT DORF - 1 sample (2)
Monobutyltin (MBT)	Plasticiser/glass coating		--		AWT DORF - 12 samples; Compost - 2 samples (1.5-35 ng/L)
Methidathion	Insecticide	LOW RISK	6	1.2	ND
Emamectin benzoate	Insecticide		8		Not Analysed
Triclopyr	Herbicide/ fungicide		10	33	AWT DORF - 3 samples (0.01-0.1)
Profenofos	Insecticide		19	2.3	Not Analysed
Fenitrothion	Insecticide		20	1.3	ND
Fluazifop-P-butyl	Herbicide		22	5.3	ND
PDBEs – brominated flame retardants					
Decabromodiphenyl ethers (DBDE)		HIGH RISK	--	491	All samples (4.7-1190 ng/g)
Polybromodiphenyl ethers (TeBDE, PeBDE, HXBDE, HpBDE, OBDE, NoBDE)			--		All samples (0.001-320 ng/g)
PAHs – combustion products of natural origin**.** Anthracene and Fluorene also used in dyes.					
Chrysene		LOW RISK	2		AWT DORF - 2 samples (0.14-0.18)

Chemical	Application	Risk of presence in MSW	Environ hazard rank	Eco Threshold Value (mg/kg)	Detection in compost & AWT DORF (range mg/kg)
Anthracene			11	45	AWT DORF - 1 sample (0.1)
Pyrene			12		AWT DORF - 9 samples (0.12-0.52)
Benzo(a)pyrene			18	65	AWT DORF - 2 samples (0.14-0.16)
Fluoranthene			23	27	AWT DORF - 7 samples (0.1-0.74)
Phenathrene			36	2.9	AWT DORF - 10 samples (0.13-0.53)
Fluorene			38	33	AWT DORF - 2 samples (0.11-0.24)
Benzo(b)&(k)fluoranthene			b:32 & k:17		AWT DORF - 2 samples (0.26-0.51)
Benzo(a)anthracene				9	AWT DORF - 3 samples (0.1-0.24)

* 2,4-D, Octhilinone, 3,3'-Dichlorobenzidine, MOCA, Clopyralid, Fenthion, Fipronil, Imidacloprid, Indoxacarb, Malathion, Nitrobenzene, NPE, Picloram and nine agricultural chemicals were tested for but not detected. In addition, Brodifacoum, Dichlofluanid, Emamectin Benzoate and Profenofos were not successfully analysed. These contaminants could not be recovered at acceptable levels under a number of different analytical screens.

DEHP and DBP were the only chemical contaminants detected in concentrations higher than their corresponding ecological thresholds with the former appearing to be more prevalent. Using the analytical results and adopting a precautionary approach, a mass balance model was developed for the application of AWT DORF to land under a number of scenarios to evaluate the final DEHP concentration that might be expected in soils. This showed that even elevated contaminant concentrations in AWT DORF material would not result in total soil concentrations of DEHP exceeding the ecological threshold level at any practical level of application.

Nevertheless, the authors suggested that a number of chemicals should be considered for routine monitoring in AWT DORF (Table 27). These chemicals are all pesticides, herbicides, fungicides or PVC plasticisers.

*Table 27: Chemical compounds recommended for routine monitoring in AWT DORF [Hyder 2008]**

Substance	Environ Hazard Rank	Ecological Threshold Value (mg/kg)	Analytical Detection in Samples	Risk of Presence in MSW
Brodifacoum	1	0.01	Not analysed	M
Chlorpyrifos	7	0.30	YES	H
Cypermethrin	4	0.86		H
DEHP (di-2-ethyl hexyl phthalate)	33	57	YES	M
Dibutyl phthalate (DBP)	40	0.72	YES	M
Dichlofluanid	28		Not analysed	M
Simazine	35	105	YES	H
Tebuconazole	5	45		M
Monobutyltin	-		YES	M
Permethrin	-	5.2	YES	M

*At the time of publishing, Hyder Consulting emphasised that robust analytical methods for Brodifacoum and Dichlofluanid still needed to be developed

5.3.4.2 Biosolids and biosolids composts

Clarke and Smith (2011) pointed out that, at the time of writing, there were 143,000 chemicals registered in the European Union for industrial use. They therefore conducted a literature review of ‘emerging’ organic contaminants in biosolids for a selection of chemicals of potential concern for land application based upon human toxicity, evidence of adverse effects on the environment and endocrine disruption.

A summary of reported concentrations of the selected ‘emerging’ contaminants examined in their study is presented in Figure 6. The concentrations are presented on a logarithmic scale in descending order of reported mean concentrations, ranging from polychlorinated alkanes (PCAs) in the range of grams per kilogram (dw) to perflurochemicals (PFCs) which were measure in the micro gram per kilogram (dw) range. Concentrations of the industrial chemical PCAs are much higher compared to contaminants that are likely from domestic sources such as quaternary ammonium compounds (QACs) and triclosan (TCS). The authors suggested that significant industrial discharges of PCAs occur into wastewater collection systems. Chemicals utilized in the domestic environment were in the next ‘high-level’ concentration range (phthalate acid esters, QACs, triclocarban, synthetic musks, TCS), followed by less commonly used industrial and domestic chemicals (organotins, PBDEs, polychlorinated naphthalenes, PFCs).

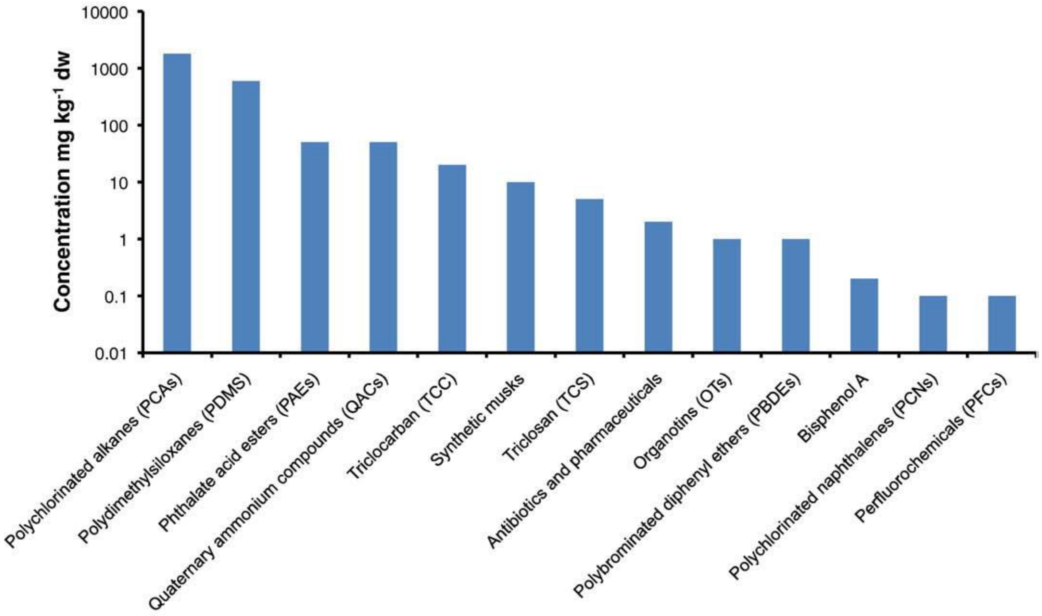


Figure 6 Typical concentrations (mg/kg dw) of selected ‘emerging’ organic contaminants in sewage sludge [Clarke and Smith 2011]

Clarke and Smith (2011) then identified research and monitoring priorities based on an assessment matrix consisting of five criteria applied to the selected ‘emerging’ contaminants (Table 28). These included:

- environmental persistence in soil environments (>6 months);
- potential for human health impacts resulting from the land application of biosolids;
- evidence or likelihood of bioaccumulation in humans or the environment;
- evidence of ecotoxicity, and;
- the quality of empirical data and trends on the contaminant in biosolids internationally.

Table 28: Assessment matrix for determining research priorities for selected 'emerging' organic contaminants in sewage sludge with respect to their potential significance for agricultural utilisation [Clarke and Smith 2011]

Emerging organic contaminant	Persistent (>6 months) 2 – yes 1- uncertain 0 - no	Human food chain 2 – possible 1 – uncertain 0 – no	Ecological bioaccumulation 2 – yes 1 – possible 0 - no	Soil ecotoxicity 2 – yes 1 – uncertain 0 - no	Research quality 3 - lack of empirical data 2 - few reported studies 1 - a number of consistent studies 0 - many consistent studies	Score (x/11)
Antibiotics and pharmaceuticals	0	2	0	1	2	5
Benzothiazoles	1	1	0	1	3	6
Bisphenol A	0	0	0	0	2	2
Organotins	1	1	2	1	2	7
Phthalate acid esters (PAEs)	0	0	0	0	1	1
Polybrominated diphenyl ethers (PBDEs)	2	2	2	1	0	7
Polychlorinated alkanes (PCAs)	2	2	1	1	3	9
Polychlorinated naphthalenes (PCNs)	2	2	1	1	3	9
Polydimethylsiloxanes (PDMSs)	0	0	0	0	1	1
Perfluorochemicals (PFCs)	2	2	2	1	3	10
Quaternary ammonium compounds (QACs)	0	0	0	0	2	2
Steroids	0	0	0	0	2	2
Synthetic musks	1	0	1	0	1	3
Triclosan	1	0	2	2	2	7
Triclocarban	1	0	2	2	2	7

As shown in Table 28, the ‘emerging’ contaminants were ranked in decreasing order of priority as follows (maximum possible score of 11):

- perfluorinated chemicals (10)
- polychlorinated alkanes (9), polychlorinated naphthalenes (9)
- polybrominated diphenyl ethers (7), organotins (7), triclosan (7), triclocarban (7)
- benzothiazoles (6)
- antibiotics and pharmaceuticals (5)
- synthetic musks (3)
- bisphenol A (2), quaternary ammonium compounds (2), steroids (2)
- phthalate acid esters (1), polydimethylsiloxanes (1).

Clarke and Smith (2011) concluded that the perfluorinated chemicals (PFOS/PFOS or the PFCs) represent a potentially major “environmental uncertainty” in that they have a unique chemistry that facilitates a degree of water solubility, which is not observed with other POPs. Thus, the barriers that normally prevent human and ecological exposures to POPs in soil amended with organic residues may not prevent movement of PFCs. Increased water solubility raises the likelihood of exposure through all pathways — water contamination, plant accumulation and grazing animal accumulation (Chaney et al., 1996 cited in Clarke and Smith (2011)). They considered that water contamination and plant accumulation were the priority pathways of concern.

PCAs were found at relatively high concentrations (mean concentration 1,800 mg/kg dw), while PCNs were typically less than 1 mg/kg dw (Figure 6). When comparing concentrations of these compounds to PCBs and PCDD/Fs it is apparent that PCAs warrant further investigation (Clarke and Smith (2011). The concentrations of PCAs are three orders of magnitude higher than those of PCBs found in contemporary biosolids. Also, the researchers provide evidence that PCAs are accumulating in the human population but the impact of these chemicals on human health and the environment is not yet known.

5.3.4.3 Regulated non-organic wastes used in composting in Queensland

GHD (2013) conducted a study for the Queensland government to develop a best practice approach to dealing with regulated non-organic waste (RNOW) in the composting process. RNOWs of particular interest in this review were coal seam gas drilling muds/fluids (DF), fly ash and other coal combustion products (CCPs), and foundry sand (FS).

Their review concluded with the following:

- Whilst the bentonite content of DF could be particularly beneficial to the composting process, the composition of DFs can be highly variable. A mix of DFs may be used to suit changing drilling conditions, even within a single drilling operation. In addition, the drilling process can intersect geological structures and groundwater that result in saline or mineralised water and solids being present in the DFs; in some instances organic contaminants (e.g. hydrocarbons) may also be present. Therefore, it would be necessary to analyse the composition of DFs batch by batch. Overall, DFs were found to be “low risk”, assuming that their composition is known and contaminant limits are met.
- CCPs and FS could have beneficial uses as soil additives in their own right, provided that contaminant limits are met. However, addition of these materials to organic feedstock may not necessarily enhance the composting process. Overall, the risks associated with CCPs and FS were deemed to be higher than DF; they were expected to pose a “medium risk”. Again, composition and variability of these materials is a major consideration. For example, FS from ferrous metal foundries

are more likely to be suitable whereas those from non-ferrous metal foundries will pose a high risk and generally should not be used.

Allowing such a wide variety of waste streams as inputs into the composting process is challenging for regulators and compost operators alike. This is because the composition and variability of each waste stream must be known in order to establish how it will affect the composting process, the overall operation of the site and the quality of the end-product. Furthermore, it is often not clear what contaminants might be present in them, and established limits are not always available. In the absence of waste-specific research, contaminant limits for the closest matching waste streams or end-use are sometimes “borrowed” from other jurisdictions.

For example, the GHD study proposed using Victorian EPA guidelines for contaminant limits in soil fill material for monitoring potential contaminants in RNOW feedstocks and composts containing them (in addition to those identified in AS4454 – 2012). The authors assumed a four-fold dilution of contaminants between the feedstock and the final product (Table 29), an approach that has been adopted by the Department of Environment and Science in setting contaminant limits for input out output material in at least one license for a composting operation.

Table 29 Recommended contaminant limits (mg/kg dm) for regulated non-organic wastes used in composting processes over and above those listed in AS 4454 – 2012 [GHD 2013]

Chemical	Feedstock limit	Final product limit
Petroleum hydrocarbons (TPH) C6-C9	400	100
Petroleum hydrocarbons (TPH) C10-C36	4000	1,000
Benzene	4	1
PAH [a]	80	20
MAH [b]	28	7
Phenols (halogenated) [c]	4	1
Phenols (non-halogenated) [d]	240	60
Chlorinated hydrocarbons [e]	4	1

[a] Total sum of 16 US EPA priority PAHs – naphthalene, acenaphthylene, acenaphthene, anthracene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluorene, fluoranthene, indeno(1,2,3-c,d)pyrene, phenanthrene and pyrene.

[b] Total sum of benzene, toluene, ethyl benzene, xylenes (includes ortho, para and meta xylenes) and styrene.

[c] Total sum of 4-chloro-3-methylphenol, 2-chlorophenol, 2,4-dichlorophenol, 2,6-dichlorophenol, pentachlorophenol, 2,3,4,5-tetrachlorophenol, 2,3,4,6-tetrachlorophenol, 2,3,5,6-tetrachlorophenol, 2,4,5-trichlorophenol, and 2,4,6-trichlorophenol.

[d] Total sum of phenol, 2-methylphenol (o-cresol), 3-methylphenol (m-cresol), 4-methylphenol (p-cresol), 2,4-dimethylphenol, 2.4-dinitrophenol, 2- methyl-4,6-dinitrophenol, 2-nitrophenol, 4-nitrophenol, 2-cyclohexyl-4,6-dinitrophenol and dinoseb.

[e] Total sum of carbon tetrachloride, chlorobenzene, chloroform, 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethene, dichloromethane (methylene chloride), 1,1,1,2-tetrachloroethane, 1,1,2,2-tetrachloroethane, 1,2,4-trichlorobenzene, 1,1,1- trichloroethane, 1,1,2-trichloroethane, trichloroethene, tetrachloroethene, vinyl chloride and hexachlorobutadiene.

Composters in Queensland that process RNOWs in their operations must routinely test for total petroleum hydrocarbons (TPH), following the limits outlined inTable 29. A small data set of products generated at six composting sites in Queensland showed elevated TPHs (C10 – C36) and TRHs (C10 – C40) levels (see Table 24), while test results of two green waste feedstock materials that were provided to the project team showed levels falling well within these limits. However, we could not find comparable data of expected TPH and TRH levels in feedstock and compost from elsewhere in the world. This is because, when measuring hydrocarbons in feedstock and compost, PAHs are usually determined instead. TPH and TRH analyses are associated with bioremediation studies that may involve composting, but information on background levels in the compost feedstock is very scarce.

However, we know that PAH (and therefore TRH) compounds can be derived from pyrogenic sources such as traffic (asphalt and vehicle exhaust) (Brändli et al. 2007) and therefore may be associated with vegetation collected from roadside trimmings (Schmutz and Bono 2012, cited in Saveyn and Eder, 2014).

5.3.4.4 Data from international studies

Saveyn and Eder (2014) conducted a comprehensive study for the European Commission on the presence of organic contaminants in composts derived from a variety of feedstocks from 16 EU-member countries.

With respect to PAHs, digestate samples contained the lowest concentrations, followed by MBT compost, whereas FOGO (bio-waste) compost, green waste compost and biosolids (sewage sludge) compost had higher overall PAH16 concentrations (Figure 7). These findings were found to be consistent with other studies (e.g. Brändli et al. 2007a). The authors combined data from various studies comprising 172 compost and digestate samples from source-separated input materials and found that >38% of the samples had PAH16 concentrations of >3 mg/kg and 10% were >6 mg/kg. The highest value encountered was 20.8 mg/kg. As a point of reference the limit proposed by GHD (2013) for compost products derived from regulated non-organic waste was 20 mg/kg (Table 29).

Some of these samples had concentrations above existing national limit or guidance values for similar materials in different EU-member states. The authors also noted that analytical results from five reference general waste samples showed that contamination could be associated with any ill-defined feedstock material.

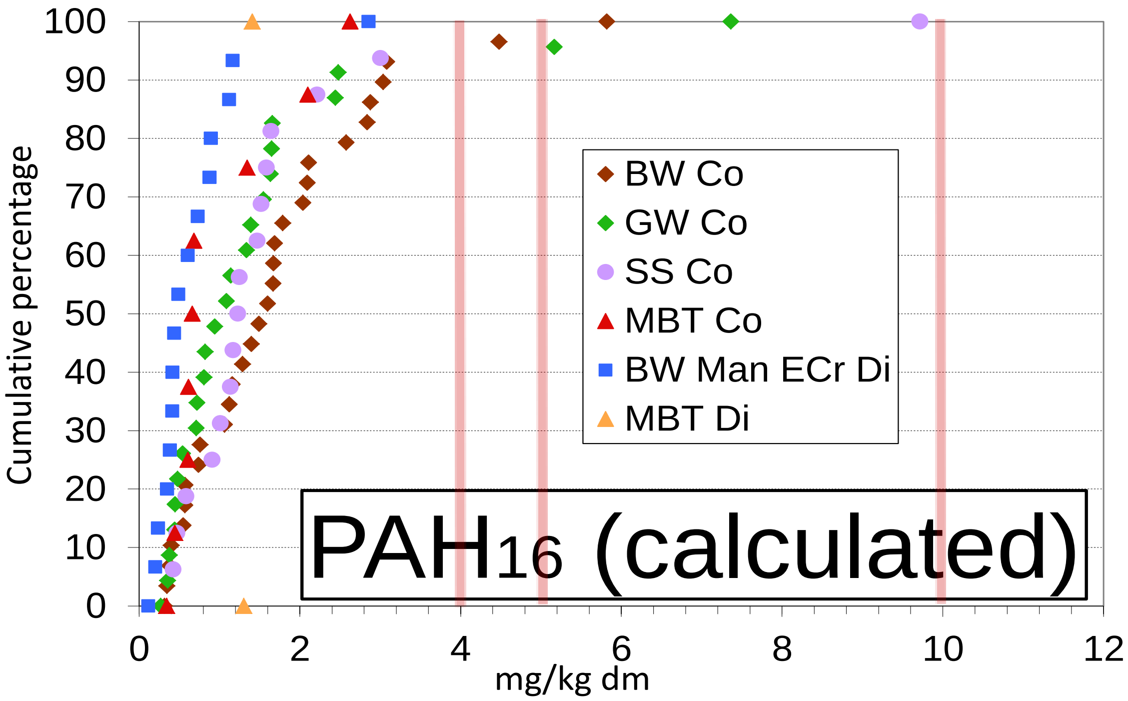


Figure 7 Calculated PAH$_{16}$ in compost and digestate samples analysed in the Saveyn and Eder (2014) study. Data are based on measured PAH$_{12}$ values and extrapolated using the 1.073 PAH$_{16}$/PAH$_{12}$ ratio derived from Brändli et al. (2007a). The semi- transparent red bars represent existing limit values in different European countries for similar materials (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment; Man=manure; ECr=energy crops)

Saveyn and Eder (2014) determined dioxin and dioxin-like toxicity in samples by means of a biological assay with the biological response expressed as TCDD equivalents (Figure 8). The researchers emphasized that this bioassay test is not specific and therefore will also yield dioxin-like toxicity response for non-dioxin compounds such as PCBs and PAHs. Nevertheless, it is a helpful diagnostic tool to screen dioxin-like toxicity effects in different samples.

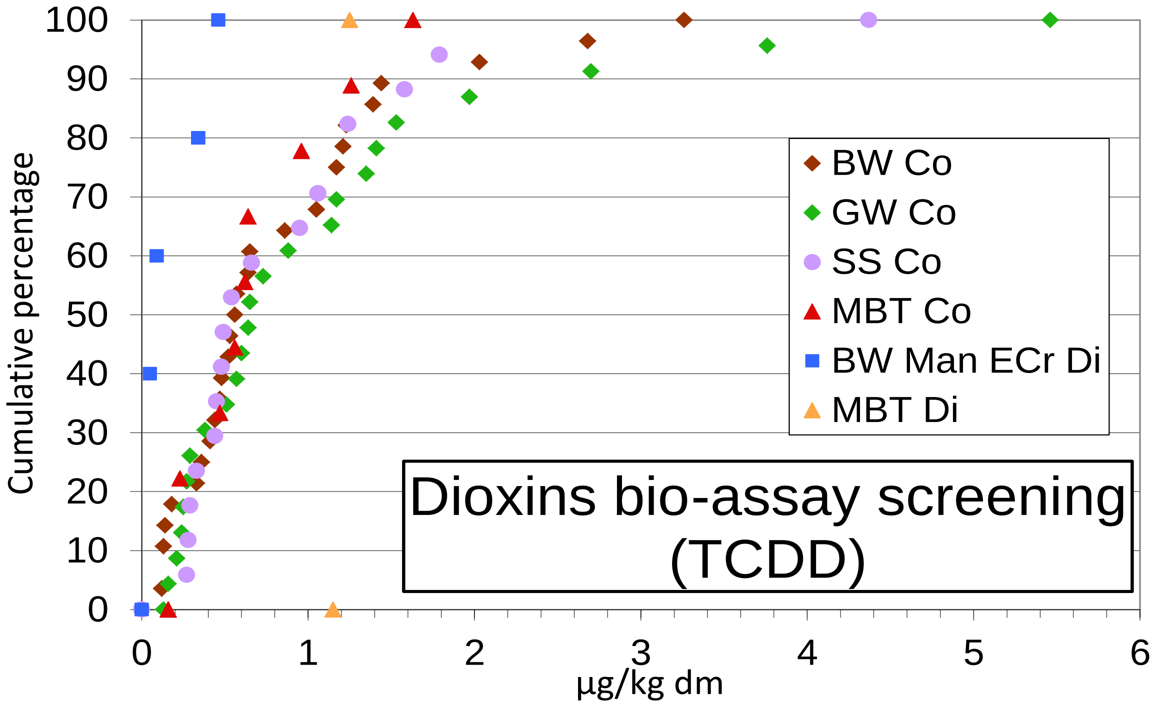


Figure 8 Dioxin effects expressed in TCDD toxicity equivalents in compost and digestate samples analysed in the Saveyn and Eder (2014) study. (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment; Man=manure; ECr=energy crops)

The dioxin bio-assay showed similar trends to that observed for PAH$_{16}$. Digestate samples had the lowest overall TCDD response, followed by MBT compost, FOGO (bio-waste) compost and green waste compost. However, no direct correlation could be established between the PAH$_{16}$ concentration of a given sample and its bio-assay dioxin response, indicating that other compounds present may have been responsible for part of the response observed.

Following the results obtained from the dioxin toxicity bio-assay, 18 samples in each category exhibiting high TCDD equivalence values were subjected to further chemical analysis for PCBs and PCDD/Fs.

None of the compost or digestate samples exceeded any of the existing EU national limit or guide values for PCBs (Figure 9) and there were no clear differences between the various sources of samples.

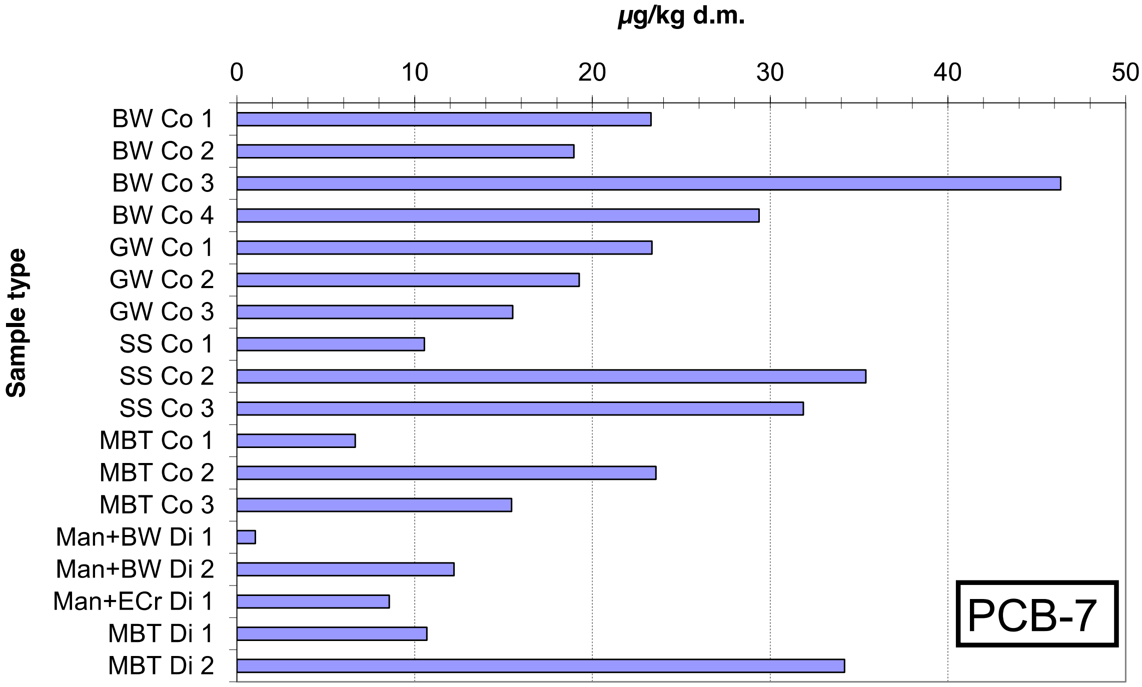


Figure 9 Sum of 7 PCB (PCBs 28, 52, 101, 118, 138, 153 and 180) compounds in compost and digestate samples analysed in the Saveyn and Eder (2014) study. The red bars represent existing limit values in different European countries (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment; Man=manure; ECr=energy crops)

The PCDD/F analysis results (Figure 10) were presented as both lower and upper bound values[4]. The results generally indicated low to medium toxicity equivalents for all samples, with no upper bound value exceeding the strictest existing EU national limit of 20 ng I-TEQ/ kg dm. Again, no clear distinctions could be made between the various sources of samples.

These findings were also found to be consistent with other published studies. For example:

- Data from 68 samples published by Brändli et al. (2007a and 2007b) showed that PCB-7 values ranged from 8.8 to 101.4 µg/kg dm. The median PCB-7 value was 27.3 µg/kg and the 90-percentile value 46.4 µg/kg. For PCDD/F, the range was 0.5 to 21.0 ng I-TEQ/kg dm, with a median value of 3.2 ng I-TEQ/kg dm and a 90-percentile value of 9.9 ng I-TEQ/kg dm in 18 samples. No correlation could be found between PCB and PCDD/F (R2 =0.0013).
- Using data obtained from 1990 to 2003 in the published literature, Brändli et al. (2005) estimated 90-percentile levels of PCB-6 for green waste compost to be about 70 µg/kg dm (based on 55 samples) and 90-percentile levels of PCB-6 for FOGO compost about 100 µg/kg dm (based on 124 samples). The 90-percentile levels of PCDD/F for green waste compost were also found to be about 20 ng I-TEQ/kg dm (based on 61 samples) and 90-percentile levels of PCDD/F for FOGO compost of about 18 ng I-TEQ/kg dm (from 124 samples).

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[4] In the case of measurement results below the detection limit, the lower bound value was calculated assuming a zero concentration value, whereas the upper bound value was calculated assuming the detection limit as concentration value. The detection limit may vary per sample as the instrument settings were adjusted to allow measurement of all compounds.

- Combining PCB literature data from various sources, Saveyn and Eder (2014) compiled a set of 168 samples for compost and digestate from source-separated input materials. These data showed that only 3 samples had PCB concentrations of between 100 and 200 µg/kg dm.
- Similarly, combining PCDD/F literature data from various sources, Saveyn and Eder (2014) compiled a set of 57 samples for compost and digestate from source-separated input materials. Analysis of the data revealed that only 3 samples contained a concentration of >15 ng I-TEQ/kg dm and 2 samples were >30 ng I-TEQ/kg dm.

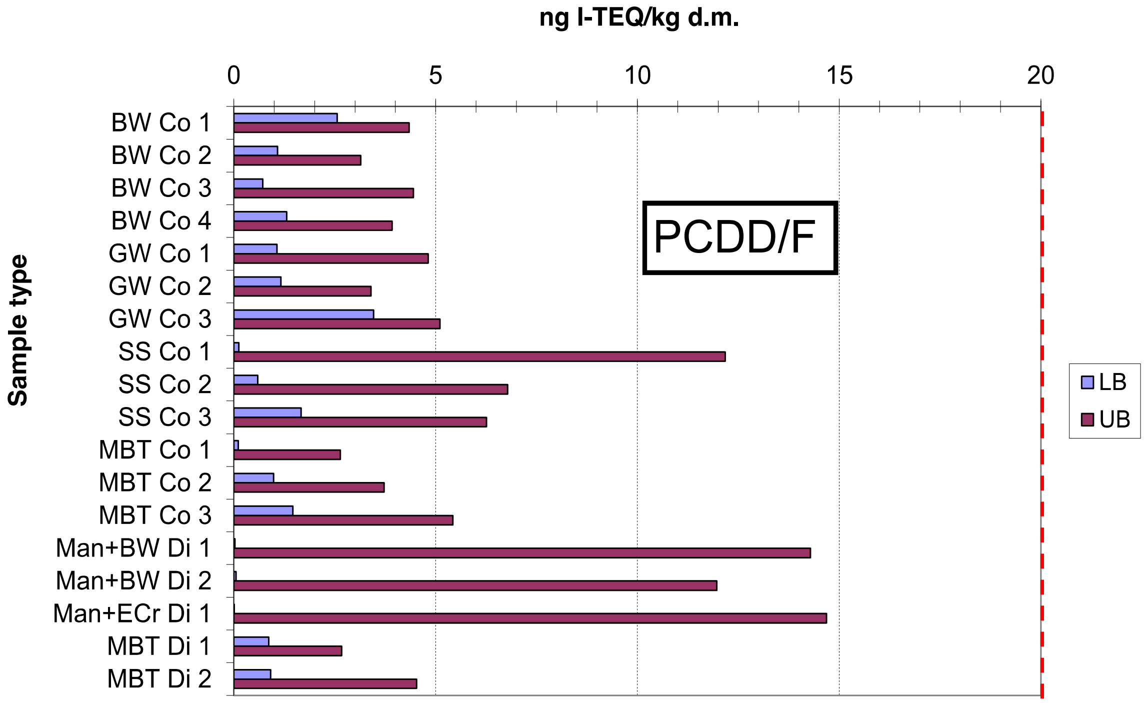


Figure 10 International toxicity equivalents (I-TEQ) of 17 PCDD/F compounds in compost and digestate samples analysed in the Saveyn and Eder (2014) study. The red bar represents an existing limit value in different European countries (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment; Man=manure; ECr=energy crops)

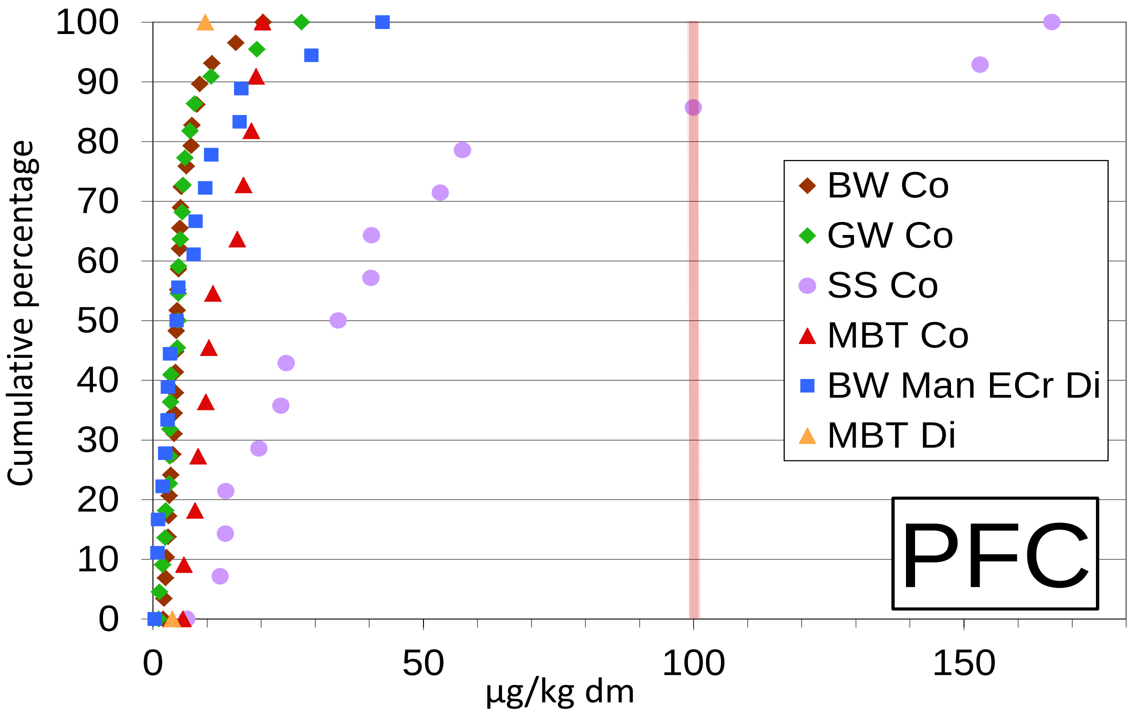


Figure 11 Perfluorinated compounds (sum of PFOA and PFOS) in compost and digestate samples analysed in the Saveyn and Eder (2014) study. The semi-transparent red bars represent existing limit values in different European countries for similar materials (Co=compost; Di=digestate; BW=source separated FOGO; GW= source separated green waste; SS=sewage sludge; MBT=mechanical biological treatment; Man=manure; ECr=energy crops)

With respect to perfluorinated compounds (the sum of PFOA and PFOS), the Saveyn and Eder (2014) study showed that FOGO and green waste composts had the lowest concentrations, followed by digestate and MBT compost (Figure 11). Biosolids composts had consistently higher PFC concentrations, with several samples exceeding the 100 µg/kg limit applicable for fertilisers in Austria and Germany. The finding that biosolids composts had higher levels of perfluorinated compounds is consistent with other studies (e.g. Clarke and Smith, 2011).

Nevertheless, published data on perfluorinated compounds in compost and related products is still very limited. Brändli et al. (2007b) combined published data on PFOA and PFOS from 18 digestate and compost samples derived from source separate collection in Switzerland and found that concentrations ranged from 1.8 to 24.6 µg/kg dm. When Saveyn and Eder (2014) combined data from various published sources for 66 compost and digestate samples, they determined that none of the samples exceeded 50 µg PFC/kg dm. Furthermore, Clarke and Smith (2011) reported that the concentration of perfluorinated compounds in biosolids was typically in the low µg/kg dm range.

Other chemical compounds were also analysed in the Saveyn and Eder (2014) study. They summarised their findings on these chemicals as follows:

- Nonylphenol (28 samples tested): The highest concentration encountered was from a green waste compost sample – 10.4 mg/kg well below the Belgian guidance limit value for compost/digestate of 25 mg/kg and just over the Danish limit value of 10 mg/kg. An EU risk assessment study (IHCP, 2002, cited in Saveyn and Eder, 2014) reported an EC10 (reproduction) threshold value of 3.44 mg/kg in soil for earthworms. However, the biodegradation half-life for this compound is 20-30 days and full mineralisation occurs in 100-300 days. Given the low concentrations encountered and its biodegradabilty, Saveyn and Eder (2014) concluded that this compound was likely to be of very low concern for compost/digestate quality.
- PBDE (polybrominated diphenyl ethers) (34 samples tested): None of the samples exceeded 1 mg/kg dm for PBDE and 40 µg/kg dm for PentaBDE. It was therefore concluded that these compounds were likely to be of very low concern for compost/digestate quality.

- Pesticides (54 samples tested): Herbicides 2,4-D, Dichlorprop, Mecoprop, MCPA, 2,4,5-T and Bentazone were tested along with the insecticide Imidacloprid. Although the pesticides analysed for in their study represent only a small fraction of all pesticides available on the market, the researchers concluded that the analytical results they obtained suggested that these chemicals were likely to be of very low concern for compost/digestate quality.

5.3.5 Fate of organic contaminants during composting

The fate of organic contaminants can involve a number of different pathways including mineralisation, partial biological degradation to secondary compounds, assimilation by microorganisms, abiotic transformation to secondary compounds, complexation with humic materials in the compost substrate (i.e. humification), or loss by volatilisation, leaching, runoff, and wind (Büyüksönmez et al. 2000). Complete mineralisation to CO_2 is the ideal, since secondary compounds that can accumulate during partial degradation can still be toxic.

The stripping of organic contaminants from the compost matrix through volatilisation can be an important contributor since the vapour pressure of volatile compounds increases as temperatures rise in the compost matrix during the composting process.

Leaching is dependent on the water solubility of a specific compound and their metabolites. In a well-managed composting system, leaching from compost piles is unlikely, so it is most likely to occur at poorly operated sites. Moreover, organic pollutants have often a high octanol-water partitioning coefficient, which results in a high retention of these compounds in the carbon-rich compost matrix (Amlinger et al. 2004). Organic compounds can therefore also be associated with dissolved organic matter (DOM) in a compost pile. For example, Hartlieb et al. (2001) found that DEHP and simazine were mainly associated with the low- to medium-molecular weight DOM fraction, whereas pyrene and its metabolites had high affinities to high-molecular weight DOM. However, the researchers also showed that the binding capacity of DOM for these chemicals was of secondary influence to their potential mobilisation in compost because the intense biochemical reactions during composting had a greater influence on the fate of these substances. Composting favoured the degradation of these chemicals to other metabolites that supported their binding to the DOM matrix. In this experiment, the binding capacity of DOM for hydrophobic contaminants was highest after 120 days of composting.

When a compound is adsorbed onto another substance, it is generally less available to microbial degradation and is therefore transformed and mineralised to a lesser extent (Amlinger et al. 2004). Whilst it appears that adsorption of organic compounds in compost becomes stronger with time, microbial degradation is generally greatest when composting conditions (i.e. physio-chemical conditions) are optimized. Increases in the concentrations of organic contaminants are sometimes observed during composting as a consequence of organic matter being converted into carbon dioxide.

Houot at al. (2012) examined the potential mineralisation of various organic contaminants in compostable materials during the thermophilic and maturation phases of composting. Four composts were used, made from FOGO, municipal solid waste (MSW), green waste (GW) and a mix of green waste and biosolids. The mineralisation of five 14C-labeled organic pollutants was tested – three polycyclic aromatic hydrocarbons (PAHs) (phenanthrene, fluoranthene and benzo(a)pyrene), one herbicide (dicamba) and one polychlorinated biphenyl (PCB, congener 52) was assessed. Composted material collected from both the thermophilic ("fresh compost") and maturation ("mature compost") phases of composting were spiked with the compounds and incubated in a laboratory at either 60°C/12 days (fresh composts) or 28°C/30 days (mature composts).

Volatilisation was also measured by trapping molecules on glass wool impregnated with paraffin oil. The researchers showed that mineralisation was microflora-dependent; it occurred only during the maturation phase of composting, or else when mature compost was inoculated into the fresh compost, except for phenanthrene, which was 60%-mineralized in the fresh GW+biosolids compost samples. PAH mineralisation decreased with increasing complexity of the PAH molecules. For example, mineralisation of phenanthrene and fluoranthene reached 50%–70% in all mature composts but for benzo(a)pyrene it was limited to 30% in the MSW mature compost. Dicamba was moderately mineralized (30%–40%), while for PCB no mineralisation was detected. However, 20% of the PCB had volatilised after 12 days at 60°C. No consistent difference was observed in the degrading capacity of the different compost sources, with the major difference being the improved mineralizing capacity of the maturation microflora compared with the thermophilic microflora.

Other laboratory-scale studies have also shown that low molecular weight PAHs decrease more rapidly during composting, whereas other compounds like the PCBs and high molecular weight PAHs remained stable (Bernal et al. 2017). Comparing composting and anaerobic digestion (AD) processes, Siebielska and Sidelko (2015) found AD to be more effective for degrading PCBs. The degradation of PCBs during composting was dependent on the chlorination level of the PCB congener, with concentrations of highly-chlorinated PCBs decreasing more slowly than those with fewer chlorine substituents.

While Siebielska and Sidelko (2015) found AD to be more effective than composting in degrading PCBs, this was not the case for Brändli et al. (2007a) who studied the concentration changes of PCBs and PAHs during composting and AD at field-scale. In this study, PCBs and PAHs concentrations did not seem to vary with AD. Furthermore, they found that concentrations of low-chlorinated PCBs *increased* during composting by about 30%, whereas a 10% decrease was observed for the higher chlorinated congeners. This is due to the biodegradation pathway of PCBs where the concentration of low-chlorinated congeners increases as high-chlorinated congeners are dechlorinated. Levels of low-molecular-weight PAHs declined during composting by 50-90%, whereas high-molecular-weight compounds were stable.

Other studies demonstrate the complexity of microbial degradation of organic contaminants. Whilst Houot et al. (2012) demonstrated greater rates of degradation of PAHs during the mesophilic stage of composting, Bertin et al. (2011) found PCB concentrations to be degraded more quickly under thermophilic conditions under anaerobic digestion. Furthermore, Patureau and Trably (2006) found that the concentrations of all of the PCB congeners they analyzed decreased during their composting study. Whilst the concentration of the most chlorinated PCBs decreased by about 40%, the decrease in concentrations of PCBs with fewer chlorine substituents was greater still. Composting conditions clearly play an important role in rates of degradation. Fully aerobic conditions are easier to maintain in laboratory-scale composting studies than in field scale systems, and this can sometimes lead to discrepancies between different studies. Siebielska and Sidelko (2015) suggested that anaerobic pockets in large-scale composting systems could favour dechlorination reactions.

Pesticide mineralisation also varies with the physico-chemical properties of the degraded molecules. Mineralisation usually increases with water solubility and decreases with the retention of the molecules by the matrix. Chlorine-carbon bonds usually render chemicals more resistant to microbial degradation. While more easily biodegradable molecules, such as 2,4-D and diazinon can be degraded during the thermophilic stage of composting (Michel et al., 1995; 1997), dicamba is more actively mineralized during the maturation phase of composting (Houot at al., 2012). Furthermore, Michel et al. (1997) showed that while only a small proportion of diazinon was fully mineralized to CO_2 during green waste composting, the majority was converted to potentially leachable, but less toxic IMHP, high molecular weight residues, and unextractable residues that were presumed to have low bioavailability.

Lashermes et al. (2010) studied the degradation pathways of four ^{14}C-labeled organic contaminants during composting: fluoranthene (a PAH), two surfactants (4-n-nonylphenol – NP and sodium linear dodecylbenzene sulfonate – LAS) and the herbicide glyphosate. The potential for compost microflora to degrade these compounds, and compost sorption properties, were characterized at different stages of composting. The highest levels of LAS and glyphosate mineralisation were found during the thermophilic stage, while for NP and fluoranthene it was at the beginning of maturation and the end of maturation, respectively. The researchers postulated that specific microflora were probably involved in the biodegradation of fluoranthene while for NP, LAS and glyphosate mineralisation was linked to total microbial activity. Adsorption of these compounds to compost particles was linked to their hydrophobicity, decreasing in the following order: fluoranthene > NP > LAS > glyphosate. Moreover, sorption decreased as compost maturity increased, except for glyphosate. The sorption coefficients were found to be positively correlated to mineralisation kinetics parameters for NP, LAS and glyphosate, suggesting a positive effect of sorption on increasing mineralisation rates.

As discussed above, total petroleum hydrocarbons (TPH) and total recoverable hydrocarbons (TRH) are not typically determined in compost and feedstock except for situations where petroleum wastes undergo bioremediation processes. The vast majority of bioremediation studies are conducted with petroleum-contaminated soil. Some international studies have investigated the composting-based bioremediation of “drill cuttings” (e.g. Kogbara et al. 2016), oils and fuels (e.g. Lin et al. 2012), tank sludges (e.g. Koolivand et al. 2018) and drilling mud/fluids (e.g. Ma et al. 2016; Rojas-Avelizapa et al., 2007).

Rojas-Avelizapa et al. (2007) investigated the efficacy of composting for TRH degradation in drill mud-contaminated soil formed into “biopiles”. One biopile treatment included the addition of nutrients to obtain a C/N/P ratio of 100/3/0.5 plus mixing with straw at a soil/straw ratio of 97/3. This was compared to other biopiles that were formed without the addition of nutrients and also to an undisturbed soil control. Moisture content was maintained around 30–35%. After 180 d, TRH concentrations decreased from 99,300 ± 23,000 mg/kg soil to 5,500 ± 770 mg/kg for biopiles amended with nutrients and to 22,900 ± 7,800 mg/kg for unamended-nutrient biopiles. The undisturbed soil control showed no change in TRH concentrations. Gas chromatographic analysis showed residual alkyl dibenzothiophene type compounds present. Highest bacterial counts were observed during the first 30 days which correlated with highest TRH removal, whereas fungal count increased at the end of the experimentation period.

Other researchers have shown that augmentation of contaminated soil/compost mixes with bulking agents and nutrients improves TPH-removal efficiencies. Ma et al. (2016) increased TPH-removal efficiency from oil-field drilling waste by about 57% and 27% with the addition of inorganic nutrients and sawdust, respectively. The same study showed that inoculation with hydrocarbon-degrading microorganisms only slightly enhanced the contaminant removal (by 7.3%). The biopile with stronger contaminant removal also had higher pile temperature and lower pile pH (6-6.5 compared to 7-7.5 for other treatments).

Sometimes, combinations of biological, chemical and sequestration treatments are involved. For example, Koolivand et al. (2018) investigated the removal of petroleum hydrocarbons from oily sludge of crude oil storage tanks under the optimized conditions of in-vessel composting combined with chemical oxidation with H_2O_2 and Fenton (a solution of H_2O_2 and ferrous iron). The sludge was pre-treated by chemical oxidation followed by co-composting with immature compost. The compost mix was prepared to a C:N:P ratio of 100:5:1 and moisture content of 55%, and the period of composting was 10 weeks. Finally, both pre-treated and composted mixtures were again chemically oxidized. TRH removal of mixes pre-treated with H_2O_2 ranged from 88% to 90%, whilst Fenton achieved results of about 84%. Without the pre-treatment oxidation step, the TRH removal rate was about 80%. The authors point out that composting conditions must be optimized in order to achieve satisfactory results for TRH removal. Sadef et al. (2015) also showed that higher degradation rates occurred under aerobic composting conditions (compared to anaerobic conditions), and that too much ready-available nitrogen in the mix can have an inhibitory effect.

In contrast, Hussain et al. (2018) demonstrated a positive response from inoculation with microbial flora together with compost and biochar in a phyto-remediation study. Hydrocarbon contaminated soil amended with biochar (5% v/v), and compost (5% v/v) was also inoculated with consortia of four hydrocarbon degrading bacterial strains (*Pseudomonas poae*, *Actinobacter bouvetii*, *Stenotrophomonas rhizophila* and *Pseudomonas rhizosphaerae*). The spiked soil was prepared by spiking agricultural soil with 3.4% (w/w) of crude oil. Italian ryegrass was sown in pots and plants were harvested after 75 days. They found that the highest hydrocarbon removal (85%) was observed in spiked soil amended with compost, biochar and consortia. Bacterial inoculation with biochar and compost showed significantly higher hydrocarbon degradation as compared to all other treatments. The highest TPH degrading bacterial counts were observed in the rhizosphere of spiked soil amended with compost, biochar and consortia. The organic amendments improved plant growth and the bacterial count in the rhizosphere, which resulted in higher removal of hydrocarbons. The authors proposed that plant-microbe interactions together with the organic soil amendments could be an emerging trend for remediation of hydrocarbons in soil.

According to Büyüksönmez et al. (2000), the patterns of pesticide degradation (and presumably other organic contaminants) in composting tend to parallel the patterns found in soils, in that those compounds that persist in soils tend to be resistant during composting as well. Those that disappear quickly in soils also disappear during composting. However, composting can be thought of as a biologically active soil environment within which the pace of transformation is accelerated. Accordingly, Büyüksönmez et al. (2000) described several studies where pesticide compounds disappeared faster during composting than they typically do in soils, as indicated by their soil half-life values. These authors also point out that microenvironments within a composting system fluctuate dramatically, with successive shifts in temperature, pH, and oxygen levels. This should have a positive effect on pesticide transformations as chemicals are exposed to varying conditions and diverse microbial populations.

5.3.6 Persistence in soil

One of the reasons why organic contaminants are classified as “persistent organic pollutants” is because of their persistence in the environment, causing ecological toxicity and potentially negative impacts to human health. However, it must be emphasized that there is often great uncertainty about these matters making the task of setting limits and regulating loading rates to land very difficult. Furthermore, when one POP is phased out, it can be replaced by another chemical for which little real-world environmental safety data is available.

The persistence in soil of many chemicals of concern is unknown. For others, their half-lives can vary from days to years. Clarke and Smith (2011) reviewed many chemical groups of concern in biosolids, and summarized their half-lives in soil. It showed that reliable data for many of these chemicals is just not available, including for many of the newly emerging chemicals that are believed to be “persistent” and highly transportable (e.g. PFOS/PFAS). A complicating factor in these considerations is that many of these chemical groups have multiple congeners (compounds closely related to one another). Interesting examples include the PDBE flame-retardants that appear to be particularly persistent in soil with half-lives ranging from 4 to 20 years.

Although our knowledge of the ultimate fate and impacts of POPs is limited, there are many examples in the literature that attempt to address these questions, but these usually involve short-term studies.

Long-term studies are needed in many cases, but these are rare. An interesting example of a long-term study was that of Umlauf et al. (2011). They reported on a field trial in Meckenheim (Germany) that had been running since 1962. Various soil treatments had been applied – mineral fertilizer, animal manure, biosolids and compost on different test plots. Soil samples were taken for analysis in 2001. The rates of applied biosolids and compost were very high – four times the limits stipulated in the “German Sewage Sludge Ordinance” and “Bio-waste Ordinance”. Moreover, the compost consisted of household waste and biosolids until 1991 after which its content had been restricted to source separated feedstock. The first thing of note was the substantial reductions in PCB and PCDD/F concentrations in the waste streams over the course of the experiment. Furthermore, the soil test results showed that PCDD/F levels were in all cases at least 4 times below German guidelines for arable land. Yet plots treated with compost and sludge still had a 2- to 3-fold higher PCDD/F concentration than the plots treated with mineral fertilizer or manure. The same observations were made for dioxin- like PCBs. Initial follow-up work indicated stable PCDD/F levels and a slight decrease of dioxin-like PCBs over time. These long-term data demonstrate the accumulation potential of PCDD/F and PCBs in the soil. Moreover, they show that a decade after switching to compost exclusively derived from source separated materials, the PCDD/F and PCB levels were still the most elevated in the compost treated plot, suggesting the high persistence of these pollutants in arable soils.

5.4 Per- and Poly-Fluoroalkyl Substances (PFAS)

Per- and poly-fluoroalkyl substances, also known as “PFAS”, are a group of manufactured chemicals that have been used since the 1950s in a range of common household products and specialty applications, including in the manufacture of non-stick cookware; fabric, furniture and carpet stain protection applications; food packaging; some industrial processes; and in some types of fire-fighting foams. There are many types of PFAS, with the best known examples being perfluorooctane sulfonate, known as “PFOS”, and perfluorooctanoic acid, known as “PFOA” and perfluorohexane sulfonate, known as PFHxS.

5.4.1 Australia

Over time, these chemicals have worked their way through the soil to contaminate surface and ground water, and have migrated into adjoining land areas, at sites where there has been historic use of fire-fighting foams that contained PFAS. The Federal Department of Health (2019) considers the release of PFAS into the environment as an emerging concern, because these chemicals are highly persistent, have been shown to be toxic to fish and some animals, and can accumulate in the bodies of fish, animals and people who come into contact with them. However, a Food Regulation Standing Committee Statement (undated), which is referenced on the Departments website emphasises that exposure of the general population to perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) is low and declining in Australia, and that there is no consistent evidence that this exposure has been harmful to human health.

As these chemical compounds are now ubiquitous in the environment, there is a possibility that they are also found in composts, particularly if the composting feedstock comprises industrial residues or biosolids. There are fears that co-composting of food organics might result in elevated contaminant levels, particularly if the composted material contains high levels of impurities or paper-based food packaging.

Elevated levels of per- and poly-fluoroalkyl substances were found in compost manufactured at two sites in South-East Queensland. However, as test results and the Department of Environment and Science's investigation resulted in court action, no factual information concerning concentrations found in various tested compost products and how widespread elevated levels were other than media reports (e.g. Brisbane Times 2018) is publicly available. As neither licensing conditions for composting operations nor end-product quality requirements specify maximum allowable limits for per- and poly-fluoroalkyl compounds in compost or mulch products, it is assumed that enforcement action by the Department of Environment and Science was based on unauthorised acceptance of contaminated waste materials (in this case water from an air force base) or on application of PFAS/PFOS contaminated material to land, as stipulated in the PFAS National Environmental Management Plan (HEPA, 2018, 2019). This has been confirmed as the second PFAS compost contamination incident reported in the press (The Australian 2019) was apparently based on ecological guideline values for aquatic ecosystems within the soil investigation criteria framework, as the compost material was applied as rehabilitation blanket at a roadside batter, where PFAS/PFOA compounds can leach out and enter aquatic ecosystems (Thompson, 2019).

The authors are not aware of publicly available information that provide an indication of PFAS/PFOA concentrations in recycled organic products manufactured in Queensland or Australia, other than biosolids destined for direct land application. The Australian and New Zealand Biosolids Partnership conducted a survey of PFAS in biosolids, with a number of major utilities providing data from over 100 samples from 13 different sewage treatment plants around Australia (Hopewell and Darvodelsky 2017). The results of the sampling and analysis program showed that PFOS and PFOA are generally present in biosolids at detectable levels in Australia, although neither PFOS nor PFOA was detected in 17 samples (Table 30).

PFOA was generally found in lower concentrations on most sites, while PFOS levels were higher at two sites with known local PFOS contamination issues. The National Survey showed a median value of 0.003 mg/kg of PFOS was detected in biosolids and 0.002 mg/kg PFOA. Maximum values detected in biosolids were 0.386 mg/kg and 0.05 mg/kg respectively. The report states that, based on the survey data it is unlikely that PFOA will be an issue in biosolids, unless there is a known problem with contamination in a particular area. The Australian and New Zealand Biosolids Partnership used the obtained information to calculate safe limits of PFOS and PFOA in biosolids and, based on the accepted National Environment Pollution Management methods recommended that regulation of PFOA was not necessary, while proposing PFOS limits in biosolids of 0.3 mg/kg for unrestricted use and of 4.2 mg/kg for agricultural use. The interim Queensland End of Waste Code for Bisolids has set a limit of 0.39 mg/kg dm total organic fluorine for all applications (see Section 3.1.4).

Table 30 Summary of PFOS / PFOA levels (mg/kg) measured in Australian biosolids [Hopewell and Darvodelsky 2017]

	PFOS	PFOA
Number of plants	13	13
Number of samples	109	98
Not detected	17	17
Median	0.003	0.002
Mean	0.021	0.003
Standard deviation	0.062	0.007
Maximum	0.386	0.050
Minimum	0.001	0.001

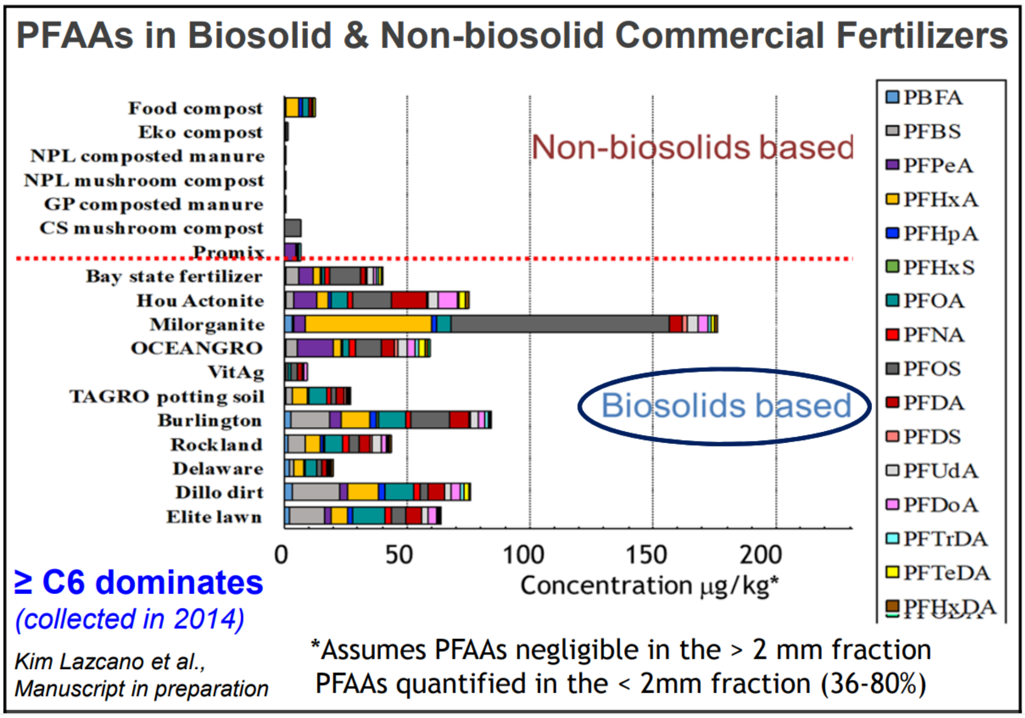
5.4.2 USA

Biosolids and paper mill residuals have received the most scrutiny so far in the USA, but composts made from various raw materials are being evaluated as well. For example, data presented by Dr Linda Lee at a Water Environment Federation webinar titled PFAS, Wastewater, and Biosolids Management showed levels of PFAS in a wide variety of commercial organic residual products (Lee 2018). In this work, Lee (2018) determined concentrations of 17 different perfluoroalkyl acids (PFAAs) in 18 commercially available organic soil amendments (sampled in 2014), including biosolids and non-biosolids based products and ten non-commercial organic soil amendments (sampled in 2017). The combined total concentrations of 17 PFAA compounds in biosolids based products, including composts, ranged from about 0.01 to 0.18 mg/kg, while non-biosolids based products contained significantly lower levels with maximum levels of approximately 0.012 mg/kg (Figure 12).

Successive determination of PFAA compounds in Milorganite, a heat dried biosolids product that is primarily marketed for urban and residential lawns (https://www.milorganite.com/) showed that concentrations of PFAAs declined sharply over a four-year period from about 0.18 mg/kg in 2014 to less than 0.07 mg/kg in 2018 (Figure 13). This is, at least in part, testimony to the fact that PFOA and PFOS have been largely phased out of use in the U.S. over the past 15 years, resulting in declining concentrations in various matrices and an expectation that concentrations of these compounds in composts, paper mill residuals, and biosolids will continue to decrease over time (Beecher and Brown 2018). Declining PFOA and PFOS blood concentrations in the US population between 1998 and 2014 (Figure 15) support this assumption.

In comparison, concentrations of the same 17 PFAAs totalled only up to ~0.005 mg/kg in composts made from vegetation residues, and concentration values in composts made from various urban and commercial organic feedstocks where food scrap feedstock often included compostable service-ware ranged from approximately 0.02 mg/kg to 0.07 mg/kg (Figure 13). In response to concerns raised by the compost industry that compostable food service-ware may be a likely source of PFAS, the Biodegradable Products Institute in the USA announced in late 2017 that its certification program for compostable products will begin to include a limit on total fluorine content of 100 mg/kg, a limit that was already in place in European composting standards (Beecher and Brown 2018). This limit is challenging for service-ware manufacturers, because PFAS remain highly useful in keeping paper from absorbing grease and water, with no current viable alternatives for moulded fibre applications. However, certified compostable products are not the only source of PFAS in food residue compost, as conventional paper products generally accepted by composters without any testing are a likely source also.

It should be noted that the above presented measurements by Lee (2018) represent only material <2 mm, resulting most likely in inflated contaminant concentrations for products that usually comprise material <10 mm or < 20 mm.



PFAAs in Biosolid & Non-biosolid Commercial Fertilizers

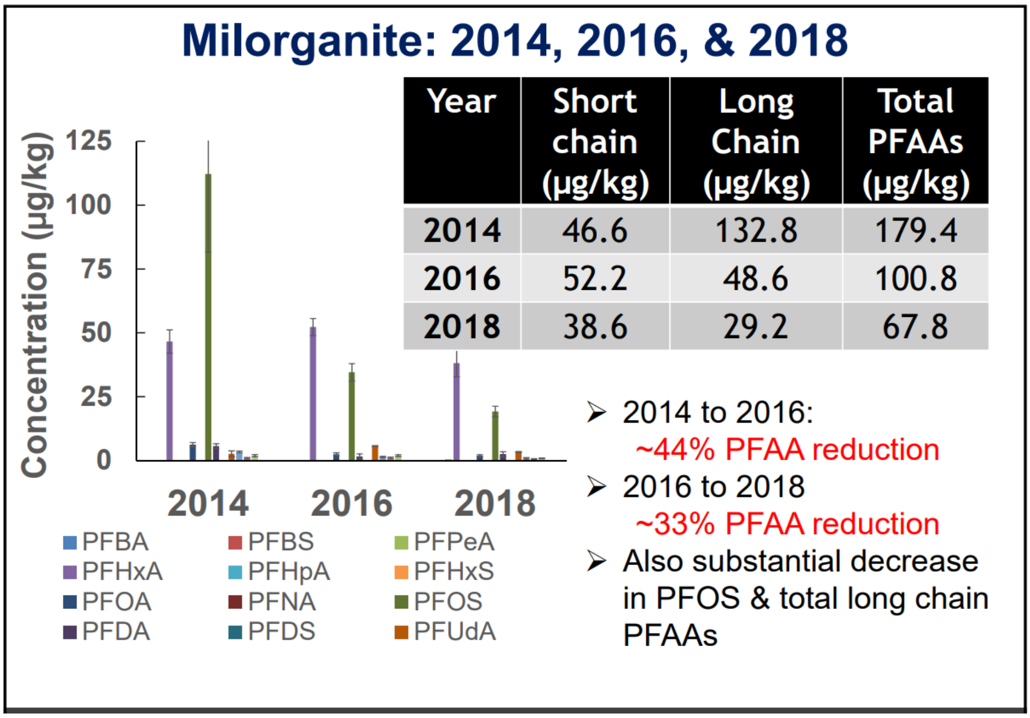
≥ C6 dominates

(collected in 2014)

Kim Lazcano et al., Manuscript in preparation

*Assumes PFAAs negligible in the > 2 mm fraction PFAAs quantified in the < 2mm fraction (36-80%)

Figure 12 Concentrations of PFAAs in commercially available biosolids and non-biosolids based organic soil amendments in the USA (Note: 1 µg/kg = 0.001 mg/kg) [Lee 2018]

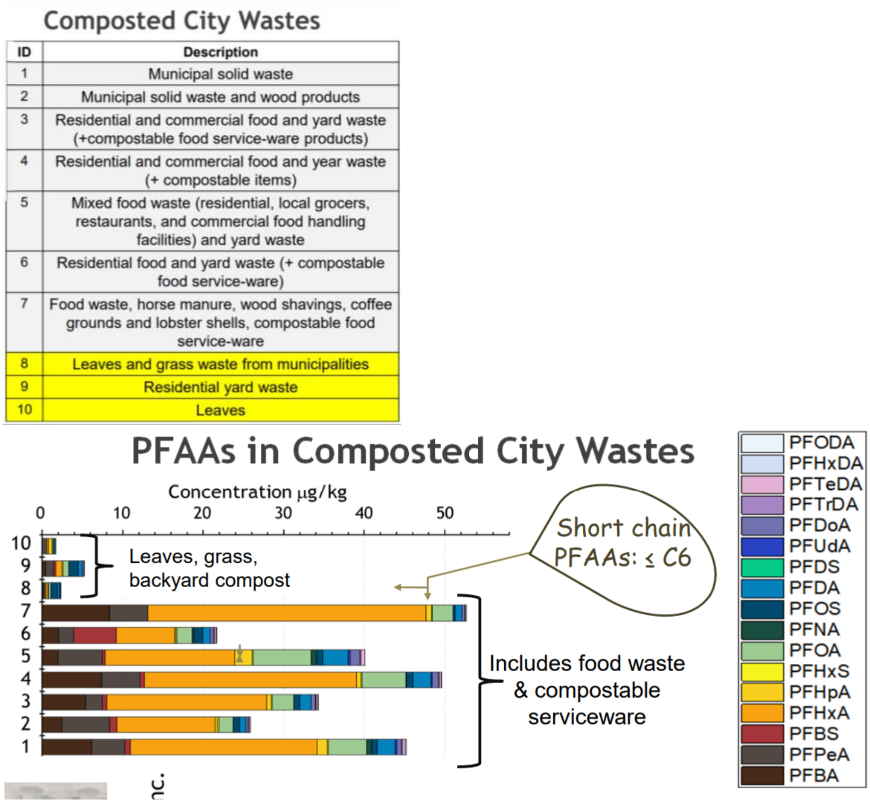


Milorganite: 2014, 2016, & 2018

Year	Short chain (µg/kg)	Long Chain (µg/kg)	Total PFAAs (µg/kg)
2014	46.6	132.8	179.4
2016	52.2	48.6	100.8
2018	38.6	29.2	67.8

- 2014 to 2016:
  ~44% PFAA reduction
- 2016 to 2018
  ~33% PFAA reduction
- Also substantial decrease in PFOS & total long chain PFAAs

Figure 13 Concentrations of PFAAs in Milorganite (heat dried biosolids) between 2014 and 2018 [Lee 2018]



Composted City Wastes

ID	Description
1	Municipal solid waste
2	Municipal solid waste and wood products
3	Residential and commercial food and yard waste (+compostable food service-ware products)
4	Residential and commercial food and year waste (+ compostable items)
5	Mixed food waste (residential, local grocers, restaurants, and commercial food handling facilities) and yard waste
6	Residential food and yard waste (+ compostable food service-ware)
7	Food waste, horse manure, wood shavings, coffee grounds and lobster shells, compostable food service-ware
8	Leaves and grass waste from municipalities
9	Residential yard waste
10	Leaves

Figure 14 Concentrations of PFAAs in composts made from various urban and commercial organic feedstocks [Lee 2018]

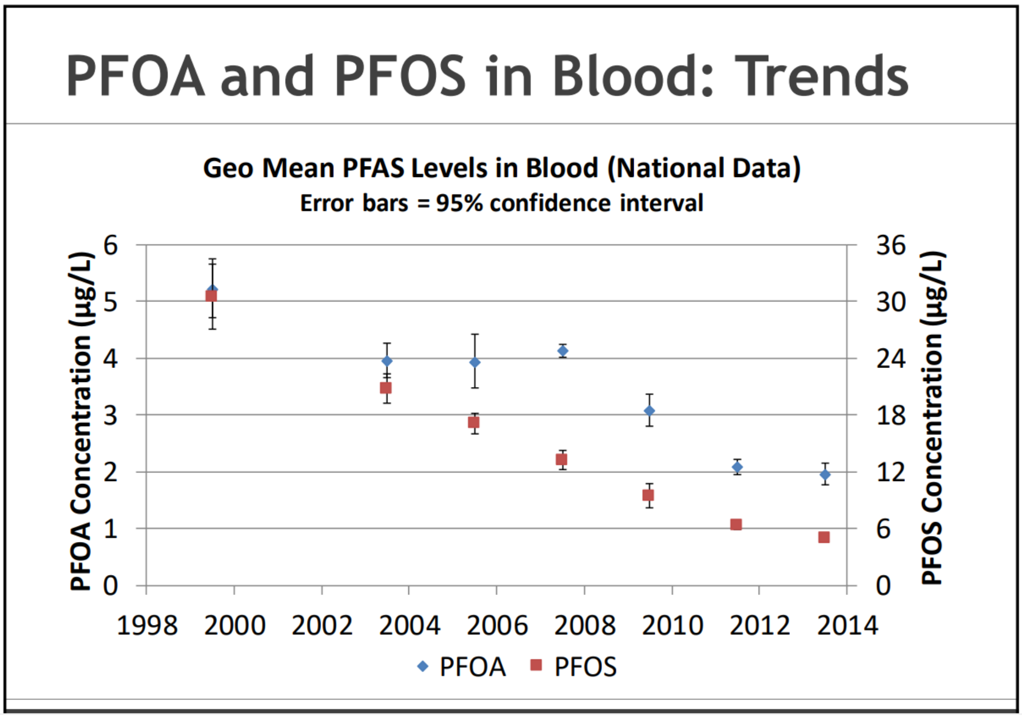
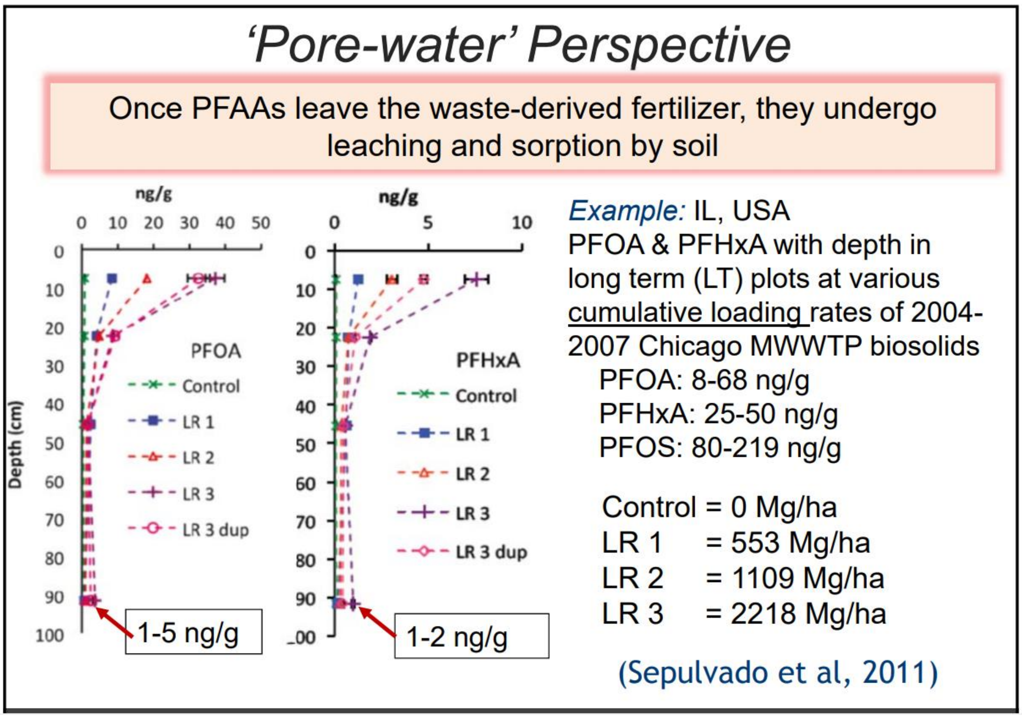


Figure 15 Development of PFOA and PFOS concentrations in blood in the US population between 1998 and 2014 [Zemba 2018]

Beecher and Brown (2018) report that, in the USA, drinking water quality has been the focus of the most recent regulatory actions related to PFAS. In 2016, the US EPA created a public health advisory (PHA) level for PFOA and PFOS in drinking water of 0.07 µg/L for the two chemicals separately or combined, which provides full protection from lifelong exposure for the most sensitive individuals and the most sensitive life stages. Some states (e.g. Minnesota, New Hampshire, New Jersey, and Vermont) have adopted the new PHA or lower drinking water enforcement standards or advisory levels, but most states have not adopted any state level PHA, relying instead on the US EPA PHA screening value, which were previously an order of magnitude higher. With reference to contaminant levels in biosolids or compost, Beecher and Brown (2018) caution that data on PFAS in any matrix other than drinking water is suspect and should be used for screening and educational purposes only since the only US EPA-approved method for PFAS is Method 537, rev. 1.1, which is specifically for drinking water only, and as appropriate methods for non-drinking waters and solids should be completed and published by the US EPA sometime in 2019.

Apparently, several states are currently considering setting PFAS contaminant levels in soil, although some leaching models used in the calculation of these limits are thought to use unrealistic values for parameters such as the fraction of organic carbon in soil and degree of molecular sorption, both of which could result in calculating unrealistically low soil contaminant limits (Severtson 2019). In support of his statement, Severtson (2019) offered the following summary of a greenhouse and field study that assessed plant uptake of perfluoroalkyl acids (PFAAs) from biosolids (Blaine et al 2013). The authors looked at PFAA concentrations in lettuce and tomato grown in biosolids amended soils using industrially impacted biosolids, biosolids from a long-term application site, as well as ‘clean’ soil in the greenhouse study. They calculated bioaccumulation factors looking at concentrations in soil relative to plant concentrations primarily from the greenhouse portion of the trial and concluded that “This study confirms that the bioaccumulation of PFAAs from biosolids-amended soils depends strongly on PFAA concentrations, soil properties, the type of crop, and analyte”. In the “field scale trial” using lettuce and tomato, and a “full-scale field study” with corn, the plant concentrations were below the level of quantification for all treatments except the 4x agronomic rate (100 t/ha). Severtson (2019) points out that this study is an example of how small-scale investigations into bioaccumulation can differ significantly from regulated, field-scale applications. He furthermore points out that the study used three types of soil: control, “industrially impacted”, and “municipal”, with the industrially impacted soil showing concentrations of PFOA of 78.5 ug/kg and PFOS of 49.7 ug/kg and the municipal soil containing concentrations of PFOA of 14.9 ug/kg and PFOS of 319.5 ug/kg, soil concentrations that are orders of magnitude higher than would realistically result from agronomic biosolids application rates.

Beecher and Brown (2018) reference literature that shows some leaching of some PFAS compounds to groundwater from biosolids land application sites at concentrations approaching the EPA PHA screening level for drinking water of 0.07 µg/L. For example, they mention work by Sepulvado et al. (2011) that evaluated four varied sites where biosolids from Chicago had been applied repeatedly (up to 2,218 t/ha cumulative application rate) and, in 2004 - 2007, found concentrations in the land applied biosolids ranging from 0.008 to 0.068 mg/kg PFOA and 0.08 to 0.219 mg/kg for PFOS, with soil levels linearly correlated with cumulative application rate. Some downward migration of PFAS was observed, with greater leaching of the short-chain versions (Figure 16). Gottschall et al. (2017) evaluated PFAS leaching to tile drain water and shallow groundwater from a single biosolids application (22 t/ha) in Ontario, Canada. These biosolids contained lower concentrations of PFOA (0.0016 mg/kg) and PFOS (0.0072 mg/kg) than the biosolids from Chicago. Levels in 2-meter groundwater reached 0.003 µg/L for PFOA and 0.0008 µg/L for PFOS, while tile drainage water reached as high as 0.023 µg/L for PFOA and 0.0011 µg/L for PFOS.



‘Pore-water’ Perspective

Once PFAAs leave the waste-derived fertilizer, they undergo leaching and sorption by soil

Example: IL, USA
PFOA & PFHxA with depth in long term (LT) plots at various cumulative loading rates of 2004-2007 Chicago MWWTP biosolids
PFOA: 8-68 ng/g
PFHxA: 25-50 ng/g
PFOS: 80-219 ng/g

Control = 0 Mg/ha
LR 1 = 553 Mg/ha
LR 2 = 1109 Mg/ha
LR 3 = 2218 Mg/ha

(Sepulvado et al, 2011)

Figure 16 Accumulation and downward movement of PFOA and PFHxA in a soil profile following repeat biosolids application [Lee 2018]

5.4.3 Germany

Generally speaking, per- and poly-fluoroalkyl substances are not considered a major problem for the beneficial agricultural use of organic residues in Europe (Amlinger 2019, Siebert 2019b, Thelen-Jüngling 2019). This is not to say that there were no incidences where land application of waste derived products resulted in contamination of land, but these were mainly due to illegal activities. The two ‘PFAS incidences’ in Germany occurred (i) in 2006 when wastewater sludges were illegally blended with residues from the photochemical industry (which waere destined for incineration) and applied to some 450 ha of agricultural land, and (ii) in 2014, when elevated PFAS levels were discovered on agricultural land, which, in 2006 - 2008 was amended with FOGO compost that was allegedly illegally blended with paper sludge (Kehres 2015).

The following section provides a summary of the situation in Germany, which was published by the German Compost Quality Assurance Association (Kehres 2015) in response to the 2014 ‘PFAS incidence’.

It is important to know that, apart from a few exceptions, since 12 December 2006 it is illegal to supply and use PFOS in the European Union, according to EU-Guideline 2006/122/EG.

It is possible that agricultural soils can be contaminated with PFAS compounds through the use of fertilisers and organic soil amendments. Uncontaminated agricultural soils, including those where biosolids or FOGO compost was applied long-term, contain PFAS levels of < 10µg/kg, while soils that are known to have been contaminated show markedly higher levels (Table 31).

Table 31 PFOS and PFOA content (mg/kg dm) in soils in Germany [Kehres 2015]

Soil	PFOA	PFOS	Total
Agricultural topsoil with previous contamination issue (mainly PAH), N=21	< 0.01	< 0.01	< 0.01

Soil	PFOA	PFOS	Total
Agricultural topsoil amended long-term with biosolids or FOGO compost , N=29	< 0.01	< 0.01	< 0.01
Agricultural topsoil amended in 2003/4 and 2006 with PFAS containing sludges, N=6	< 0.01 to 0.032	< 0.01 to 0.045	0.0125 to 0.078
Agricultural topsoil amended in 2006 - 2008 with compost and paper sludges, but investigation re cause is ongoing	No data	No data	0.022 to 0.442
Agricultural soil amended in 2006 with PFAS containing sludges	< 0.001 to 0.910	< 0.01 to 8.60	< 0.01 to 9.25

Contaminant limits of 0.1 mg/kg dm (total PFOA + PFOS) were established for fertilisers in the 2012 German Fertiliser Regulation. These limits apply equally for growing media, organic soil amendments and manures and also for every raw material that is used for manufacturing fertilisers. Contaminant concentrations have to be declared when total PFOA + PFOS values exceed 0.05 mg/kg dm. However, there are no drinking water limits only guideline values. The general guideline value for total PFOA + PFOS of ≤ 0.3 µg/L drinking water is intended to provide the entire population with full protection from lifelong exposure, the public health guideline value of ≤ 0.1 µg/L drinking water represents a goal for long-term and intergenerational protection of drinking water. It is recommended that babys and sensitive individuals should not consume water that contains total PFOA + PFOS concentrations of more than 0.5 µg/L drinking water. If total PFOA + PFOS concentrations in drinking water exceed 5 µg/L, it should no longer be drunk or used for cooking in any circumstance.

The 2014 contamination incidence brought back into focus the potential risk paper manufacturing sludges pose when utilised via direct land application or via co-composting. There were speculations that direct land application or co-composting of paper recycling sludge between 2005 and 2008 was the primary cause of elevated PFAS levels in agricultural land. The use of sludge generated during paper recycling was prohibited already in those days for fear of elevated contamination levels. However, a more recent (2015) analysis of sludges generated during paper production from virgin raw materials and from recycled paper did not reveal excessive PFOA and PFOS concentrations (Table 32). In fact, contaminant concentrations detected in 19 samples were all well below the limit of 0.1 mg/kg dm (total PFOA + PFOS)

Table 32: PFOS and PFOA content (mg/kg dm) in paper manufacturing sludge [Kehres 2015]

Substrate	PFOA	PFOS	Total	Limit
Sludge generated during paper manufacturing with virgin raw materials, N=11	< 0.01 to 0.011	< 0.01	< 0.01 to 0.011	0.1
Sludge generated during paper manufacturing with recycled paper, N=8	< 0.01	< 0.023	< 0.01 to 0.023	

Over the past 30 years, the collection, processing and beneficial use of source separated garden and food organics has been well established in Germany. In early 2019 there were over 550 composting and more than 170 anaerobic digestion facilities that convert around 13 million tonnes of organic residues into nine million tonnes of quality assured compost and digestate products annually (Bundesgütegemeinschaft Kompost 2019b). The majority of source segregated food and garden organics is processed in composting facilities, some of which have integrated anaerobic digestion as a processing step. About 80% of generated compost and digestate is utilised as organic fertiliser and soil ameliorant for land management purposes.

Raw materials for composting comprises primarily kerbside collected source separated garden and food organics (FOGO) and self-hauled garden organics originating primarily from residential properties and public parks and gardens. Feedstock processed at anaerobic digestion facilities is more varied and includes commercial food residues, out of date food stuff, grease trap waste, manures, energy crops and other organic residues with high biogas generation potential. However, in either case, organics processing facilities are only allowed to accept and process feedstock materials that do not cause concern and are acceptable input materials according to the FOGO Regulation and/or Fertiliser Regulation.

Analysis of 62 compost samples did not show elevated PFOA or PFOS concentrations above the detection limit (0.01 mg/kg dm), neither in garden organics compost nor in FOGO compost (Table 33). In the case of liquid digestate, 85% of samples (N=70) showed equally low PFOA and PFOS concentrations (Table 34). However, 10 samples did show detectable contaminant levels, two of which were above the concentration that requires declaration of PFAS content (0.05 mg/kg dm). These findings raised the questions whether

- all organic residues that are currently allowed as feedstock for organics processing facilities under the FOGO / Fertiliser Regulation, are really suitable and can be utilised without concern;
- it is adequate to only analyse for PFOA and PFOS, or whether the spectrum of analytes should be expanded
- the current detection limit of 0.01 mg/kg dm in solid matrixes such as soil and fertiliser is adequate for risk assessments, or if the detection limit needs to be lowered, if this can be done without losing confidence.

Having raised these questions, the German Compost Quality Assurance Association commissioned the analysis of five garden organics composts and five FOGO composts for 18 different PFAS compounds at a detection limit of 0.001 mg/kg dm (=1 µg/kg dm). The results are presented in Appendix C and show that PFOS was the dominant compound found in composts, while no PFOA was detected. Most of the tested PFAS compounds were not detected in the assessed compost products, and those that were detected showed concentrations between 0.001 and 0.004 mg/kg dm, well below the existing limit of 0.1 mg/kg dm.

Table 33 PFOS and PFOA content (mg/kg dm) in FOGO and garden organics compost in Germany [Kehres 2015]

Substrate	PFOA	PFOS	Total	Limit
FOGO compost, N=37	< 0.01	< 0.01	< 0.01	0.1
Garden organics compost, N=25	< 0.01	< 0.01	< 0.01	

Table 34: Distribution of total PFOA + PFOS concentration in liquid digestate samples (FOGO processing) with regard to various threshold limits in Germany [Kehres 2015]

Substrate Liquid digestate (N=70)	Sample Number	Sample Proportion
Concentration below detection limit (< 0.01 mg/kg dm)	60	85%

Substrate Liquid digestate (N=70)	Sample Number	Sample Proportion
Concentration below limit for declaration of PFAS content (0.01 to < 0.05 mg/kg dm)	8	11%
Concentration that requires declaration of PFAS content (> 0.05 mg/kg dm)	2	4%
Concentration above Fertiliser Regulation limit (> 0.1 mg/kg dm)	0	0%

5.5 Treated Timber

The Timber Preservers Association of Australia (undated) provides the following generic information regarding various methods of treating and preserving timber. Wood preservatives may be dissolved in water, oil, or a light organic solvent such as mineral turpentine. This allows a preservative to be classified into one of three main groups. The list below covers only those preservatives that are used to treat wood to the specifications in Australian Standard AS/NZS 1604 Specification for preservative treatment.

Water based preservatives

Timber treated with this group of preservatives has a wide variety of applications, both indoors and outdoors, for residential, commercial, and industrial uses. Products in this category includes

- Copper Chrome Arsenate, also referred to as CCA, and the treated wood is green in colour
- Copper Quaternary or ACQ, turns the wood green but a different shade compared to CCA,
- Copper azole (CuAz) turns the wood a brown-green colour.

CCA, ACQ and CuAz react chemically with the wood, making them insoluble and so suitable for use in situations where the treated wood may be exposed to the weather. This set of preservatives is effective in protecting wood from attack by borers, termites and decay.

Boron-based preservatives are water soluble and do not become insoluble after treatment. Because of this, products that are protected with boron-based preservatives can only be used in situations where the wood does not get wet.

Oil-borne preservatives

Timber treated with oil-borne preservatives is mainly used for heavy duty construction and in the marine environment. The oil-borne preservatives approved for use in Australia are creosote and pigment emulsified creosote (PEC). Oil-borne treated products include utility poles, rail sleepers and marine piles

Light Organic Solvent Preservatives (LOSP)

LOSP systems are used for products treated in their final shape and form. This includes high value joinery such as balustrades, fascias etc. LOSP treatments are only suitable for products used out of ground contact, and treated products that are destined for outdoor use are often sold with a primer coat of paint. As copper naphthenate is the only coloured LOSP treatment (green), other LOSP treatments may contain a tracer colour. The AS/NZS 1604 specified LOSPs include:

- Tributyl tin naphthenate or TBTN is a fungicide (stops decay or rot) and leaves the wood colourless. This preservative must include one of the termite protections (insecticides) listed below.
- Copper naphthenate or CuN is being increasingly used in the US, turns the wood green and is a fungicide only. This preservative must also be used with an insecticide.
- Tebuconazole/propiconazole or teb/prop is, like TBTN, a colourless fungicide and must be used with an insecticide.
- The synthetic pyrethroids, permethrin, deltamethrin, bifenthrin, and cypermethrin are used for termite and insect control and have no ability to stop decay. These preservatives are colourless and often have a dye or pigment added, e.g. blue framing.

Glue line additives

This type of preservative does not neatly fit into the three groups of preservative just described. This is because the preservative is added to the glue when products such as plywood or laminated veneer lumber or chipboard are being prepared for gluing. Preservatives in this group currently include two synthetic pyrethroids, imidacloprid and zinc borate.

The estimated minimum quantity of potentially hazardous compounds in wood preservation products in accordance with hazard classification codes can be found in Table 35.

Table 35 Estimated minimum amount of preservative in treated wood by hazard class (mg/kg wood) [Hann et al. 2010]

Chemical		Hazard Class					
		H1	H2	H3	H4	H5	H6
CCA	Cu	87.5	800	950	1,580	2,500	5,000
	Cr	157.5	1,440	1,710	2,840	4,500	9,000
	As	129.5	1,180	1,410	2,330	3,700	7,400
ACQ	Cu	1,139	2,350	2,350	5,960	9,450	-
	DDAC	748	1,540	1,540	3,920	6,200	-
Cu azole	Cu	-	-	2,210	4,020	7,330	-
	Azole	-	-	100	170	320	-
Boron	B	470	3,500	-	-	-	-
TBTN	Sn	-	-	800	-	-	-
Cu N	Cu	-	-	1,000	-	-	-
Permethrin		60	200	200	-	-	-
Cypermethrin		60	300	300	-	-	-
Deltamethrin		6	20	20	-	-	-
Bifenthrin		12	47	50	-	-	-
Creosote		-	-	80,000	200,000	245,000	400,000

5.5.1 Copper chrome arsenate (CCA)

Copper chrome arsenate, or CCA, is a water-based heavy metal mixture that was developed in the 1930's, and usually includes arsenic, chromium and copper (Mayes, 2008). Arsenic in CCA protects against insects and copper-tolerant fungi, copper acts as the fungicide and chromium is used to bind these chemicals to the wood surface (Hann et al. 2010). Preservation with CCA is popular and effective and accounts for over half of treated timber volume in Australia (Hann et al. 2010). The chemicals are pressure-impregnated into the wood where they react with the cells and become highly resistant to removal. There are many concerns that these metals persist in the environment as they have been designed to allow the timber to withstand decay and degradation and ultimately extend its service life. All three substances, arsenic, copper and chromium are heavy metals and can have detrimental effects on the environment and human health when released from timber (Solo-Gabriele et al. 2004; Khan et al. 2006).

All new preservative formulations must be approved by The Australian Pesticides and Veterinarian Medicines Authority (APVMA) under the *Agricultural and Veterinary Chemicals Code Act* 1994. In 2005, the APVMA implemented rules to restrict the use of CCA and required that CCA-treated timber be labelled so it could be clearly identified by consumers. Further restrictions were put in place in 2012, when APVMA classified CCA as a restricted chemical and imposed an authorisation system to regulate and limit its use. Yet, this does not directly regulate its end use or disposal.

Since the early 1990s, Alkaline Copper Quaternary (ACQ) became available as an alternative for treating timber and has increasingly been replacing CCA. Other alternative treatment options for timber include copper azole or creosote, depending intended use of the timber.

CCA treated timber can be classified into hazard classes H1 to H6, which represents a ranking according to increasing contaminant concentrations and hence the potential hazard they pose to the environment. Table 36 provides an overview of hazard classes for CCA treated timber and associated typical applications, and Table 35 above shows estimated quantities of copper, chromium and arsenic in treated wood according to hazard class.

Table 36 Hazard classes for timber treatment with CCA

Hazard Class	CCA Concentration	Typical Applications
H1	Increasing concentration	Indoor borers—indoor use
H2	(Retention levels of CCA)	Insect borers and termites—indoor use
H3	↓	Insect borers termites and decay—outdoor, above ground constructions eg pergola
H4		Insect borers termites and severe decay Outdoor below ground eg viticultural industry— posts
H5		Insect borers termites and extreme decay. Outdoor in ground-near saturated conditions
H6		Marine organisms, extreme decay, eg piers,

5.5.2 Metals in treated timber

Arsenic has continued to be found on the surfaces of CCA treated timber for at least 20 years after it has been applied (Hall and Beder 2005). The exposure to arsenic can cause cancers and affect many systems in the human body such as; respiratory, pulmonary, cardiovascular, gastrointestinal, haematological, hepatic, renal, neurological and immunological (Jackson Environment and Planning 2017). Arsenic does occur naturally in the soil at low levels, usually in an organic form, which makes it less mobile.

Chromium has been classified as a carcinogen to humans, whereas copper poses more of a risk to marine environments. The toxicity threshold for boron in plants is very low and therefore wood treated with boron should not be used for the production of mulch and compost. The Australian Standard for Composts, soil conditioners and mulches (AS4454 – 2012) has a threshold of less than 100 mg/kg dm. More detailed information on heavy metals has already been provided in Section 5.2.

5.5.3 Methyl Bromide

Methyl Bromide is not a long-term timber treatment as such, compared to the agents discussed above. Rather it is used as a fumigant for timber which is internationally imported or exported, including pallets and packaging used for global shipping.

It was withdrawn from widespread use globally and in Australia in 2005 under the Montreal Protocol, due its detrimental effect on the ozone layer. However, it was allowed to be used for exempt quarantine and production purposes for which there was no suitable alternative to methyl bromide. As such, it continues to be used as a fumigant under the quarantine exemption in some applications.

In quarantine use, it is also commonly used as a fumigant to treat food products, including fruit and other foods, that are imported or destined for export. Methyl Bromide is also used to fumigate soils on strawberry farms to eliminate fungi and pests. Given this use, it is lethal to most soil organisms and can be toxic to animals and humans at low concentrations. It is also very toxic in aquatic environments and exposure of plant seeds to methyl bromide may result in a delay in or loss of germination, depending on the moisture content of the soil.

It is one of two common methods used to treat timber pallets to protect them from pests and prevent the spread of wood eating pests via international shipping. The other method, which is generally becoming more common and considered more effective, is heat treatment. Any wood packaging imported into Australia must be treated but pallets that are only used domestically do not need to be treated.

There has been concerns raised about the potential for pallets which seem to be clean untreated timber, which may be used in composting or mulch production, to be contaminated with Methyl Bromide. However, when wood is fumigated with Methyl Bromide, the gas penetrates into the wood and then dissipates, generally leaving no chemical residue in the wood[5].

Methyl Bromide is a gas at room temperature and fumigation takes place in an enclosed chamber so the compound soaks into the timber itself. Pallets which have been treated with Methyl Bromide should be stamped with a ‘MB’ marking in accordance with international conventions.

Studies have shown that the chemical is moderately mobile in soil but the majority is expected to evaporate in this application. The chemical is not rapidly biodegradable, but limited biodegradation may occur. The aerobic biodegradation of the chemical was determined by one study to be 17% in 28

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[5] https://www.nicnas.gov.au/chemical-information/imap-assessments/imap-assessments/tier-ii-environment-assessments/bromomethane#_ENREF_14

days and estimates of its half-life in soil vary from 1 to 29 days, although the reliability of these estimates is not clear. It is not expected to bio-accumulate in aquatic or terrestrial biota.

The use of Methyl Bromide is generally being phased out where other alternative methods exist.

Overall, the risk posed by Methyl Bromide in contaminating clean timber that might be used in composting, particularly from pallets, is considered low. However, further investigation may be warranted.

5.5.4 Effects on the environment

The composting of wood and timber involves particle size reduction of feedstock, which increases the surface area of treated timber and increases also the potential for the chemicals to disperse into the environment as the generated products are used. Creosote will degrade to some degree (60 - 70%) during aerobic composting, although conditions need to be optimal (Lease 2006). However, accumulation of large PAHs, such as benzo(a)pyrene and fluoranthracene, can still occur and therefore creosote treated timber should not be composted. Additionally, there is potential for leachate from composting sites to contain contaminants originating from treated timber, which could pollute surrounding soil and water if leachate is not managed properly.

Leaching of chemicals from treated timber into soil and groundwater depend on climatic and geological conditions, the age of the timber product, UV exposure and acid levels (Hall and Beder 2005). Acid conditions can increase leaching, which might mean that contaminants become more soluble during the initial stages of the composting process when pH levels decline temporarily due to the formation of organic acids as part of the degradation process of organic matter. There is particular concern to human health with mulching and composting of CCA treated timber and the subsequent use in landscape applications as it may result in ingestion, inhalation or skin absorption, particularly around parks and play areas. The use of mulch or compost containing CCA-treated timber on food crops and pastures is also of concern as this increases the risk of human exposure through the food chain via contaminated crops or livestock (Mercer and Frostick, 2012).

It can be difficult to visually identify and separate treated timber, especially when weathered, which is why treated and non-treated timber needs to be separated at source.

The main markets for recovered wood in Europe are the particleboard industry (Italy, Germany, Belgium, the UK) and energy production (Germany and Sweden) (van Benthem 2007; The Age 2006; The Peter Heath Consultancy 2005). In Australia, wood waste is recycled and beneficially used via particle board manufacturing, use in animal bedding, mulching and composting, for biofilters and for energy generation (Timber Development Association 2012), with a relatively large proportion being utilised in landscaping applications (mulch / compost) and for energy generation. More accurate figures for the UK show that about 22.5% of wood waste was utilised as mulch or compost (BIS 2012). Energy generation from wood waste in Australia is primarily achieved through one of the following options:

- Biomass and wood waste fired power stations, which are often smaller energy production facilities (<30MW) at sawmills or sugarmills (Rocky Point Sugar Mill and NSW sugar mills with Delta Energy)
- Co-generation
- Co-firing wood e.g. Adelaide Brighton Cement (co-fired with gas)

The main issue regarding these alternatives for burning treated timber is the management of emissions with appropriate filter systems.

5.5.5 Regulations, guidelines and standards

The National Environmental Protection Council of Australia (NEPC) Controlled Waste National Environment Protection Measure (NEPM) has not identified CCA treated timber as a controlled waste; hence it may cross interstate borders without tracking.

The **Australian Standard AS 5605 - 2007 Guide to the safe use of preservative treated timber** provides consumer safety information and states that all the preservatives used for the protection of wood against biodegradation are toxic to some degree and therefore have the potential to be hazardous.

The standard categorises treated timber into the following categories:

- Waterborne preservatives (CCA)
- Oil-borne preservatives (e.g. creosote and pigment-emulsified creosote)
- Light organic solvent-borne preservatives (LOSP)
- Glueline additives

The Standard recommends against its use for some recycling and energy recovery applications and states that '*offcuts and waste are not recommended for mulching or animal bedding.'* The Standard also provides guidelines and recommendations on its safe use and the potential health and environmental risks associated with handling and disposing treated timber. Table 37 indicates potential exposure pathways to contaminants contained in treated timber.

Table 37 Potential human exposure pathways to treated timber [adapted from AS 5605 – 2007]

Activity	Contaminated Material	Exposure Route	
Machining (sawing, cutting, drilling, etc.)	Wood dust	Direct contact	Inhalation*
			Ingestion
			Dermal
Surface residues	Dislodgeable residues	Direct contact	Ingestion*
			Dermal
Leaching	Soil/water ways	Direct contact	Ingestion*
			Dermal
			Inhalation
		Plant uptake	Ingestion

*Principal exposure route

The Australian Standard **AS 1604.1 – 2012 Specification for preservative treatment** describes relevant specifications for preservative treatments and sets a series of requirements for treatment of wood with preservative. Timber preservative formulation shall;

a) Comply with the composition of preservatives requirements of Appendix B of the Standard
b) When used in Australia be approved and registered by the pesticide's registrar.

The standard also outlines that all preservative-treated timber shall be legibly and sufficiently permanently marked with;

a) Unique identifier for the treatment plant
b) Unique identifier for the preservative

c) Hazard class, of which each hazard class has its own marking requirements

Regulations regarding treated timber are most comprehensive in NSW where the NSW EPA regulates treated wood under the *Protection of the Environment (Operations) Act 1997*, the *Pesticides Act 1999*, and the *Contaminated Land Management Act 1997*. Treated timber was listed as a waste of concern under the NSW framework for Extended Producer Responsibility, which resulted in the formation of a National Timber Product Stewardship Group (NTPSG).

Under the NSW Mulch Order 2016, mulch must not contain any asbestos, or preservative treated or coated wood residues. It also states that on or before supplying mulch, the processor must ensure that the mulch does not contain preservative treated or coated wood residues.

NSW does not classify the waste as hazardous, but provides a general approval of immobilisation of contaminants in the waste, other than waste that is building and demolition, inert or municipal waste. Therefore, total concentrations of the heavy metals are not applied to the waste assessment. The material may be classified according to leaching concentrations determined via the Toxicity Characteristic Leaching Procedure. CCA timber at end of life must be disposed of at a lawful *General Solid Waste* landfill in accordance with the *NSW Waste Classification Guidelines* (NSW EPA 2014).

Regulations in Queensland define wood treatment and preservation as a Notifiable Activity under Schedule 3 in the *Environment Protection Act 1994*.

The Australian Standard Leaching Procedure (ASLP) test is used in In Western Australia to determine potential hazards from treated timber. CCA treated timber waste is classified as ‘Type 1 Inert waste’ (Department of Water and Environmental Regulation 2018), which includes wastes that are largely non-biodegradable, non-flammable and not chemically reactive.

Internationally, the European Union classifies CCA treated timber as a hazardous waste and therefore it is banned from going to landfill. The amendment of the European Union Commission Directive 76/769/EEC in 2003 states that CCA may not be used in the preservation of wood and wood preserved with CCA may not be supplied into the market, except for specific applications. Some countries, such as Denmark, Switzerland, Vietnam and Indonesia have banned the use of CCA treated wood altogether (CSIRO 2005).

5.6 Emerging Contaminants

There are a range of emerging contaminants constantly being investigated and discovered. As new chemicals are manufactured and used, or as the understanding of the toxicity or persistence of chemicals currently or formerly in use progresses, new groups of emerging contaminants are likely to be identified over time.

While commonly found in effluent streams, it should be assumed that any feedstock that has been in contact with industrial chemicals or been subject to processing / treatment / anthropogenic interventions may contain unknown chemicals. Ongoing analysis as new contaminants are documented and publicised is the only way to confirm their presence or absence in feedstocks.

PFAS is an example of a pervasive contaminant that has been with us for a long time, but was not on the ‘watch list’, and took many in the composting industry by surprise. There is a need for an ‘early warning system for emerging contaminants’ that is operated by regulatory authorities that can forewarn the organics recycling (and other industries) of what may lay ahead. This needs to go hand in hand with a higher level of awareness and education within industry about emerging contaminants, so that management measures can be developed as early as possible.

The US EPA publishes a comprehensive list and information on ‘contaminants of emerging concern’ including pharmaceuticals and personal care products, as part of efforts to inform broader industry awareness[6]. The list includes the materials and compounds below. It is not clear which, if any, could potentially present in composting feedstocks but this highlights the need to monitor international research.

- 1,2,3-Trichloropropane (TCP)
- 1,4-Dioxane
- 2,4,6-Trinitrotoluene (TNT)
- Dinitrotoluene (DNT)
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
- Nanomaterials
- N-Nitroso-dimethylamine (NDMA)
- Perchlorate

5.7 Pathogens

Pathogens is a broad category covering biological contaminants including any potential bacteria, virus or other organism which may impact human, animal or plant health. A range of pathogens such as E.coli and Salmonella are typically associated with faecal contamination and derive from any sewage related waste streams and materials that come in contact with animal manures. As such, they can affect a wide range of animal and food processing, and effluent wastes.

Properly managed aerobic composting provides a high degree of pasteurisation which should be adequate to destroy or reduce most common pathogens to levels that pose minimal risk. There is ample guidance on minimum pasteurisation requirements to achieve this, such as in AS4454. As such, it is not considered that further management controls are required for this group of contaminants.

5.8 Contamination pathways

There are a number of different pathways that humans or the environment can be exposed to contaminants within compost feedstocks. At a high level, these include:

- Collection and transport to the composting facility – spillages / accidents, leaks, dust
- Storage and handling on site – operational staff handling and exposure, seepage to soil and groundwater, stormwater runoff / leachate
- Exposure of neighbouring properties – surface water discharges, groundwater migration, windblown dust / vapours
- Transport, storage, handling and spreading of the products
- Exposure from soils containing the products, either through direct contact or via stormwater runoff and groundwater migration
- Consumption of food grown in or indirectly affected by the products.

For humans, the exposure pathways include:

- Direct skin contact when applying compost or digging in soils treated with compost
- Direction ingestion of compost or treated soils, accidentally (young children) or as particles on food crops

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[6] https://www.epa.gov/wqc/contaminants-emerging-concern-including-pharmaceuticals-and-personal-care-products

- Uptake into plant crops (grains, fruits, vegetables)
- Ingestion by grazing animals used for human food

Environmental exposure pathways include:

- Direct impacts on soil organisms and health
- Solubilisation and seepage to surface or ground waters
- Runoff sediment into waterways
- Windblown dust

It is important to understand these different pathways, but in an environment where it is difficult to control the end use of compost products, it is prudent to base risk assessment and control measures on the highest risk pathways, which is human exposure directly to products or in food.

Chapter 5 – key findings and recommendations

- The use of source separated FOGO and green waste materials tends to lead to better results for heavy metals and organic contaminant concentrations than when mixed municipal waste or sewage sludge is used as input material.
- Microplastics (< 5mm) are likely to be an emerging problem for reuse of recycled organics, particularly for the future use of FOGO compost in agriculture and horticulture, based on research from Europe which highlights the scale of the issue. Area-based assessment of impurities should be considered to better account for highly visible light weight impurities.
- The presence and variation of metals and trace elements in the environment (i.e. soil, water, plants, animal and humans) is the result of the natural occurrence of elements, mainly depending on geological processes underlying soil formation, as well as human activities. Metals such as copper, zinc are essential to the healthy growth of plants and animals. There has been no evidence of adverse impacts on plants from application of composts and biosolids with typical levels of copper. Ruminant animals are sensitive to copper deficiency. Bioavailability of copper in compost tends to be low and copper toxicity to animals is unlikely from compost. Zinc phytotoxicity has been observed in sensitive crops when biosolids with high zinc concentrations were applied to acidic soils (pH < 5.5.).
- Metals and trace elements in composted organic residues form various compounds or associations when applied to soil which can affect their uptake by plants and their mobility through soils. They can be complexed by organic compounds, co-precipitated in metal oxides, be in a water-soluble state, or bound on soil or organic matter colloids in an exchangeable form. Hence, measuring total trace element content in soil or organic amendments does not predict soil-plant interactions, i.e. bioavailability and plant uptake.
- As soil acidity increases, the solubility of metals and trace elements increases, and so does the potential for uptake by plants. However, this paradigm is not universally applicable as factors such as compost feedstock, soil type and plant species may affect uptake.
- However, organic matter within compost has a high cation exchange capacity compared to mineral soil, and therefore tends to bind or chelate metal ions such as Cu, Ni, Zn and Cd. Organic matter binds metals more strongly at a soil pH below 7.5, which is why metal availability in acidic soil is lower when organic matter content is high compared to the same soil with low organic matter content.
- Metal-organic matter complexes play an important role in the micronutrient cycles in the soil, and are relevant here as (i) soluble organic compounds that otherwise would precipitate, (ii) metal ion concentrations may be reduced to non-toxic levels through complexion, and (iii) trace element availability to plants may be enhanced by various organic-metal-organic complexes. Plant availability and plant uptake of metals (e.g. Cd and Zn) is lower from composted than from uncomposted organic soil amendments.
- There are a wide range of organic chemicals / contaminants that could potentially present in composts from a range of different feedstocks, and new compounds of concern emerging constantly.

Chapter 5 – key findings and recommendations

- Elevated total petroleum and total recoverable hydrocarbons have been detected in finished compost samples analysed by DES, at levels which are higher than in limited analysis results obtained by Arcadis for key feedstocks such as green waste and grease-trap waste. Given many hydrocarbons are biogradable in a composting process, it is not known where the hydrocarbons in the finished product might have come from and there is very little research or data in the literature on this topic. Further investigation and speciation of the hydrocarbons is needed to identify the source.
- The fate of organic contaminants in composting can involve a number of different pathways including mineralisation, partial biological degradation to secondary compounds, assimilation by microorganisms, abiotic transformation to secondary compounds, complexation with humic materials in the compost substrate (i.e. humification), or loss by volatilisation, leaching, runoff, and wind. Complete mineralisation to carbon dioxide is the ideal, since secondary compounds that can accumulate during partial degradation can still be toxic.
- In view of the difficulty of establishing limits for so many potential chemicals of concern, many countries instead focus on tight feedstock control together with source separation. In many cases, only specific feedstocks that are unlikely to contain high concentrations of or unknown contaminants can be composted (positive list). Potentially problematic organic residues are excluded from composting.
- Hazardous compounds that are ubiquitous in many man-made products, and therefore also in the environment, such as PFAS, that are considered a major concern for human health and the environment need to be banned from production / use. Only requesting organics residue producers to comply with stringent product and end-use requirements, without banning the use of these compounds is inequitable and counter productive.
- On average, all materials tend to show comparable concentration levels for PAH, PCB, PCDD/F and PFC, with the sole exception of biosolids compost that tends to have higher PFC levels. Although few international limits exist, the exceedance of guidance values appear to occur most frequently for the PAH compound class. Other organic pollutants tend to show very low concentration levels in all materials and are generally not considered as compounds of concern in most countries (though this might be changing).
- There are a range of emerging contaminants constantly being investigated and discovered. As new chemicals are manufactured and used, or as the understanding of the toxicity or persistence of chemicals currently or formerly in use progresses, new groups of emerging contaminants are likely to be identified over time. Ongoing analysis as new contaminants are documented and publicised is the only way to confirm their presence or absence in feedstocks.

Recommendations – Contaminants

- Area-based assessment of impurities should be considered as a superior method to better account for highly visible light weight impurities such as film plastics, which could break down into microplastics.
- Further investigation is needed to evaluate the risks associated with new ‘emerging’ chemicals of interest, especially PFOS/PFAS. An approach similar to that used by Clarke and Smith (2011) would be highly valuable. Use this to reset the proposed suite of Organic Chemicals to be tested. This list may vary a little depending on the waste being composted.
- Assess whether elevated TPH and TRH levels found in the finished compost samples collected by DES in 2017 are widespread and common, and what the specific hydrocarbons are, or whether this was an aberration.

6 RISK ASSESSMENT OF FEEDSTOCKS

One of the primary objectives of the study was to develop a risk assessment based framework to determine the suitability of feedstocks that are or could be incorporated into composting and soil conditioner manufacturing operations. The risk assessment approach detailed below focuses on the raw feedstocks, as they would likely be received at a composting facility but takes into account current practices and the impacts of the composting process on that feedstock. It assumes existing controls such as End of Waste codes are in place and complied with, which indicates that certain contaminant levels are expected to be within a range, even if the values are not known.

In Phase 1 of the project, a qualitative assessment of the odour contribution potential or odour risk of each feedstock was developed and this is summarised below in section 6.1. It was also necessary to qualitatively assess the contamination risks associated with currently used feedstocks and this process is set out in 6.2 below. The risk assessment process is mostly qualitative at this stage due to a lack of comprehensive compositional data for current composting feedstocks.

The risk assessments of odour and contamination risks, were conducted on the 109 feedstocks identified in Phase 1, as discussed in Section 4, with the aim to classifying each potential feedstock into defined categories that govern their use and potential control measures. Separate categories are proposed in the following sections to describe odour and contamination risk, as the two factors are generally mutually exclusive. Given the lack of compositional data for all feedstocks, and the ambiguity around the source and make-up of numerous feedstocks, this assessment should be considered as preliminary and should be further refined as more information becomes available. The process of assessing each feedstock is clearly explained, so that it can be applied to new or additional feedstocks in the future.

6.1 Odour Contribution Potential

6.1.1 Qualitative Risk Ranking

As noted in Section 2.4 above and discussed in some detail in the Phase 1 report, odour generation in a composting process is a function of many factors but one of the most significant is the feedstocks and their composition and mixing ratios. The Phase 1 report focused on these aspects and understanding the odour risks associated with different composting feedstocks. This led to development of a qualitative rating by Arcadis of the potential odour contribution of each feedstock in a composting process, based on the likely nature, state and chemical components.

Based on the research undertaken in Phase 1, a number of key feedstock ‘odour factors’ were identified relating to the composition of feedstocks. There is limited detailed data available on the composition and physico-chemical characteristics of most of the feedstocks identified in Section 3.1.5 above. Many can be inferred by the feedstock name and generic assumptions made about the characteristics, but given the lack of data, the odour risk assessment is inherently qualitative and somewhat subjective.

The key factors which are considered to contribute to odour risk are detailed below, based on the research conducted in Phase 1 of this project. The potential for an individual material to cause or contribute to an odour issue within a composting process is a function of the composition and nature of that material in its raw form (as received at the composting facility), but also of the various operational aspects and engineering controls in place, which were addressed in some detail in Phase 1.

Aspects such as appropriate blending with other materials to balance moisture, carbon/nitrogen ratio and porosity were found to be key to minimising odour during composting. Therefore, it is challenging to apply generic classifications that cover all situations. Consequently the assessment below focuses on the compositional characteristics of potential feedstocks, while assuming that acceptable composting practices would be in place to manage other aspects.

In assessing the potential odour contribution of feedstocks, the following risk factors were considered:

- Feedstocks which are highly putrescible - e.g. materials which contain a high proportion of readily biodegradable solids and/or a high concentration of dissolved organic compounds (indicated by a high Biological Oxygen Demand are at higher risk of going anaerobic or being anaerobic upon delivery, and releasing odours during the mixing / blending and initial rapid decomposition phase. These materials are often in liquid or slurry form, or have a high moisture content, which enhances this effect. Such materials are therefore considered to pose a higher risk of odour generation.
- Being a liquid feedstock or having high moisture content in itself does not necessarily correlate to high potential odour contribution. It is assumed that liquid or wet feedstocks would be adequately blended with green waste or other dry materials to balance the moisture levels, and avoid issues such as saturation of piles and puddling of liquids, which can contribute to odour release.
- Feedstocks which contain high concentrations of nitrogen compounds (such as food, proteins, animal waste, manure, biosolids, grass clippings) are assumed to present a risk of producing ammonia gas during composting and therefore higher risk.
- Feedstocks which contain high concentrations of sulphur or sulphurous compounds (such as food waste, paper, gypsum, manure and biosolids) are a risk of producing hydrogen sulphide during composting (under anaerobic conditions) and therefore pose a higher risk.
- Feedstocks which contain proteins, fats and oils are a risk of producing volatile nitrogen and sulphur compounds, as well as VOCs, during composting and are considered higher risk.
- Feedstocks which contain the above components in a highly concentrated form, such as a thickened or dewatered sludge, are also at increased risk of odour generation because it may be difficult to even disperse such materials during the blending phase.

6.1.2 Risk Ranking Scores

Considering these risk factors, Arcadis has scored each feedstock according to a high level assessment of four key factors, with further details of the scoring approach provided in the tables following:

- Factor A: Putrescible content – the extent to which the material contains readily biodegradable solids or high concentrations of dissolved organics (e.g. sugars) which are likely to decompose rapidly, enhanced by the moisture content of the material (see Table 38)
- Factor B: Concentration – the extent to which the relevant odour contributing components are concentrated (or diluted) within the raw material, potentially compounding their impact (Table 39)
- Factor C: Nitrogen content of the feedstock (Table 40)
- Factor D: Sulphur content of the feedstock (Table 41)
- Factor E: Content of fats, oils and proteins within the feedstock (Table 42).

The scores adopted for each of these factors and the descriptions for each of the scores are detailed in the tables below.

Table 38: Putrescible content scores (Factor A)

Score	Definition
0	Very low or zero carbon content overall (i.e. inert materials) and no other significant odour contributing compounds.
1	Low content of readily degradable solids with carbon present as slowly degradable or non-biodegradable organic matter, and usually with low moisture content and little or no dissolved organics.
2	Moderate content of degradable solids and moisture, and/or dilute dissolved organics if in liquid form.

Score	Definition
3	High content of dissolved or readily degradable solids, likely to decompose and turn putrid rapidly, and likely to arrive at a composting facility in anaerobic state. Particularly where no pre-treatment or digestion has occurred.

Table 39: Concentration factor (Factor B)

Score	Definition
1	Odour contributing components are already present in low concentrations or in diluted form in the unblended feedstock, such as weak effluent solutions.
2	Odour contributing components are present in moderate concentrations, mostly naturally occurring levels – not particularly diluted, nor concentrated.
3	Odour contributing components are present in very concentrated and readily available form.

Table 40: Nitrogen content scores (Factor C)

Score	Definition
1	Low or virtually zero content of nitrogen in any form.
2	Moderate content of nitrogen.
3	High content of nitrogen in concentrated solid / sludge form (e.g. dewatered sludges, animal manures) or in concentrated chemical form (e.g. chemical fertiliser residues), particularly if nitrogen is present as ammonia / ammonium.

Table 41: Sulphur content scores (Factor D)

Score	Definition
1	Low or virtually zero content of sulphur in any form.
2	Moderate content of sulphur.
3	High content of sulphur in concentrated solid / sludge form (e.g. dewatered sludges) or in concentrated chemical form (e.g. gypsum), particularly if already present in reduced form (sulphides).

Table 42: Fats, oils, protein content scores (Factor E)

Score	Definition
1	Low or virtually zero content of fats, oils or proteins.
2	Moderate content of fats, particularly if derived from vegetable sources or digested fats and proteins (e.g. biosolids, animal manures)

Score	Definition
3	High content of fats and proteins derived from animals and animal products, high content of volatile oils and greases

An overall score was calculated that combines the scoring of the factors as described above. Given that factors C, D and E could all lead to high odour potential, either individually or in combination, these factors are summed together, and then multiplied by factors A and B which have a compounding impact, as follows:

Total odour contribution potential score = A x B x (C + D + E)

A more quantitative based assessment was constrained by lack of detailed compositional data for most feedstocks, and the vague and ambiguous product names given to some feedstocks. There is potential to improve the robustness of the assessment as better data becomes available over time.

Based on the overall score, each material was assigned a rating of its potential odour contribution within a composting process (including receival) as set out in Table 43 below. Due to the scores being skewed at the upper end of the score range by the multiplying effect of factors A and B, the five risk categories are not equally spread across the total score range.

The overall potential odour contribution rating takes into account the potential cumulative impacts of these factors, where a feedstock has multiple risk factors. For example, animal processing wastes can be expected to feature all of the odour factors above - high in proteins and fats, high in nitrogen, high in readily biodegradable solids and high in moisture content. They are likely to arrive on site in an anaerobic state, hence they have been categorised as very high potential odour contribution. On the other end of the scale, for materials which are effectively inert and very unlikely to make any contribution to odour (e.g. ash), the potential odour contribution is rated as ‘none’.

The approach to rating potential odour contribution is summarised in the table below.

Table 43: Potential odour contribution risk rating approach

Risk Ranking Scores	Odour Risk Category	Description
0	None	Feedstocks which are essentially inert (no or negligible biodegradable content) and no significant chemical compounds that could contribute to odour. Feedstocks considered to have no odour risk include: • Ash in various forms • Chemical and industrial effluents with negligible odour indicators such as brine water, water based paints and inks • Soils and sands, including foundry and blasting sands • Residues such as cement slurry, bauxite sludge • Natural minerals such as lime and bentonite Of the feedstocks assessed, 28 were scored as No potential odour contribution.
1 to 7	Low	Feedstocks may contain slowly biodegrading organic matter with low nitrogen (high C:N ratio) and/or trace concentrations of chemicals which may contribute to odour. Considered to be generally uncontaminated, other than physical impurities or trace chemical contaminants.

Risk Ranking Scores	Odour Risk Category	Description
		Low risk feedstocks can be used in composting with minimal controls. Solid biomass residues can be used as bulking agents and have a beneficial impact on odour management when blended with other odorous streams. Low potential odour contribution feedstocks include: • Agricultural or forestry biomass materials such as cane residue, straw, saw dust, mulch, bark, or wood chips • Carbon containing but dilute effluents and waste waters • Storm and washdown waters with trace hydrocarbon levels. Of the feedstocks assessed, 37 were scored as ‘Low’ potential odour contribution.
8 to 14	Medium	Feedstocks with moderate biodegradable content but mostly vegetation based, and/or moderate levels of sulphur or nitrogen. Medium risk feedstocks are generally suitable for use in composting from an odour perspective, provided they are appropriately blended to balance moisture and C:N ratio. Medium potential odour contribution feedstocks include: • Green waste and green waste mulch • Vegetable, vegetable oil, beer and brewery waste • Dilute fertiliser effluents and sludges • Plasterboard and gypsum Of the feedstocks assessed, 17 were scored as ‘Medium’ potential odour contribution.
15 to 30	High	Feedstocks with high biodegradable content and moderate or high levels of nitrogen and moderate or high moisture content, have been rated as high risk. High risk feedstocks may be acceptable for use in composting from an odour perspective provided strict management controls are in place, including characterisation assessment to confirm their suitability; appropriate blending with bulking agents to balance moisture and C:N; and potentially enclosed storage and mixing facilities. High risk feedstocks include: • Animal manures and paunch • Food organics and food processing effluents and sludges • Processed biosolids • Acid sulphate sludge Of the feedstocks assessed, 14 were scored as ‘High’ risk.
31+	Very High	Feedstocks which exhibit all of the key odour factors to a relatively high degree, have been rated as very high odour potential. They typically contain very high biodegradable content; high levels of nitrogen and/or sulphur; high levels of fats, oils and proteins or may contain unstabilised human waste; likely to arrive in a putrid state and with high moisture content. Very high risk feedstocks may be acceptable for use in composting from an odour perspective provided strict management controls are in place, including characterisation assessment to confirm their suitability; and appropriate blending with bulking agents to balance moisture and C:N. It is likely that storage and mixing facilities will need to be enclosed to manage the risk of

Risk Ranking Scores	Odour Risk Category	Description
	🟥	odour release from anaerobic materials upon receipt, and operators should assess the need for the initial composting phase to be enclosed. Very high risk feedstocks include: • Abattoir and animal processing wastes, tallow and hide curing wastes • Grease trap waste and treated grease trap sludges • Unstabilised sewage wastes including sewage sludge, septic sludges and nightsoil • Organics extracted from mixed household waste (based on industry experience) • Landfill leachate Of the feedstocks assessed, 13 were scored as ‘Very High’ risk.

6.1.3 Feedstock Risk Ranking

The potential odour contribution risk ranking for feedstocks currently or potentially in use in composting in Queensland is presented in Appendix A and summarised in Table 44 below. The feedstocks are sorted in ascending order of risk score.

The risk ranking exercise indicates that the majority or 65 out of the 109 feedstocks assessed were rated as posing no or low risk in terms of odour contribution. A further 17 materials were rated as presenting a medium odour contribution risk, including green waste. Materials rated as medium should generally be manageable in terms of odour risk, provided standard operational controls are in place such as appropriate blending.

A total of 27 of the feedstocks assessed were considered to present a high or very high potential odour contribution. These materials include animal and food processing residues as well as sewage processing residues, that are likely to contain concentrated levels of odour contributing components. From an odour management perspective, these materials can still be used in composting but are likely to require a higher degree of operational, and potentially engineering, controls to manage the odour risk. The list includes a number of feedstocks which are commonly used in some Queensland composting operations such as grease trap waste, animal manures and abattoir residues.

It is noted that within each feedstock type, the characteristics and nature of the material may vary between sources or generators. Conservative assumptions have generally been applied in terms of estimating the content of odour contributing components but there will be cases where an alternative rating can be justified in a specific local circumstance (e.g. if green waste in a particular location is predominantly dry, woody material, this may justify a ‘low’ rating). It is expected that with some refinement of feedstock descriptions, and collection of analytical data to clarify feedstock composition, it may be possible to refine the risk ranking of many feedstocks.

Table 44: Summary of potential odour contribution risk, in ascending score order

None	Low risk	Medium risk	High risk	Very high risk
Abrasive blasting sand (excluding heavy metal contaminated sands)	Cane residues	Green waste	Dewatered fertiliser sludge	Organics extracted from mixed household waste / MSW
Ash	Grain Waste	Tub ground mulch	Acid Sulphate Sludge	Leachate Waste
Boiler blow down water	Cypress chip	Beer	Ammonium Nitrate	Abattoir waste
Brine Water	Forest mulch	Brewery effluent	Wood molasses	Animal processing waste
Calcium Water	Pine bark	Mushroom compost (substrate)	Yeast Waste	Hide curing effluent
Cement Slurry	Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Vegetable waste	Animal manures, including livestock manure	Tallow Waste
Coal ash	Wood chip	GPT Waste	Food Organics	Nightsoil
Dye Waste (water based)	Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs	Mill mud	Food processing effluent and solids	Septic wastes
Fly ash	Car Wash Mud & Sludge	Waste Water	Quarantine waste treated by an AQIS approved facility	Sewage sludge
Ground Water	Carbon Pellets	Molasses Waste	Treatment tank sludges and residues	Sewage treatment tank or treatment pit liquids, solids or sludges
Lime Slurry	Compostable PLA plastics	Effluent Waste	Paunch material	Grease trap - treated grease trap waters and dewatered grease trap sludge
Mud and Dirt Waste	Coolant Waste	Vegetable oil wastes and starches	Activated sludge and lime sludge from wastewater treatment plants	Grease trap waste
Muddy Water	Forecourt Water	Filter cake and presses	Biosolids	Animal Waste, including egg waste and milk waste
Natural textiles	Latex Washing	Paper pulp effluent	Food processing treatment tank or treatment pit liquids, solids or sludges	
Pot ash	Low level organically contaminated stormwaters or groundwaters	Paper sludge dewatered		
Soil treated by indirect thermal desorption	Oily Water	Plaster board		
Water based inks	Paint Wash	Gypsum		
Water based paints	Paper mulch			
Waterbased glue	Polymer Water			
Waterbased Lacquer Waste	Process Fluid			
Amorphous silica sludge	Soapy water			
Bauxite sludge	Stormwater Waste			
Bentonite	Vehicle wash down waters			
Crusher dust	Wash Bay Water			
Lime	Water blasting wash waters			
Sand	Carpet cleaning wash waters			
Soil				
Foundry sands				

None	Low risk	Medium risk	High risk	Very high risk
	Treated timber waste Worm castings suitable for unrestricted use Bilge waters Drilling Mud / Slurry (Coal Seam Gas) Fertiliser water and fertiliser washings Filter/ion exchange resin backwash waters Total Petroleum Hydrocarbon Water Soft Drink Waste Sugar and sugar solutions Starch Water Waste Sullage waste (greywater)			

6.1.4 Feedstock Classification - Odour

Based on the potential odour contribution assessment, Arcadis has classified each feedstock into one of two categories as defined below.

Table 45: Odour category definitions

Odour Category	Description
1	**High odour risk - potentially suitable for use in composting subject to additional management measures and controls**, which is materials rated as having a High or Very High odour contribution potential. These materials should typically constitute a minor proportion of the compost mix and controls are likely to include enclosure of reception, storage and blending processes. Operators may also need to consider enclosing the first phase of the composting process and/or employing forced aeration methods, depending on the particular feedstocks. Blending ratios should be carefully managed to balance moisture and nutrients. The onus will be on the operator to demonstrate that controls are adequate to manage any odour risk in the context of the site and surrounds, particularly if seeking to justify not employing additional engineering controls.
2	**Suitable for use in composting** and likely to pose a minimal risk of contributing to odour during the composting process. This category includes feedstocks rated with a Medium odour contribution potential or less, whereby the odour risk should be manageable through standard best practice composting processes (e.g. appropriate blending, maintaining aerobic conditions).

The classification of feedstocks is linked to the risk assessment outcomes as follows:

- Feedstocks which are rated as having an odour contribution potential of ‘high’ or ‘very high’ are classified as odour category 1 – high odour risk, but potentially suitable for composting with additional controls.
- Feedstocks which are rated as having an odour contribution potential of ‘medium’ or less are classified as odour category 2 – suitable for composting, subject to standard composting practice.

The outcomes of this assessment are summarised in Table 53 overleaf, along with the risk assessment findings and assumptions about the nature of each feedstock. A total of 27 feedstocks were considered to present a high or very high potential odour contribution risk and were therefore categorised as odour category 1 – suitable for composting but with additional controls.

It is noted that this assessment focuses on odour – contamination risk is assessed separately in section 6.2, which may lead to additional controls or classification of some materials as unsuitable.

Table 46: Summary of qualitative potential odour contribution risk assessment results

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
Animal Matter	Abattoir waste	Animal / meat waste only, with some minor potential for cleaning residues etc.	- decomposing meat and fat content, high protein - wet and potentially anaerobic on arrival	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Animal manures, including livestock manure	Animal waste only, no other products such as cleaning residues, 'sheep dip', etc.	- wet and high nitrogen content - potentially anaerobic on arrival	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Animal processing Waste	Animal / meat waste only, no other products such as cleaning residues etc.	- wet and high nitrogen content - decomposing meat / fat content, high protein - potentially anaerobic on arrival	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Animal Waste, including egg waste and milk waste	Animal waste only, no other products such as cleaning residues, etc.	- high fat and protein content -wet and likely anaerobic on arrival	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Hide curing effluent	Effluent and wastes from tanneries. Potentially from the various steps involved in preparing animal hide e.g. Washing for removal of hair, fat removal, chemical treatment. Curing hides requires large amounts of salt, which results in brine waste water.	- decomposing meat and fat content, high protein - potentially anaerobic on arrival	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Paunch material	Partially digested gut contents of slaughtered animals from abattoir, consists mainly of undigested grass, hay, other feed products such as grain, and water as well as body fluids, including saliva	- partially digested / fermented grass - likely anaerobic on arrival	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Tallow Waste	Rendered meat fat residues or wastes	- high fat and protein content - likely anaerobic on arrival	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
Chemical residues	Ammonium Nitrate	Assumed pure or dissolved ammonium nitrate, as in off-spec or damaged fertiliser products. A salt of ammonia and nitric acid, that is widely used in fertilisers. It is the most common nitrogenous component in artificial fertilisers. Solid ammonium nitrate can undergo explosive decomposition when heated in a confined space. It is highly soluble in water.	- soluble ammonium form - potential release of ammonia vapour - very concentrated form of nitrogen	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Dewatered fertiliser sludge	By-product from fertiliser production, assumed no other waste materials cross-contaminate the stream. The most commonly manufactured fertiliser is ammonia nitrate as it is very water-soluble.	- unknown composition, may contain volatile ammonia	High	1 – High odour risk, suitable in composting with additional controls	Composition analysis, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Fertiliser water and fertiliser washings	By-product from fertiliser production, assumed no other waste materials cross-contaminate the stream. Subject to an EoW code for fertiliser wash water - derived from cleaning or washing or fertiliser plant or hygroscopic sorbing of moisture into fertiliser products.	- may contain volatile ammonia, assume dilute	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Filter/ion exchange resin backwash waters	Unknown composition or origin - some form of effluent treatment process	- unknown composition / source - assume organic content	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Pot ash	Potassium compounds, most commonly used as a fertilizer but also used in industry. Unknown whether pot ash feedstock is from the manufacture of pot ash or includes by-products from industrial uses.	- Minimal	None	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
Food & Food processing waste	Food Organics	Food wastes, assumed no other products such as cleaning residues etc.	- may contain meat / fat - high moisture / nitrogen - likely anaerobic on arrival	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Organics extracted from mixed household waste / MSW	Currently applies to Suez Cairns only, organic fraction mechanically separated from mixed waste. Assumed similar to NSW 'MWOO' grade waste	- may contain meat / fat - high moisture / nitrogen	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
		stream, which studies showed can contain contaminants	- likely anaerobic on arrival			
	Quarantine waste treated by an AQIS approved facility	Assumed to be food and organic material treated by irradiation or similar. May include chemical additives, treatment chemicals, or unknown materials. Excluded from list of acceptable organic materials by DES	- potentially contains meat / food	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Beer	Assume waste beer, non-compliant product	- wet, potentially anaerobic?	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Brewery effluent	Food waste residues from beer brewing, assumed no contamination by cleaning products, etc.	- wet, potentially anaerobic?	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Food processing effluent and solids	Food wastes, potential for minor residues from cleaning products or other industrial processing inputs.	- wet / high nitrogen - likely anaerobic on arrival	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Food processing treatment tank or treatment pit liquids, solids or sludges	Food wastes, potential for minor residues from cleaning products or other industrial processing inputs.	- wet / high nitrogen - likely anaerobic on arrival	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Grain Waste	Assume mostly hulls / waste grains	- assume dry, high carbon - potentially fermented?	Low	2 – Suitable in composting with standard controls	Standard composting best practice

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Grease trap - treated grease trap waters and dewatered grease trap sludge	Greases and food by-products separated waste pumped out of grease traps (restaurants, commercial kitchens, etc). May contain residues of cleaning products	- wet, food and grease content - likely anaerobic on arrival	Very High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Grease trap waste	Greases and food by-products pumped out of grease traps (restaurants, commercial kitchens, etc). Mostly water, may contain residues of cleaning products	- wet, food and grease content - likely anaerobic on arrival	Very High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Molasses Waste	Waste products from sugar processing and molasses manufacture	- highly biodegradable - potentially anaerobic on arrival?	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Soft Drink Waste	Food manufacturing wastes, potential for minor residues from cleaning products or other industrial processing inputs	- assume high sugar content	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Starch Water Waste	Assumed food or industrial waste product with high starch content and minor residues from processing	- high starch / sugar content	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Sugar and sugar solutions	Waste products from sugar processing with high sugar content and minor residues from processing	- assume high sugar content	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Vegetable oil wastes and starches	Greases and food by-products from food industry	- high carbon - wet, could be anaerobic on arrival	Medium	2 – Suitable in composting with standard controls	Standard composting best practice

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Vegetable waste	Food wastes, assumed no other products such as cleaning residues etc.	- high nitrogen / moisture	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Yeast Waste	Assumed to be beer or food manufacturing waste product	- fermented, yeast odour - potentially anaerobic	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
Industrial residues	Abrasive blasting sand (excluding heavy metal contaminated sands)	Industry waste from sand blasting, may contain traces of paint etc from sand blasting process	- none, assumed inert	None	2 – Suitable in composting with standard controls	None
	Amorphous silica sludge	Concrete additive made from silica	- none, assumed inert	None	2 – Suitable in composting with standard controls	None
	Ash	Industrial by-product (e.g. coal power generation), may be wood, coal, or other sources of ash. See EoW code for Coal Combustion Products.	- none, assumed inert	None	2 – Suitable in composting with standard controls	None
	Bauxite sludge	Alumina refinery by-product. May be highly alkaline containing iron oxide and other metals	- none, assumed inert	None	2 – Suitable in composting with standard controls	None
	Carbon Pellets	Unknown source - may be spent or unused pellets from a range of sources or industries. Likely to have been used in water or air filtration so	- assume dry and stable, so low but depends on usage	Low	2 – Suitable in composting with standard controls	Standard composting best practice

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
		composition will depend on previous use				
	Cement Slurry	Mix of cement, sand, water and additives	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Coal ash	Industrial by-product (e.g. coal power generation). See EoW code for Coal Combustion Products	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Compostable PLA plastics	Plastics made from plant products such as corn starch. Biodegradable under optimal conditions.	- none, assumed inert	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Coolant Waste	Waste water with coolant (e.g. glycol), by-product from industry or small scale mechanics.	- volatile alcohols	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Dye Waste (water based)	By-product from industrial dying processes.	- assume none	None	2 – Suitable in composting with standard controls	None
	Filter cake and presses	Concentrated waste streams from water treatment in a filter press. Source industry unknown.	- unknown composition / source - assume organic content	Medium	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Fly ash	Industrial by-product (e.g. coal power generation), may be wood, coal, or other sources of ash. See EoW code for Coal Combustion Products.	- none, assume inert	None	2 – Suitable in composting with standard controls	None

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Foundry sands	Sand used in foundry mouldings, stabilised with phenol compounds. See EoW code for Foundry sand.	- should be inert	None	2 – Suitable in composting with standard controls	None
	Paint Wash	Assumed wash down water with some paint residues, potentially with solvents, surfactants, oils, etc.	- minimal assuming water based	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Paper mulch	Assumed solid paper wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	- high carbon content, assume relatively dry	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Paper pulp effluent	Assumed mix of solid and liquid paper fibre wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	- depends on process - may contains sulphate, chlorine?	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Paper sludge dewatered	Assumed solid paper wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	- depends on process - assume mostly fibres - may contains sulphate, chlorine?	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Plaster board	Assumed to be comprised of gypsum with potential for multiple additives - plasticisers, fire retardants, water repellents, 'foaming agents', etc.	- sulphate content	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Polymer Water	Unknown composition or source. Potentially associated with coagulants added to process water.	- unknown content / source	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Process Fluid	Unknown source or composition.	- unknown content / source	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Total Petroleum Hydrocarbon Water	Assumed run-off from hard surfaces, or industrial waste water, with potential for other contaminants to be present	- VOCs / light hydrocarbons	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Treated timber waste	Timber treated with a range of chemicals and heavy metals to inhibit decomposition, including CCA, ACQ, CuAz and methyl bromide	- high carbon	Low	2 – Suitable in composting with standard controls	Composition analysis
	Water based inks	Assumed liquid wastes from ink use or manufacture	- assume none	None	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Water based paints	Assumed liquid waste paint, potentially undiluted. Pigments may include various metals and minerals (eg White: Titanium dioxide (TiO2); Black: carbon; Blue copper calcium silicate; Red: cadmium sulphide). Binder may be Latex, vinyl (Polyvinyl Chloride), acrylic, Poly Vinyl Alcohol (made from the hydrolysis of polyvinyl acetate and is the most common binder in water-based paint - PVA can generally be regarded as a biologically degradable synthetic polymer, but aerobic / moisture conditions need to be	- assume none	None	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
		optimal). Latex should be natural form. Acrylic and PVC not biodegradable.				
	Water blasting washwaters	Assumed dilute concentration contaminants may be present from cleaning ('water blasting') process	- unknown content / source	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Waterbased glue	Potentially undiluted glue comprised of polymers and solvents	- assume none	None	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Waterbased Lacquer Waste	Waste liquid lacquers from manufacture or use, potentially undiluted	- assume none	None	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Wood molasses	Results from a process that transforms the wood cellulose into sugars (glucose). Usually involves the pyrolysis of wood using high temperatures and pressures with acids and then cooled and neutralised with lime. It is being used as an additive in animal food and in agriculture as a soil improver.	- potential VOCs / ammonia, acidic	High	1 – High odour risk, suitable in composting with additional controls	Composition analysis, appropriate blending rates
Plant matter	Cane residues	Assumed sugar cane wastes from the harvesting of sugar cane (e.g. tips and leaves)	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Cypress chip	Assumed untreated wood chips	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Forest mulch	Assumed untreated wood / bark product	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	GPT Waste	Gross pollutant trap wastes, including general waste, leaf litter, stormwater sediments, etc. Assumed that wastes such as plastics are mechanically removed prior to composting.	- mostly vegetation and sludge, wet	Medium	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Green waste	Assumed untreated green wastes from domestic and commercial sources. Composition will vary - seasonal.	- moisture content will vary - potentially moderate nitrogen (grass) - depends on age / storage	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Mill mud	See EoW code for sugar mill by-products. By-product from sugarcane processing, contains filter mud from clarification of cane juice plus ash, potentially some lime	- organic / sugar content - moderate nutrient content	Medium	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Mushroom compost (substrate)	Mushroom growth medium and residues, generally comprised of straw, manure, lime/chalk, etc	- assume composted but not mature - composting odours	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Natural textiles	Assumed by-product of fabric manufacturing, including wool, cotton, bamboo, etc.	- assume dry and stable	None	2 – Suitable in composting with standard controls	None

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Pine bark	Assumed untreated wood product	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Assumed majority is untreated wood product, although some treatment residues (e.g. ACC) may be present	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Tub ground mulch	Fine to medium mulch products, assumed majority is untreated wood product, although some treatment residues (e.g. ACC) may be present	- high carbon	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Wood chip	Assumed untreated wood product	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs	Assumed to largely be untreated wood product, however inclusion of manufactured wood products (e.g. pallets) may introduce contaminants into feedstock stream	- high carbon	Low	2 – Suitable in composting with standard controls	Standard composting best practice
	Worm castings suitable for unrestricted use	Assumed to be comprised of largely organic worm castings, minor potential for some contaminants	- assume mostly stabilised / matured	Low	2 – Suitable in composting with standard controls	Standard composting best practice
Sewage & STP residues	Activated sludge and lime sludge from wastewater treatment plants	Assume from sewage treatment but may also be from industrial wastewater treatment plants. May contain a range of	- biomass from sewage treatment - wet and likely anaerobic on arrival	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
		contaminants, including pharmaceuticals and emerging contaminants.				
	Biosolids	Solid residues from sewage treatment. Varying pre-processing and stabilisation conditions. May contain a range of contaminants, including pharmaceuticals and emerging contaminants.	- high moisture and nitrogen content - potentially anaerobic depending on storage	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Nightsoil	Sludge and solid residues from remote septic tanks (sewage waste).	- from sewage / septic tanks - high organic / nitrogen content - likely anaerobic	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Septic wastes	Sludge and solid residues from remote septic tanks (sewage waste).	- from sewage / septic tanks - high organic / nitrogen content - likely anaerobic	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Sewage sludge	Sludge and solid residues from sewage treatment.	- from sewage treatment - high organic / nitrogen content - likely anaerobic	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Sewage treatment tank or treatment pit liquids, solids or sludges	Sludge and solid residues from sewage treatment.	- from sewage treatment - high organic / nitrogen content - likely anaerobic	Very high	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
Earthworks waste and additives	Acid Sulphate Sludge	Naturally occurring but contains high levels of iron-sulphide. Can be acidic / acid forming when oxidised and cause the	- sulphide content	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
		dissolution / release of mineral metals (iron, aluminium, other heavy metals, arsenic)				
	Bentonite	Mined clay waste, no other products from use of bentonite (e.g. drilling fluids). Assume from drilling muds but can also be found in paints, in the manufacturing of paper and is used as a water softener.	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Crusher dust	By-product of quarrying or mining, assumed natural unprocessed rock with no additives	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Drilling Mud / Slurry (Coal Seam Gas)	See EoW approval for CSG Drill Muds. Mix of natural rock / soils with additives (salts, bentonite, etc).	- assume inert - some may contain sulphate compounds although the draft EoW requires drill muds to be free from detectable offensive odours	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Gypsum	Assumed quarry or mining waste, with no additives or industrial by-products	- sulphate content	Medium	2 – Suitable in composting with standard controls	Standard composting best practice
	Lime	Assumed quarry or mining waste of calcium carbonate, with no additives or industrial by-products	- none, assume inert	None	2 – Suitable in composting with standard controls	None

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Lime Slurry	Assumed construction or industrial by-product, with a mix of lime, sand and water	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Mud and Dirt Waste	Unknown sources, potentially contaminated	- assume inert, none	None	2 – Suitable in composting with standard controls	None
	Sand	Assumed untreated or from greenfield source	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Soil	Unknown sources, potentially contaminated?	- assume inert	None	2 – Suitable in composting with standard controls	None
	Soil treated by indirect thermal desorption	Assumed that soils were contaminated prior to thermal desorption treatment	- assume inert	None	2 – Suitable in composting with standard controls	None
Wastewater & wash-waters	Bilge waters	Sea and fresh water from ship pump outs, may contain oil, sludge and other chemicals.	- potential hydrocarbon / oil vapours	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Boiler blow down water	Waste water from boilers to remove suspended solids, scale, contaminants, etc.	- none, assume inert	None	2 – Suitable in composting with standard controls	None
	Brine Water	Unknown sources, assumed hyper-saline water from industrial or food processes	- assume no organic content, so minimal	None	2 – Suitable in composting with standard controls	None
	Calcium Water	Unknown sources, assumed calcium containing water ('hard' water) is from industrial or food processes	- assume no organic content, so minimal	None	2 – Suitable in composting with standard controls	None

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Car Wash Mud & Sludge	Waste slurry captured in drains at car washes	- assume low	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Carpet cleaning washwaters	Likely contains highly alkaline chemicals and chemical enzymes, high levels of VOCs, disinfectants, high concentrations of sodium bicarbonate, sodium citrate, sodium silicate or sodium phosphate, dyes, polymers, bleachers, esters, forms of butyl, dirt, soap, oil, grease, a variety of solvents, esters and other toxic chemicals	- VOCs, high pH	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Effluent Waste	Assumed to comprise either industrial or domestic effluent streams	- unknown composition / source, assume dilute	Medium	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Forecourt Water	Run off from service station forecourts	- VOCs / light hydrocarbons - likely very dilute	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Ground Water	Unknown source or composition	- unknown content, but should be inert	None	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Latex Washing	Effluent from rubber and latex processing	- assume dilute, natural rubber	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Leachate Waste	Landfill leachate, potentially contains complex mix of contaminants	- likely high ammonia, sulphides, methane - will be anaerobic	Very high	1 – High odour risk, suitable in composting with additional controls	Composition analysis, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Low level organically contaminated stormwaters or groundwaters	Unknown source or composition	- unknown content, but should be inert	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Muddy Water	Unknown sources, potentially contaminated	- assume inert, none	None	2 – Suitable in composting with standard controls	None
	Oily Water	Assumed run-off from forecourts or hard surfaces, with water collected from bunded areas with high potential for oils	- VOCs / hydrocarbons	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Soapy water	Unknown source or composition - containing detergents but potentially other contaminants depending on the use	- assume low organics	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Stormwater Waste	Assumed run-off captured in bunded areas which is unable to be directly discharged, with high potential for oils or other wastes	- unknown content / source, assume dilute	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Sullage waste (greywater)	Greywater / wastewater from domestic or commercial buildings excluding sewage, includes waters drained in showers, sinks, laundries, etc. Likely to contain soap, soil, chemicals, detergents, bleaches, lint, food particles	- may contain food / organics - potentially anaerobic on arrival	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates

Type	Feedstock material	Assumed source / nature	Odour Factors	Odour Contribution Potential	Feedstock Classification	Controls
	Treatment tank sludges and residues	Unknown, potentially highly variable industrial wastes	- unknown content / source - could be high organics / anaerobic	High	1 – High odour risk, suitable in composting with additional controls	Containment of reception / storage / blending, appropriate blending rates
	Vehicle wash down waters	Waters collected at car wash facilities	- unknown content / source, assume dilute	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Wash Bay Water	Waters collected at wash down areas	- unknown content / source, assume dilute	Low	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates
	Waste Water	Unknown source or composition	- unknown content / source - could contain organic waste / anaerobic	Medium	2 – Suitable in composting with standard controls	Composition analysis, appropriate blending rates

6.2 Potential Contamination Risk Ranking

The first step is assessing contamination risk is to qualitatively assess the potential contamination risk in order to prioritise those materials which are likely to pose the greatest risk and/or require further investigation. The purpose of the initial qualitative assessment is to:

- identity the types and characteristics of feedstocks currently in use;
- identity key issues and data gaps in the current management of contamination in feedstocks (particularly around characterisation and composition of the feedstocks); and
- aid in the prioritisation of works to mitigate risks associated with current and future feedstocks.

This section details the process undertaken to qualitatively assess contamination risks associated with currently used feedstocks. Following on from this risk ranking, management options have been identified to mitigate risk, with a more specific framework proposed for assessing potential contamination risks in feedstocks provided in Section 6.3 below.

The risk ranking of currently used feedstocks was undertaken based on the limited information gathered on feedstock composition and characteristics, and the data provided on different contaminants presented in Section 5 of this report, with incorporation of a number of assumptions as detailed below. The risk assessment was conducted on the 109 feedstocks identified in Phase 1, as discussed in Section 4, with the aim to categorise feedstocks according to the following categories numbered 1 to 4.

Table 47: Contamination risk category definitions

Contamination Category	Description
1	**Generally unsuitable for use in composting** as likely to pose an unacceptable risk to human health or the environment in composted products and providing no clear benefit to the final product
2	**Potentially suitable for use in composting, subject to specified management measures and controls** (e.g. blending ratios, removal of physical contaminants, pasteurisation levels or process residence times)
3	**Suitable for use in composting** and likely to pose a negligible risk to human health or the environment with unrestricted use of compost products, provided the material is as described and there are no unforeseen contaminants.
4	**Potentially suitable for use in composting, but due to significant data gaps** or other factors it cannot be determined at this time whether they may pose an unacceptable risk to human health or the environment in composted products. Further data and investigation is needed to confirm suitability with the objective of reclassifying.

The risk assessment process was based upon a qualitative risk ranking method as detailed below. This process enables sorting of the long list of feedstocks to identify highest to lowest risk feedstocks, which in turn enables prioritisation of efforts to assess or manage the various feedstock streams.

A key factor that impacted upon the risk assessment scores was the lack of information regarding feedstock sources or composition; conservative assumptions have been made where necessary based on available information.

Given the lack of data or detailed description on the composition or source of the feedstocks, assumptions were necessary to enable an assessment of potential contamination issues. These assumptions were based on professional judgement and an understanding of likely contaminants in different waste streams or from natural sources as discussed above. The key assumptions made regarding potential composition and associated likely contaminants for each feedstock are detailed in the risk ranking table attached in Appendix A.

Ultimately, the aim should be to reduce the number of materials classified under Category 4 by undertaking further analysis and investigation to allow reclassification into another category (1 to 3). For commonly processed materials in category 4 it may be appropriate for DES to undertake those investigations, but generally the onus should be on operators to demonstrate that their feedstocks are suitable.

6.2.1 Health and Environmental Investigation Levels for Soil

As noted above, AS4454 is the primary reference for composters in Australia but in terms of contamination, it only covers a relatively narrow group of contaminants including some metals, selected organic chemicals, nutrients, pathogens and physical impurities. AS4454 was never developed to deal with the broad range of potential contaminants that may be introduced from the various industrial and regulated waste streams that are used in some Queensland composting facilities.

As such, there is a need to reference broader contaminant guidelines. The Health Investigation Levels (HILs) for soil form part of the *National Environment Protection (Assessment of Site Contamination) Measure* 1999 (the NEPM). The HILs were designed to provide guidance on scientific, risk-based levels for the assessment of potential risks to human health from chronic exposure to contaminants from existing site contamination. The NEPM defines risk assessment as '*the process of estimating the potential impact of a chemical, physical, microbiological or psychosocial hazard on a specified human population or ecological system under a specific set of conditions and for a certain timeframe'.*

Thresholds for health-based Soil Investigation Levels are presented and compared to unrestricted use limits for compost in Appendix B. If a contaminated site shows concentration of a contaminant that is above the threshold, further appropriate investigation and evaluation should be undertaken. Therefore, the HILs are not a definitive limit as such, but designed to be used to highlight the contaminants that may require a more detailed risk assessment. The NEMP states expressly that it *does not provide guidance on prevention of site contamination* and makes clear that *regulations apply appropriate controls to contaminant sources to minimise any ongoing contamination of sites and their application is the principal strategy for prevention of soil and groundwater contamination*.

Consequently, the HILs (and Environmental Investigation Levels, EILs) are not intended to define 'acceptable' or 'unacceptable' contaminant levels neither in soil nor in compost products, but are intended to assist with determining where additional data collection and risk assessment should be conducted, taking into consideration site-specific exposure pathways, consequences of exposure and characteristics of the exposed population.

6.2.1.1 Principles and methodology for generating the HILs

The HILs risk assessment methodology follows the five-step risk assessment process and practice as outlined in Schedule B4 (Site-Specific Health Risk Assessment Methodology) of the *National Environment Protection (assessment of Site Contamination) Measure 1999* (Australian Government 1999a) and used in the guidelines for assessing human health risks from environmental hazards developed by the Australian Health Protection Principal Committee (2012).

The five-step risk assessment process entails the following activities:

1. *Issues identification*; establishes scope and purpose
2. *Hazard assessment (or toxicity assessment);* identifies the effect of contaminants of concern on sensitive populations and provides the most appropriate reference value for the quantitative assessment of dose-response
3. *Exposure assessment*; entails the relevance and estimation of the magnitude, frequency, extent and duration of exposures to contaminants under each land use scenario

4. *Risk characterisation*; combines outcomes of all stages of risk assessment into quantitative and qualitative risks and uses these to derive risk-based HIL values
5. *Risk communication and management*

In addition, the following aspects are also considered as part of the risk assessment process:

- *Data collection and evaluation;* involves the analysis of information about contaminants of concern and exposure pathways
- *Uncertainty and sensitivity analysis;* identifies key assumptions and data gaps associated with the derivation of HILs and identifies the exposure parameters that have the greatest impacts for the resultant HILs.

The HILS were developed to protect the health of people who could be exposed to soil contaminants under the following four broad land use categories (not including sensitive sub-populations) based on sensitive populations and intensity, frequency and means of exposure to soil contaminants for different land uses.

HIL A – residential with garden/accessible soil (home-grown produce <10% fruit and vegetable intake and no poultry; includes childcare centres, preschools, primary schools)

HIL B – residential with minimal opportunities for soil access (dwellings with fully and permanently paved yard space such as units, high-rise buildings and apartments)

HIL C – public open space/ recreational areas (parks and playgrounds, playing fields (e.g. ovals), secondary schools and footpaths)

HIL D - commercial / industrial premises (shops, offices, factories and industrial sites)

The HIL threshold for scenarios A, C and D are most relevant for the compost industry as a large proportion of urban derived recycled organic products are supplied as blended soils and for other landscaping applications, which could potentially end up in residential gardens or similar accessible soil situations (HIL A); in public parks and sporting fields (HIL C) or in commercial / industrial settings which would likely also include less accessible uses such as road verges and mine rehabilitation. Some scenarios may not be adequately addressed in the generic land-use scenarios in HILs, for example agricultural land, which will be a key end-market for compost.

These land use scenarios are broadly consistent with exposure settings A, D, E and F respectively, as described in National Environment Protection (assessment of Site Contamination) Measure (Australian Government 1999b), where:

- **A**: 'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children’s day-care centres, kindergartens, preschools and primary schools.
- **D**: Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high-rise apartments and flats.
- **E**: Parks, recreational open space and playing fields; including secondary schools.
- **F**: Commercial/industrial: includes premises such as shops and offices as well as factories and industrial sites.

6.2.1.2 Exposure pathways

The level of exposure is related to physiological factors and frequency, extent and duration of exposure to contaminated soil. Children are more exposed to contaminants because of their relatively low body weight, yet higher rates of inhalation and ingestion and a relatively large skin surface area that is contact with soil when crawling and playing. The exposure pathways addressed in the derivation of HILs include:

- Incidental ingestion of surface soil, dust/particulates and soil adhering to home-grown produce
- Indoor and outdoor inhalation of dust particulates

- Consumption of home-grown produce (including vegetables and fruit, but excluding poultry meat and eggs)
- Dermal contact with surface soil and dust/particulates
- Indoor and outdoor inhalation of vapours derived from soil.

The pathways were based on the following exposure parameters;

- Body weight
- Exposure duration
- Exposure frequency
- Soil / dust ingestion rate
- Soil / dust to skin adherence factor
- Skin surface area
- Fraction of skin exposed
- Dermal absorption factor
- Time spent indoors/outdoors on site each day
- Home-grown proportion of vegetables consumed
- Vegetable/fruit consumption rate
- Averaging time for carcinogens
- Dust lung retention factor

6.2.1.3 HILs in the compost industry

The HILs can be used to assist in (i) determining which contaminants should be monitored in ‘at risk’ compost products, and (ii) in assessing the risks of using organic soil amendments with elevated contamination levels in various environments, based on the type and concentration of contaminants they contain. It might be possible to apply the parameters and risk assessment principals used in HILs to end-products leaving composting facilities and assist in determining whether further testing of the product should be conducted.

Many residential, public and commercial areas use organic soil amendments and therefore the industry and regulatory authorities have the responsibility to ensure that there are no negative effects on human health and the environment. However, comparison of thresholds for health-based Soil Investigation Levels and limits for unrestricted use of compost as established in AS 4454 – 2012 shows that, where contaminants are referenced in both documents, HILs thresholds are generally significantly higher than AS 4454 – 2012 limits (see Appendix B).

6.2.2 Risk Ranking Scores

To calculate a risk ranking score, values were adopted to weight each feedstock for each of the following categories:

- Factor A: Uncertainty regarding composition, with a factor of 2 adopted where there is greater uncertainty and potential for contaminants to be present
- Factor B: Hazard of raw feedstock, with higher scores adopted for more hazardous materials*
- Factor C: Persistence of potential contaminants through the composting process, with a factor of 2 applied where the key contaminants of concern are unlikely to diminish significantly in the composting process

* Note for materials that are subject to an End of Waste code, it is assumed that the material complies with the contaminant thresholds and other conditions within the code.

The scores adopted for each of these factors and the descriptions for each of the scores are detailed in the tables below.

Table 48: Uncertainty Regarding Composition Scores (Factor A)

Score	Definition
1	Composition is known, either through analytical data or high confidence that feedstock is as described and composition is understood (e.g. beer waste or untreated wood chips); or composition is unknown but it with low likelihood that feedstock is contaminated with compounds that may pose an unacceptable risk.
2	Composition unknown, with high likelihood that feedstock is contaminated with compounds (e.g. metals) that may pose an unacceptable risk.

** For materials subject to an End of Waste code, they are assumed to be compliant and therefore scored 1, acknowledging there may still be some variation.*

Table 49: Hazard Score of Raw Feedstock (Factor B)*

Score	Description
1	No known toxins, or all potential contaminants known to be <HIL-A or equivalent.
2	Unlikely that feedstock contains toxins or contaminants.
3	Raw feedstock potentially contains contaminants or unknown compounds that may pose a risk.
4	Raw feedstock likely poses risk in untreated form. Includes feedstocks where toxins / contaminants are treatable and can degrade through the composting process (e.g. pathogens).
5	Potentially highly toxic or poses significant risk in raw feedstock form (e.g. explosive nature of ammonium nitrate). Concentrations likely to be elevated above HIL-As.

** For materials subject to an End of Waste code, they are assumed to be compliant and scored 3, acknowledging there may still be some residual risk.*

Table 50: Persistence Score (Factor C)

Score	Description
1	The main contaminants of concern are likely to chemically degrade or decompose with time, pasteurisation, or other composting processes (excluding dilution). Includes contaminants such as pathogens, TRH, or VOCs.
2	The main contaminants of concern are likely to be persistent through the composting process, and will not substantially chemically degrade or decompose. Includes contaminants such as metals, microplastics, PFAS, PAHs, etc.

Total risk scores were calculated for each feedstock by multiplying out the score for each of the five factors above to result in a total risk ranking score as follows.

Total contamination risk score = A x B x C

The possible range of values that could be calculated was 1 to 20, with all key assumptions and risk ranking scores for each feedstock presented in Appendix A.

A risk level was assigned to each feedstock based on the risk classifications detailed in Table 51 below. Due to the scores being skewed at the upper end of the score range due to the multiplying effect of scores, the four risk categories are not equally spread across the total score range.

Table 51: Risk Category Descriptions for Feedstocks

Risk Ranking Scores	Contaminant Risk Category	Description
1 to 4	Low	Feedstocks considered to be generally uncontaminated, or any toxins present such as pathogens will be managed through standard composting procedures. Low risk feedstocks are generally acceptable for use in composting with unrestricted use of the final product. Low risk feedstocks include: • green waste and biomass materials such as mulch, bark, or untreated wood • food industry wastes, such as vegetable waste, beer residues, grease trap waste, etc • animal processing wastes, such as abattoir waste, paunch, manures, etc. • earthworks or mining by-products (with no additives or known contaminants), such as sand, lime, or gypsum. Of the feedstocks assessed, 36 were scored as ‘Low’ risk.
5 to 9	Medium	Feedstocks unlikely to be significantly contaminated, however due to uncertainty in the composition or source of the feedstock there is potential for the feedstock to contain contaminants that may require management. Medium risk feedstocks are likely acceptable for use in composting, but require further assessment to confirm their suitability and may require additional management controls. Medium risk feedstocks include: • by-products of mining or earthworks, whereby feedstock may contain naturally derived contaminants including elevated natural metals, such as acid sulphate sludge, bentonite, etc. • feedstocks which are subject to existing controls such as End of Waste codes (including coal ash, fly ash and drilling muds) but which may still present some residual risk. • by-products of industrial processes considered lower risk, such as polymer water, latex washing, coolant waste, etc. Of the feedstocks assessed, 25 were scored as ‘Medium’ risk.
10 to 15	High	Feedstocks likely to be contaminated with compounds that may pose a risk in the final product, however there is uncertainty regarding the extent of contamination, or the concentrations that may be present. While the likely contaminants are generally not persistent, there is potential for both feedstock and final compost product to contain contaminants that may require management.

Risk Ranking Scores	Contaminant Risk Category	Description
		High risk feedstocks may be acceptable for use in composting under some circumstances and with management controls, but require assessment to confirm their suitability. High risk feedstocks include: • Biosolids and other effluents or sludges from sewage treatment which may contain PFAS and a range of emerging pharmaceutical contaminants of concern. • by-products of industrial processes known to use more contaminating chemicals / materials, such as paper pulp effluent, paper mulch, mill mud, oily water, treated soil, dye waste, etc. Of the feedstocks assessed, 32 were scored as ‘High’ risk.
16+	Very High	Feedstocks are likely contaminated, with high degree of uncertainty regarding composition, and with potential for concentrations of contaminants to be above health investigation levels. Very high risk feedstocks are generally unacceptable for use in composting, although further assessment may be undertaken to confirm their contaminant risk. Very high risk feedstocks include: • Poorly described industrial effluent streams, such as process fluids and wastewater treatment plant wastes • by-products of industrial processes, such as filter cake, hide curing effluent, water based paints, etc. Of the feedstocks assessed, 16 were scored as ‘Very High’ risk.

6.2.3 Feedstock Risk Ranking

The final risk ranking for feedstocks currently or potentially in use in composting in Queensland is presented in Appendix A and summarised in Table 52 below. The feedstocks are sorted in ascending order of risk score. As noted above, the lack of compositional data has necessitated assumptions to be made, in which case Arcadis has generally adopted a conservative approach. However it is acknowledged that there is significant variability and ambiguity with some feedstocks and this assessment should be considered as indicative.

The risk ranking exercise indicates that a large number of feedstocks potentially pose an unacceptable risk to end users. Additionally, some feedstocks may represent a potential risk to workers or the environment at composting facilities, although it is expected that operational controls would mitigate potential risks at the composting sites.

One of the key factors that is evident from the risk ranking is that many risk scores are likely elevated due to the ‘uncertainty’ score as the composition is unknown, or at least limited data was available to the project team. Feedstocks given an uncertainty score of 2 were considered likely to contain some form of contamination, however the actual concentrations that may be present are unknown and would likely be highly variable depending on the source (e.g. arsenic in bentonite clay is known to be elevated in some deposits). This uncertainty was exacerbated by the limited information afforded by current feedstock naming conventions (e.g. “ground water”, “process fluid”, etc).

In general, as the level of human intervention increases, the level of risk due to contamination also increases. Highest risk feedstocks are therefore associated with industrial processes and waste streams, or from effluent streams which are potentially contaminated with a large number of contaminants from domestic and industrial sources.

Lower risk feedstocks included green waste, food and food industry wastes, and animal processing waste related feedstocks (noting that some of these feedstocks would be hazardous in their raw feedstock form, such as abattoir waste, but risks would be managed through current standard composting procedures). While many mining and earth works related feedstocks are also considered low risk, there can be uncertainty regarding the presence of naturally occurring contaminants such as metals, additives such as drilling fluids, or the presence of contamination for materials generated from brownfield sites; hence, further assessment of these feedstocks may be required to confirm contamination status.

It is expected that the characteristics and nature of each feedstock may vary significantly between sources or generators. Conservative assumptions have been applied where necessary, with many feedstocks likely allocated into a higher risk category than may be appropriate. This conservative risk scoring was applied where there was a lack of clarity regarding the source or composition of the material, high potential variability and / or due to a lack of data on actual contaminant concentrations. It is expected that with some refinement of feedstock descriptions, and collection of analytical data to clarify feedstock composition, it may be possible to lower the risk ranking of many feedstocks.

Table 52: Summary of feedstock contaminant risk ratings

Low risk	Medium risk	High risk	Very high risk
Food Organics	Tub ground mulch	Soil	Paint Wash
Vegetable waste	Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs	Amorphous silica sludge	Sullage waste (greywater)
Cypress chip	Food processing treatment tank or treatment pit liquids, solids or sludges	Mud and Dirt Waste	Bilge waters
Forest mulch	Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Quarantine waste treated by an AQIS approved facility	Dye Waste (water based)
Green waste	Brine Water	Abrasive blasting sand (excluding heavy metal contaminated sands)	Water based inks
Pine bark	Calcium Water	Paper mulch	Forecourt Water
Wood chip	Fertiliser water and fertiliser washings	Paper pulp effluent	Treatment tank sludges and residues
Beer	Acid Sulphate Sludge	Paper sludge dewatered	Hide curing effluent
Grain Waste	Wood molasses	Plaster board	Filter cake and presses
Gypsum	Waterbased glue	GPT Waste	Water based paints
Lime	Coolant Waste	Mill mud	Filter/ion exchange resin backwash waters
Sand	Polymer Water	Soil treated by indirect thermal desorption	Waste Water
Cane residues	Soapy water	Bauxite sludge	Leachate Waste
Crusher dust	Ground Water	Water blasting wash waters	Process Fluid
Lime Slurry	Low level organically contaminated stormwaters or groundwaters	Carbon Pellets	Effluent Waste
Molasses Waste	Ash	Waterbased Lacquer Waste	
Soft Drink Waste	Coal ash	Latex Washing	
Vegetable oil wastes and starches	Fly ash	Boiler blow down water	
Yeast Waste	Drilling Mud / Slurry (Coal Seam Gas)	Car Wash Mud & Sludge	
Cement Slurry	Dewatered fertiliser sludge	Oily Water	
Animal manures, including livestock manure	Bentonite	Stormwater Waste	
Animal processing waste	Compostable PLA plastics	Vehicle wash down waters	
Animal Waste, including egg waste and milk waste	Natural textiles	Wash Bay Water	
Paunch material	Muddy Water	Carpet cleaning wash waters	
Abattoir waste	Total Petroleum Hydrocarbon Water	Foundry sands	
Tallow Waste	Treated timber waste	Biosolids	
Brewery effluent		Nightsoil	
Food processing effluent and solids		Sewage sludge	
Grease trap - treated grease trap waters and dewatered grease trap sludge		Sewage treatment tank or treatment pit liquids, solids or sludges	
Grease trap waste		Septic wastes	
Starch Water Waste			

Low risk	Medium risk	High risk	Very high risk
Sugar and sugar solutions Worm castings suitable for unrestricted use Mushroom compost (substrate) Pot ash Ammonium Nitrate		Activated sludge and lime sludge from wastewater treatment plants Organics extracted from mixed household waste / MSW	

6.2.4 Feedstock Classification – Contamination

Based on the preliminary contamination risk assessment above, Arcadis has classified each feedstock into one of the four categories as defined at the start of this section (6.2). The classification is linked to the risk ranking as follows:

- If the potential contamination risk is rated as ‘very high’, it is classified as *contamination category 1 – generally unsuitable for composting.* The onus should be on operators who wish to process these materials, to demonstrate that the risk profile is lower.
- If the potential contamination risk is rated as ‘high’ and the composition uncertainty score is 1 (i.e. composition is known, see Table 48), it is classified as *contamination category 1 – generally unsuitable for composting.* The onus should be on operators who wish to process these materials, to demonstrate that the risk profile is lower.
- If the potential contamination risk is rated as ‘medium’ and the composition uncertainty score is 1 (i.e. composition is known, see Table 48), it is classified as *contamination category 2 – Potentially suitable for composting, subject to additional management controls.*
- If the potential contamination risk is rated as ‘low’, it is classified as *contamination category 3 – Suitable for composting.*
- If the potential contamination risk is rated as ‘medium’ or ‘high’ and the composition uncertainty score is 2 (i.e. composition is unknown, see Table 48), it is classified as *contamination category 4 – Potentially suitable for composting, but significant data gaps and further analysis required.*

The outcomes of this assessment are summarised in Table 53 overleaf, along with the risk assessment findings and assumptions about the nature of each feedstock.

It shows that 16 feedstocks were classified as unsuitable for composting (contamination category 1), many with vague and ambiguous names which imply a manufacturing or process industries origin. Clarification of the nature and source of those feedstocks may change the classification.

A total of 36 of the feedstocks were considered suitable for composting and unlikely to pose significant risk (contamination category 3), assuming the materials are as their name implies, without unforeseen contaminants. Only six feedstocks were considered potentially suitable for composting but likely to require enhanced control measures (contaminant category 2) such as maximum blending ratios within a compost mix, or potential restrictions on end use to minimise direct human contact (e.g. highway verges, mine rehabilitation, forestry).

Almost half of feedstocks (51) were classified as contamination category 4 – Potentially suitable but requiring more data; reflecting the lack of useful data available to properly classify and assess feedstocks. As noted above, further analysis and investigation of these materials is needed to confirm suitability and ultimately, to reclassify them into another category. Given most of the materials in this category are somewhat unusual composting inputs and not likely to be in widespread use across multiple operators, the onus should be on the operators to undertake that analysis and demonstrate to DES that the materials are suitable.

Table 53: Summary of qualitative contamination risk assessment results

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
Animal Matter	Abattoir waste	Animal / meat waste only, with some minor potential for cleaning residues etc.	Pathogens, detergents	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Animal manures, including livestock manure	Animal waste only, no other products such as cleaning residues, 'sheep dip', etc.	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Animal processing Waste	Animal / meat waste only, no other products such as cleaning residues etc.	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Animal Waste, including egg waste and milk waste	Animal waste only, no other products such as cleaning residues, etc.	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Hide curing effluent	Effluent and wastes from tanneries. Potentially from the various steps involved in preparing animal hide e.g. Washing for removal of hair, fat removal, chemical treatment. Curing hides requires large amounts of salt, which results in brine waste water.	Chromium, metals, pathogens, low pH, dyes, others?	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Paunch material	Partially digested gut contents of slaughtered animals from abattoir, consists mainly of	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		undigested grass, hay, other feed products such as grain, and water as well as body fluids, including saliva				
	Tallow Waste	Rendered meat fat residues or wastes	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
Chemical residues	Ammonium Nitrate	Assumed pure ammonium nitrate, as in off-spec or damaged fertiliser products. A salt of ammonia and nitric acid, that is widely used in fertilisers. It is the most common nitrogenous component in artificial fertilisers. Solid ammonium nitrate can undergo explosive decomposition when heated in a confined space. It is highly soluble in water.	Ammonia, nitrate, pH, explosive / combustible	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Dewatered fertiliser sludge	By-product from fertiliser production, assumed no other waste materials cross-contaminate the stream. The most commonly manufactured fertiliser is ammonia nitrate as it is very water-soluble.	Ammonia, nitrate, other fertilisers, pH, potentially explosive / combustible	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Fertiliser water and fertiliser washings	By-product from fertiliser production, assumed no other waste materials cross-contaminate the stream. Subject to an EoW code for fertiliser wash water - derived from cleaning or washing or fertiliser plant or hygroscopic sorbing of moisture into fertiliser products.	Ammonia, nitrate, other fertilisers, pH, explosive / combustible	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Filter/ion exchange resin backwash waters	Unknown composition or origin - some form of effluent treatment process	Unknown, could contain a large number of toxins, such as metals, PFAS, microplastics, emerging contaminants, etc.	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Pot ash	Potassium compounds, most commonly used as a fertiliser but also used in industry. Unknown whether pot ash feedstock is from the manufacture of pot ash or includes by-products from industrial uses.	Unknown	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
Food & Food processing waste	Food Organics	Food wastes, assumed no other products such as cleaning residues etc.	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Organics extracted from mixed	Currently applies to Suez Cairns only, organic fraction mechanically	Metals, microplastics, PFAS, pharmaceuticals,	High	4 - Potentially suitable but more data	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	household waste / MSW	separated from mixed waste. Assumed similar to NSW 'MWOO' grade waste stream, which studies showed can contain contaminants	emerging contaminants, others?		needed on contamination risk	
	Quarantine waste treated by an AQIS approved facility	Assumed to be food and organic material treated by irradiation or similar. May include chemical additives, treatment chemicals, or unknown materials. Excluded from list of acceptable organic materials by DES	Pesticides, herbicides, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Beer	Assume waste beer, non-compliant product	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Brewery effluent	Food waste residues from beer brewing, assumed no contamination by cleaning products, etc.	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Food processing effluent and solids	Food wastes, potential for minor residues from cleaning products or other industrial processing inputs.	Detergents	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Food processing treatment tank or treatment pit	Food wastes, potential for minor residues from cleaning products or other	Detergents	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	liquids, solids or sludges	industrial processing inputs.				
	Grain Waste	Assume mostly hulls / waste grains	Trace pesticides etc, but likely negligible amounts in food streams	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Grease trap - treated grease trap waters and dewatered grease trap sludge	Greases and food by-products separated waste pumped out of grease traps (restaurants, commercial kitchens, etc). May contain residues of cleaning products	Fatty acids, detergents, TRH / TPH	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Grease trap waste	Greases and food by-products pumped out of grease traps (restaurants, commercial kitchens, etc). Mostly water, may contain residues of cleaning products	Fatty acids, detergents, TRH / TPH	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Molasses Waste	Waste products from sugar processing and molasses manufacture	High BOD	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Soft Drink Waste	Food manufacturing wastes, potential for minor residues from cleaning products or other industrial processing inputs	Detergents	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Starch Water Waste	Assumed food or industrial waste product with high starch content and minor residues from processing	Pathogens, others?	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Sugar and sugar solutions	Waste products from sugar processing with high sugar content and minor residues from processing	High BOD, others?	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Vegetable oil wastes and starches	Greases and food by-products from food industry	Fatty acids, detergents	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Vegetable waste	Food wastes, assumed no other products such as cleaning residues etc.	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Yeast Waste	Assumed to be beer or food manufacturing waste product	Pathogens	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
Industrial residues	Abrasive blasting sand (excluding heavy metal contaminated sands)	Industry waste from sand blasting, may contain traces of paint etc from sand blasting process	Silica, metals, trace paints	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Amorphous silica sludge	Concrete additive made from silica	Silica, metals	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Ash	Industrial by-product (e.g. coal power generation), may be wood, coal, or	PAHs, TRH, metals, VOCs, high pH	Medium	2 - Potentially suitable subject to controls	Compositional analysis, blending as a minor proportion

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		other sources of ash. See EoW code for Coal Combustion Products.				
	Bauxite sludge	Alumina refinery by-product. May be highly alkaline containing iron oxide and other metals	Metals, high pH	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Carbon Pellets	Unknown source - may be spent or unused pellets from a range of sources or industries. Likely to have been used in water or air filtration so composition will depend on previous use	TRH, PAH, metals, VOCs, contaminants (if spent)	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Cement Slurry	Mix of cement, sand, water and additives	Potential for small proportion to comprise unknown additives	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Coal ash	Industrial by-product (e.g. coal power generation). See EoW code for Coal Combustion Products	PAHs, TRH, metals, VOCs, high pH	Medium	2 - Potentially suitable subject to controls	Compositional analysis, blending as a minor proportion
	Compostable PLA plastics	Plastics made from plant products such as corn starch. Biodegradable under optimal conditions.	Microplastics, dyes, VOCs, additives	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Coolant Waste	Waste water with coolant (e.g. glycol), by-product from industry or small scale mechanics.	TRH, anti-freeze (e.g. ethylene glycol), metals	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Dye Waste (water based)	By-product from industrial dying processes.	Pigments, detergents, surfactants, metals, VOCs, fixing agents (formaldehyde), others?	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Filter cake and presses	Concentrated waste streams from water treatment in a filter press. Source industry unknown.	Unknown, could contain a large number of toxins, such as metals, PFAS, microplastics, emerging contaminants, etc.	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Fly ash	Industrial by-product (e.g. coal power generation), may be wood, coal, or other sources of ash. See EoW code for Coal Combustion Products.	PAHs, TRH, metals, VOCs, high pH	Medium	2 - Potentially suitable subject to controls	Compositional analysis, blending as a minor proportion
	Foundry sands	Sand used in foundry mouldings, stabilised with phenol compounds. See EoW code for Foundry sand.	Heavy metals, phenols	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Paint Wash	Assumed wash down water with some paint residues, potentially with solvents, surfactants, oils, etc.	Metals, dyes, TRH, VOCs, others?	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Paper mulch	Assumed solid paper wastes from paper manufacturing, potentially	Metals, dyes, dioxins, VOCs, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		containing dyes, solvents and chemical residues				
	Paper pulp effluent	Assumed mix of solid and liquid paper fibre wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	Metals, dyes, dioxins, VOCs, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Paper sludge dewatered	Assumed solid paper wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	Metals, dyes, dioxins, VOCs, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Plaster board	Assumed to be comprised of gypsum with potential for multiple additives - plasticisers, fire retardants, water repellents, 'foaming agents', etc.	VOCs, phthalates, PFAS, emerging contaminants, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Polymer Water	Unknown composition or source. Potentially associated with coagulants added to process water.	VOCs, others?	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Process Fluid	Unknown source or composition.	Unknown	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Total Petroleum Hydrocarbon Water	Assumed run-off from hard surfaces, or industrial waste water, with potential for other contaminants to be present	TRH, PAHs, metals, VOCs, others?	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Treated timber waste	Timber treated with a range of chemicals and heavy metals to inhibit decomposition, including CCA, ACQ, CuAz and methyl bromide	Heavy metals (copper, chrome, arsenic), creasote, organic solvents, boron, methyl bromide	High	1 - Generally unsuitable for composting	Avoid composting
	Water based inks	Assumed liquid wastes from ink use or manufacture	Metals, VOCs, solvents, others?	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Water based paints	Assumed liquid waste paint, potentially undiluted. Pigments may include various metals and minerals (eg White: Titanium dioxide ($TiO2$); Black: carbon; Blue copper calcium silicate; Red: cadmium sulphide). Binder may be Latex, vinyl (Polyvinyl Chloride), acrylic, Poly Vinyl Alcohol (made from the hydrolysis of polyvinyl acetate and is the most common binder in water-based paint - PVA	Metals, VOCs, solvents, others?	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		can generally be regarded as a biologically degradable synthetic polymer, but aerobic / moisture conditions need to be optimal). Latex should be natural form. Acrylic and PVC not biodegradable.				
	Water blasting washwaters	Assumed dilute concentration contaminants may be present from cleaning ('water blasting') process	Metals, TRH, PAHs, solvents, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Waterbased glue	Potentially undiluted glue comprised of polymers and solvents	VOCs, solvents, PVA (or other polymers such as latex)	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Waterbased Lacquer Waste	Waste liquid lacquers from manufacture or use, potentially undiluted	VOCs, solvents, metals, polymers	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Wood molasses	Results from a process that transforms the wood cellulose into sugars (glucose). Usually involves the pyrolysis of wood using high temperatures and pressures with acids and then cooled and neutralised with lime. It is being used as an additive in animal food and in	Potential PAHs / hydrocarbons, VOCs, high BOD, low pH	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		agriculture as a soil improver.				
Plant matter	Cane residues	Assumed sugar cane wastes from the harvesting of sugar cane (e.g. tips and leaves)	Pesticides, herbicides	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Cypress chip	Assumed untreated wood chips	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Forest mulch	Assumed untreated wood / bark product	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	GPT Waste	Gross pollutant trap wastes, including general waste, leaf litter, stormwater sediments, etc. Assumed that wastes such as plastics are mechanically removed prior to composting.	TRH, metals, microplastics, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Green waste	Assumed untreated green wastes from domestic and commercial sources. Composition will vary - seasonal.	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Mill mud	See EoW code for sugar mill by-products. By-product from sugarcane processing, contains filter mud from clarification of	Metals, high pH, PAHs	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		cane juice plus ash, potentially some lime				
	Mushroom compost (substrate)	Mushroom growth medium and residues, generally comprised of straw, manure, lime/chalk, etc	Pathogens, potential pesticide residues	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Natural textiles	Assumed by-product of fabric manufacturing, including wool, cotton, bamboo, etc.	Pathogens, metals, dyes, dioxins (from bleaching), others?	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Pine bark	Assumed untreated wood product	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Assumed majority is untreated wood product, although some treatment residues (e.g. ACC) may be present	Metals, pesticides	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Tub ground mulch	Fine to medium mulch products, assumed majority is untreated wood product, although some treatment residues (e.g. ACC) may be present	Metals, pesticides	Medium	2 - Potentially suitable subject to controls	Compositional analysis to confirm contaminants
	Wood chip	Assumed untreated wood product	None	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Wood waste (excluding chemically	Assumed to largely be untreated wood product, however inclusion of	Metals, pesticides	Medium	2 - Potentially suitable subject to controls	Compositional analysis to confirm contaminants

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	treated timber) including pallets, offcuts, boards, stumps and logs	manufactured wood products (e.g. pallets) may introduce contaminants into feedstock stream				
	Worm castings suitable for unrestricted use	Assumed to be comprised of largely organic worm castings, minor potential for some contaminants	Microplastics, metals	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
Sewage & STP residues	Activated sludge and lime sludge from wastewater treatment plants	Assume from sewage treatment but may also be from industrial wastewater treatment plants. May contain a range of contaminants, including pharmaceuticals and emerging contaminants.	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Biosolids	Solid residues from sewage treatment. Varying pre-processing and stabilisation conditions. May contain a range of contaminants, including pharmaceuticals and emerging contaminants.	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Nightsoil	Sludge and solid residues from remote septic tanks (sewage waste).	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Septic wastes	Sludge and solid residues from remote septic tanks (sewage waste).	Pathogens, metals, pharmaceuticals, microplastics, potential emerging contaminants	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Sewage sludge	Sludge and solid residues from sewage treatment.	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Sewage treatment tank or treatment pit liquids, solids or sludges	Sludge and solid residues from sewage treatment.	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
Earthworks waste and additives	Acid Sulphate Sludge	Naturally occurring but contains high levels of iron-sulphide. Can be acidic / acid forming when oxidised and cause the dissolution / release of mineral metals (iron, aluminium, other heavy metals, arsenic)	low pH, sulphates, metals	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Bentonite	Mined clay waste, no other products from use of bentonite (e.g. drilling fluids). Assume from drilling muds but can also be found in paints, in the manufacturing of paper and is used as a water softener.	Metals	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Crusher dust	By-product of quarrying or mining, assumed natural unprocessed rock with no additives	Metals	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Drilling Mud / Slurry (Coal Seam Gas)	See EoW approval for CSG Drill Muds. Mix of natural rock / soils with additives (salts, bentonite, etc).	Metals, TRH, surfactants	Medium	2 - Potentially suitable subject to controls	Compositional analysis to confirm contaminants, blending as a minor proportion
	Gypsum	Assumed quarry or mining waste, with no additives or industrial by-products	sulphate	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Lime	Assumed quarry or mining waste of calcium carbonate, with no additives or industrial by-products	high pH	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Lime Slurry	Assumed construction or industrial by-product, with a mix of lime, sand and water	High pH, metals or trace cross-contamination	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Mud and Dirt Waste	Unknown sources, potentially contaminated	Metals, PFAS, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Sand	Assumed untreated or from greenfield source	Metals	Low	3 - Suitable for composting	Standard composting best practice, analysis to confirm risk
	Soil	Unknown sources, potentially contaminated?	Metals, asbestos, TRH, others?	High	4 - Potentially suitable but more data	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
					needed on contamination risk	
	Soil treated by indirect thermal desorption	Assumed that soils were contaminated prior to thermal desorption treatment	Metals, PFAS, asbestos, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
Wastewater & wash-waters	Bilge waters	Sea and fresh water from ship pump outs, may contain oil, sludge and other chemicals.	TRH, PAHs, antifoulants, metals, VOCs, emerging contaminants	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Boiler blow down water	Waste water from boilers to remove suspended solids, scale, contaminants, etc.	Metals, TRH, VOCs, treatment chemicals, others	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Brine Water	Unknown sources, assumed hyper-saline water from industrial or food processes	high pH, others?	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Calcium Water	Unknown sources, assumed calcium containing water ('hard' water) is from industrial or food processes	high pH, others?	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Car Wash Mud & Sludge	Waste slurry captured in drains at car washes	TRH, PAHs, VOCs, detergents, exhaust residues	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
	Carpet cleaning washwaters	Likely contains highly alkaline chemicals and chemical enzymes, high levels of VOCs, disinfectants, high concentrations of sodium bicarbonate, sodium citrate, sodium silicate or sodium phosphate, dyes, polymers, bleachers, esters, forms of but yl, dirt, soap, oil, grease, a variety of solvents, esters and other toxic chemicals	Surfactants, detergents, PFAS, dyes, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Effluent Waste	Assumed to comprise either industrial or domestic effluent streams	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Forecourt Water	Run off from service station forecourts	TRH, metals, PAHs	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Ground Water	Unknown source or composition	Unknown	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Latex Washing	Effluent from rubber and latex processing	Latex, detergents, others?	High	4 - Potentially suitable but more data	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
					needed on contamination risk	
	Leachate Waste	Landfill leachate, potentially contains complex mix of contaminants	Ammonia, sulphides, pathogens, metals, PFAS, pharmaceuticals, potential emerging contaminants	Very High	1 - Generally unsuitable for composting	Avoid composting – alternative treatment options are available
	Low level organically contaminated stormwaters or groundwaters	Unknown source or composition	Unknown	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Muddy Water	Unknown sources, potentially contaminated	Metals, PFAS, others?	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Oily Water	Assumed run-off from forecourts or hard surfaces, with water collected from bunded areas with high potential for oils	TRH, PAHs, metals, VOCs, others?	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Soapy water	Unknown source or composition - containing detergents but potentially other contaminants depending on the use	Unknown, likely detergents, oils, low concentrations of other residues, etc.	Medium	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Stormwater Waste	Assumed run-off captured in bunded areas which is unable to be directly discharged, with high	TRH, PAHs, metals, VOCs, others?	High	4 - Potentially suitable but more data	Compositional analysis to confirm rating

Type	Feedstock material	Assumed source / nature	Assumed contaminants	Potential Contam Risk	Feedstock Classification	Controls
		potential for oils or other wastes			needed on contamination risk	
	Sullage waste (greywater)	Greywater / wastewater from domestic or commercial buildings excluding sewage, includes waters drained in showers, sinks, laundries, etc. Likely to contain soap, soil, chemicals, detergents, bleaches, lint, food particles	Detergents, surfactants, oils, pharmaceuticals, pathogens, others?	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Treatment tank sludges and residues	Unknown, potentially highly variable industrial wastes	Unknown	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk
	Vehicle wash down waters	Waters collected at car wash facilities	TRH, PAHs, metals, VOCs, detergents, exhaust residues	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Wash Bay Water	Waters collected at wash down areas	TRH, PAHs, VOCs, detergents, exhaust residues	High	4 - Potentially suitable but more data needed on contamination risk	Compositional analysis to confirm rating
	Waste Water	Unknown source or composition	Unknown	Very High	1 - Generally unsuitable for composting	Avoid composting, unless further analysis / definition demonstrates lower risk

** Likely synthetic but fits the DES definition of organic under 'a substance used for manufacturing fertiliser for agricultural, horticultural or garden use'*

6.3 Specific Feedstock Risk Assessment

As noted above, the lack of comprehensive and representative data on the composition of composting feedstocks has precluded a more detailed assessment of the specific risks posed by feedstocks that are or could be used in composting in Queensland.

Arcadis proposes that a simple risk assessment template could be developed which predicts the contaminant contribution of each feedstock material in a given compost mix, to the final product. The combined contaminant contributions of all feedstocks would then be assessed against an agreed set of thresholds to determine whether the overall contamination risk is acceptable. The contamination risk needs to take into account the blending ratios of different feedstocks, noting that some materials are only ever blended in minor proportions in the compost mix. It is not within the scope of this study to determine the assessment thresholds.

Such an assessment should take into account a number of factors:

- The chemical composition of the raw feedstock as likely to be received at the composting facility, and as demonstrated through sufficient number of samples according the variability and seasonality of the composition (more variable feedstocks need a larger sample set to adequately characterise the feedstock).
- The compositional analysis should generally cover the groups of potential contaminants identified in section 5, noting that some will not be relevant to certain feedstocks. The assessment should include physical impurities, pathogens, metals, organic compounds (organochlorine pesticides, herbicides, PAHs), hydrocarbons (TPH/TRH and BTEX), and PFOS / PFAS compounds.
- The expected degree of variability in the composition between loads and over time (e.g. seasonal variations), rated as low, moderate or high. Where the feedstock is highly variable, the risk assessment should conservatively focus on the worst-case maximum contaminant concentrations.
- The expected maximum proportion of the material in any compost mix (by weight).
- The proposed end use for the compost product, which in turn may dictate which set of contaminant thresholds should apply. There is a strong case to assume all compost products should be suitable for unrestricted use, and have a single set of thresholds to avoid market confusion.
- Whether the feedstock is likely to add beneficial components to the final compost product such as carbon content, nutrients (nitrogen and other macro nutrients), essential metals and trace elements, and physical structure / porosity.
- The moisture content and other key parameters such as total degradable carbon content, total nitrogen content, pH, electrical conductivity and mineral salts.
- The likely reduction in contaminants through the composting process, taking a conservative estimate but assuming standard composting practice. Reduction may occur through bio-degradation, decomposition, mineralisation or volatilisation.
- Contaminants should be assessed on a dry matter basis to eliminate effects of moisture loss / addition during the composting process.

For each contaminant in each feedstock, the contribution of each contaminant to the overall concentration in the final product can be calculated as:

Raw concentration in feedstock x Proportion in mix (%) x (100%-Expected reduction factor(%))

It is then a matter a summing the contributions of a particular contaminant across all feedstocks in the mix, to estimate the total final product concentration. That concentration is then compared against the agreed assessment thresholds to determine the risk to human health or the environment.

Appendix B includes an example template which demonstrates this concept.

Chapter 6– key findings and recommendations

- Due to the lack of specific and comprehensive data on feedstock composition, Arcadis has developed qualitative approaches to assess the risks associated with composting feedstocks, for both potential odour contribution and contamination of the products.
- The assessments help to prioritise feedstocks for further investigation and potential tighter management or regulatory controls, but the lack of data is a constraint on more accurate risk assessment at this stage. A framework has been outlined to undertaken feedstock specific assessments against an agreed set of contaminant thresholds.
- Feedstocks have been assessed to determine their potential odour contribution in a composting process (odour risk). Following from these assessments, feedstocks have been classified into one of five categories as follows:
  - 27 feedstocks were considered to present a high or very high potential odour contribution risk and were therefore categorised as *odour category 1 – suitable for composting but with additional controls.*
  - The remaining 82 feedstocks were categorized as *odour category 2 – suitable for composting, subject to standard composting practice,* meaning that any odour risk is manageable through current / acceptable composting practices.

  Feedstocks have also been assessed to determine their potential contamination impact on final products (contamination risk). The assessment has classified feedstocks into one of four categories:

  - 16 feedstocks were categorised as *contamination category 1 – generally unsuitable for composting.* Many of these have vague and ambiguous names which imply a manufacturing or process industries origin but further clarification of the source and nature of the wastes may allow a reclassification.
  - 6 feedstocks were considered potentially suitable for composting but likely to require enhanced control measures (contamination category 2) such as maximum blending ratios within a compost mix, or potential restrictions on end use to minimise direct human contact (e.g. highway verges, mine rehabilitation, forestry).
  - 36 feedstocks were considered suitable for composting and unlikely to pose a significant risk (contamination category 3).
  - 51 feedstocks were classified as potentially suitable for composting but requiring more data (contamination category 4); reflecting the lack of useful data available to properly classify and assess feedstocks. Further analysis is required by operators who process these materials to demonstrate their suitability.

Recommendations – Risk Assessment

- The odour risk assessment has identified 14 feedstocks classified as high risk and 13 as very high risk of contributing to odour issues in a composting process. These materials may be acceptable for use in composting but should be subject to tighter management controls including characterisation assessments to confirm their suitability; and appropriate blending with bulking agents to balance moisture and C:N ratios. It is likely that storage and mixing facilities may need to be enclosed to manage the risk of odour release from anaerobic materials upon receipt, and operators should assess the need for the initial composting phase to be enclosed.
- The initial contaminant risk assessment has identified 32 feedstocks considered to pose a high risk and 16 ranked as very high risk of leading to contamination in compost products. In many cases, the high ranking is partly due to uncertainty in composition so could potentially be re-assessed and reduced with better data.

7 INDUSTRY CONSULTATION

Extensive stakeholder and industry consultation was outside the scope of the current study but Arcadis did engage with composting operators in a limited fashion to better understand their perspectives and openness to regulatory change. Arcadis engaged with the Australian Organics Recycling Association (AORA), which is generally considered the peak representative body for composters in Queensland, although it is not the only body and does not have all Queensland composters as members. AORA subsequently invited Arcadis to attend and give a brief presentation at a scheduled AORA Queensland branch seminar and members meeting (14 May 2019). At that meeting, Arcadis gave an overview of the study scope and objectives, but did not discuss any findings or specific recommendations, noting that they were all still in draft form at the time.

The purpose of the session was to inform industry and seek initial feedback on potential options to improve regulation of composting in Queensland. Operators gave some feedback during that meeting but were subsequently given an opportunity to respond to a written questionnaire, and to provide their view on a range of potential options (six companies responded). Dominic Schliebs from Arcadis and Johannes Biala (CROWN) attended the seminar.

The AORA member audience was very appreciative of the opportunity to provide input. The following key issues / comments were raised in discussion:

- Industry is open to change and improving standards, provided it is done in a way that applies consistently to all and with consideration of the commercial implications.
- Of particular relevance to this study, there was general support for tighter regulation of composting feedstocks and product quality, but the role of waste generators and transporters and the information they provide, needs to be considered.
- There was some support for harmonisation and updating of EA conditions, provided it leads to more consistency and that operators are given sufficient time to adjust / transition. Others noted the need for consistent enforcement of existing conditions.
- It was clear that any new changes or system should be tailored to the specific Queensland context, not copied from any other jurisdiction. There was some support for an End of Waste approach, where compliant compost products are no longer regulated as wastes.
- Operators generally felt that a regulatory approach to improving standards, or perhaps a certification system, would be more effective than a voluntary industry led approach such as a code of conduct.
- There were a mix of views around the use of more prescriptive conditions to control issues such as odour. Most seemed to favour better guidance and education, rather than prescriptive conditions. There was support for regulating aspects such as site specific odour management plans. There was little support for prescriptive conditions requiring operators to better characterise their feedstocks to optimise blending rates, with most operators believing this is already done or can be achieved by other means.
- There was mixed support for the use of odour dispersion modelling as a tool to help manage odour, with most preferring this be used in the approval stage of a project.
- With respect to enhanced engineering controls (such as enclosed processing and forced aeration), there was a mix of views but strong caution about the application of a one-size-fits-all approach noting the differences between South East Queensland and regional markets; and caution about the adverse commercial impact on industry.
- There was general support for limiting or banning the use of feedstocks that present an unacceptable contamination risk in compost. However, there was limited support for differentiating categories of compost products based on contamination risk. Rather, there should be consistent control of contaminants (End of Waste codes seem to be a favoured approach) and appropriate information provided to customers, to let the market make informed decisions. There was mixed support for the concept of a certification or labelling system.

- The apparent strained relationships or disconnection between DES regulatory branch, DES policy branch and industry was noted as a significant barrier to positive progress.
- There were several comments in support of a more collaborative relationship with DES – industry and regulators working together to resolve issues and better understand the others perspective. The idea of a joint DES-industry workshop to discuss regulatory options was raised and well supported, as was the concept of a joint DES-industry working group to meet regularly.
- There were several comments about the net benefits of composting not being recognised or considered by DES, and that regulators tend to be too narrow in their focus on compliance issues.
- Industry is enthusiastic to engage to be involved in shaping any future regulatory changes – they feel strongly that they should be consulted in a meaningful way throughout the options assessment process, before any decisions are made on preferred models.
- Lifting of standards will require input and buy-in from all stakeholders including DES, waste generators, waste transporters, composting facilities and recycled organic product purchasers.
- There is a need for councils and governments to control encroachment on established composting facilities and better plan the locations of future facilities.
- Training and education was noted as a current gap and there was consistent support for targeted training for both industry and regulators / officers, as well as best practice guidance. AORA is planning to be more active in this space and would support any programs.

8 RECOMMENDATIONS

Based on Phases 1 and 2 of the current review, a number of recommendations are proposed as set out below.

8.1 Odour Control Recommendations

A number of recommendations were proposed in Phase 1 to improve the management and regulation of odour from composting facilities. Those recommendations are presented below for completeness.

8.1.1 Best Practice Management Guidelines – Odour Control

A number of the recommendations made in Phase 1 related to operational measures to control or minimise odour and while it is up to DES to determine the most effective way to implement these measures or encourage their implementation by industry, one option is to develop a Queensland specific Best Practice Environmental Management Guideline for organics processing, which may include and build upon these recommendations. The following recommendations can be considered best practice measures that could be incorporated into any future guidance, noting that any such guidance would need to cover a broader range of operational and management aspects beyond those on which this study has focused, such as siting, water management, dust, noise, fire / safety and monitoring.

1. Turned windrow management – there is no best practice standard for the frequency and method of turning. Turning methods and schedules need to be optimised for the feedstock mix, available machinery and site requirements. This requires a balancing of several factors such as maintaining aerobic conditions versus releasing accumulated odours; loosening of the compost and breaking up clumps versus reducing the porosity of the compost mix; and redistribution of moisture. The optimal turning strategy should be determined by an experienced operator through site trials and measurements.
2. That said, there are some common considerations in optimising the turning strategy for an open windrow operation:
    - Focus on adequate porosity - mix odorous materials with a generous and appropriate ratio of bulking material (e.g. shredded green waste) that has both readily available carbon sources and large, structurally stable particles that are able to maintain adequate porosity (ideally 35-45%) to facilitate passive aeration of windrows, which is driven by the temperature gradient between internal and external windrow temperatures.
    - Minimise turning events for windrows containing odorous feedstocks, especially during the first 7-10 days of composting, with only the minimum turning required to support pasteurisation and moisture redistribution. This enables the odorous by-products generated during this initial phase to be oxidised to less odorous compounds before they are released to the atmosphere. The compounds will continue to decompose as they move through the windrow mass.
    - When turning with a front-end loader, ensure that the operators do not drive up on the compost when windrows are being formed, which can cause compaction and reduce airflow.
3. Composters processing odorous materials in open windrows should be encouraged to experiment with caps (or blankets) of mature compost as a measure to reduce odour emissions during the initial stage of composting and to ultimately implement this is as a regular operational control.
4. Composting operations that process highly odorous materials and/or are located close to sensitive receptors should consider enclosing the waste reception / storage / blending functions and assess the implementation of some form of forced aeration and/or enclosed composting process, for at least the initial phase of composting.
5. Forced aeration, if adopted, needs to be optimised for a particular compost mix, so as not to have an adverse impact on odour emissions.

6. Engineered biofilters are a very efficient and cost-effective method of treating odours if they can be captured within an enclosed or forced aeration composting system. They could similarly be applied to treat air from an enclosed feedstock receival and mixing building. Other measures including physical and chemical treatments are unlikely to be as effective.
7. For best practice feedstock receival, operators should:
    - Keep an ample stockpile of bulking agent or high carbon material at the receiving area to immediately mix with all deliveries of odorous materials
    - Immediately mix potentially odorous materials upon receipt and ensure that materials are mixed uniformly throughout
    - Consider enclosing the receival facilities for highly odorous materials and the initial mixing operation, with appropriate ventilation and biofilter systems
    - Consider blanketing odorous solid materials with a thick layer of bulking agent
    - Work with generators and transporters of commercial organic residues to increase collection frequency
    - Have a system in place to assess and reject unacceptably odorous materials and eliminate troublesome feedstock sources
    - Undertake small scale trials of new feedstocks prior to accepting regular full loads, to assess the practical aspects of handling the new material and to monitor its performance in a composting pile.
8. Operators should have a clear procedure in place to ensure the initial compost mix is optimal in terms of C:N ratio, moisture and porosity and to understand the odour potential of each feedstock. This should include testing and analysis of feedstocks to understand their physicochemical characteristics. Such testing need not be of every load for consistent feedstocks, but sufficient to understand the key parameters and variability.
9. Parameters such as temperature and pH should be regularly monitored throughout the composting process. Other parameters such as moisture content and oxygen levels may also be measured, at least during critical phases (e.g. the first few days) and particularly when processing wet or odorous feedstocks.
10. Compost piles should not be moved to the maturation or curing stage until the thermophilic stage of composting has been completed, indicated by consistent temperatures below 45°C (assuming all other aspects managed correctly).
11. Maturity tests such as Solvita^{TM} are widely accepted and can be done on site, to ensure compost is mature enough to be safely stored.

8.1.2 Regulation of odour

Regulation of composting facilities is primarily controlled by conditions set out in the Environmental Authorities of each composting facility as well as general obligations which apply to all businesses in Queensland under the *Environmental Protection Act 1994*.

A review of those EAs has identified vast differences in the degree of control and regulation applied to each operator. In some cases, this is due to operators undertaking other environmentally relevant activities which increases the risk associated with the operation, such as processing of regulated wastes under ERA 55. In most cases though, it is a function of the age of each approval and the difficulty of changing an existing approval unless the operator voluntarily agrees to those changes.

The discrepancy means that there are some composters, including some very large-scale operations, which are operating with minimal controls over key environmental risk aspects such as waste acceptance, product quality, and management of odour, leachate and stormwater.

12. DES should investigate options to harmonise and reduce the inconsistency in EA conditions for composting operations with a similar risk profile and implement consistent minimum standards on

key aspects such as waste acceptance (including testing requirements), product quality and odour control. There are good examples amongst some of the more recent existing EAs which may serve as a template, but the main focus should be on achieving consistency. The initial (and so far, limited) feedback from industry suggests they are open to changes provided it applies consistently to all and helps to 'level the playing field'.

13. DES should consider whether there is a need for more stringent regulation or conditioning on sites that receive feedstocks considered to have a high or very high contribution to odour risk (as assessed in the Phase 1 report). This is not to suggest that these feedstocks are not suitable for composting, but that additional control measures may be warranted such as maximum blending ratios with green waste in the compost mix, additional requirements for their storage and mixing, more sophisticated processing (aerated / enclosed), and/or additional analysis and documentation requirements.
14. With respect to odour, DES should consider whether the current outcomes-based approach is appropriate for regulating odours from composting facilities. Outcome based conditions are generally preferred by industry but challenging to enforce when the outcome itself is difficult to measure and quantify, or to trace back to a specific activity. These challenges are heightened even more so when there are multiple operators potentially having a similar impact in one area, as is the case at Swanbank and elsewhere. The existing outcome based conditions should be retained but could be supplemented with specific additional conditions which address the root causes of odour as discussed in detail in the Phase 1 report (e.g. feedstock storage and blending; characterising feedstocks, and monitoring of key process parameters). There is a fine balance to be struck between being overly-prescriptive and maintaining flexibility for lower risk applications, which other states have not necessarily achieved in full. Therefore, a Queensland specific approach is recommended, considering some of the operational methods noted in the Phase 1 report but refined in consultation with industry.
15. It is apparent that waste collectors and transporters exert a high degree of power within the organic waste management supply chain (commercially and in terms of controlling feedstocks), yet it is the composters at the end of that chain that bear the brunt of regulation. In considering how to better regulate the composting industry, DES should be cognisant of this and consider options to better regulate the whole supply chain, making sure that waste generators and transporters are taking responsibility for providing adequate and accurate information about their waste streams, and ensuring they are managed appropriately. The new amendments under the Regulated Waste Framework will go some way to addressing this (for regulated wastes), provided they are properly applied by all parties in the supply chain and enforced by DES.
16. It is also apparent that the current waste tracking system is ineffective at tracking and flagging anomalous waste movements which may indicate waste has been taken to an inappropriate facility. DES should consider options to upgrade or overhaul the Waste Tracking System to an electronic platform that ensures that critical information is accessible to transporters, operators and the regulator in real time. This could potentially stop, for example, transporters 'shopping around' for an alternative disposal option after being rejected from one facility.
17. For new facilities, industry, local governments and residents could benefit from clear guidance produced by DES on the regulation of composting facilities including aspects such as locating composting facilities, separation distances, process and operational controls to minimise odour issues. Guidance documents from other states provide examples which may be considered, but the guidance should be tailored to Queensland context, be risk-based and allow a degree of flexibility for low risk applications.
18. To improve standards at existing facilities, industry seems open to measures to lift operational standards and knowledge levels. However, commercial competition means that measures such as voluntary codes of practice are unlikely to be developed by industry in isolation and may not be universally adopted. Government may have a role to play in leading and facilitating the collaborative development of minimum standards and training requirements. Consideration would need to be given as to how to incentivise existing operators to comply with the standards, if not regulatory.

8.1.3 Assessing odour from composting facilities

The Phase 1 report presented extensive information about different odour assessment and measurement techniques. It is apparent that some composters have rather limited technical understanding of how odours are caused and dispersed in the atmosphere, and it seems that the use of odour modelling and other tools to inform that understanding for their specific site, is limited. As such, the project team recommends more robust assessment and analysis of odour sources and dispersion mechanics, including the use of modelling and sampling where appropriate, but also training and development of industry knowledge on these aspects.

19. For any new proposed composting facilities, an odour impact assessment should be undertaken as part of the site's environmental and development approval processes. The assessment may vary depending on the risk posed by the scale, feedstocks and location but would generally include the following components:

    - An assessment of background odour in the existing environment. The assessment should include all sources of odour emissions from other existing activities in the local area with specific attention given to activities that may generate odours of a similar character or degree of offensiveness. This is to understand the current odour situation in the area, the frequency of potential odour episodes and the likelihood that the community is sensitised to odour or not. It is not for inclusion as background odour concentrations for use in an odour dispersion model unless the odour is deemed to be similar in character or from a sources at a similar activity, e.g., a proposed composting facility is located near an existing composting facility, landfill, waste transfer station, wastewater treatment plant or other activity where similar volatile sulphur and organic compounds may be released.

    - A representative odour dispersion model should be developed to assess the odour footprint of facility operations under all site-specific operating and meteorological conditions. The model should adequately represent the important features of the region's topography, land surface characteristics, and sensitive receptor locations and density.

20. For higher risk facilities, once it is approved and commences operation, an odour emissions audit should be conducted to develop a representative odour emissions inventory of the site's operations. A representative number of samples from each emission source should be collected and analysed by the methods prescribed in the Australian standards e.g., AS4323.3 and AS4323.4, to suitably assess the site's odour footprint. Further details of odour sampling, testing and assessment techniques are provided in the EPAQ (1997) and EPA (2006). Notwithstanding the guidance provided in these standards, consideration should be given in sampling device selection to the conditions, chemical mass transfer properties and diffusion mechanisms taking place at the surface of each odour source being sampled to ensure worst case emissions are captured for analysis.

    Once operational data is collected, it can be fed back into the site odour dispersion model (developed for the facility's environmental approvals) to calibrate and refine the model. The odour impact assessment can then be reviewed to evaluate whether the facility is likely to comply with the conditions under which it was approved, or whether further control measures may be warranted to ensure ongoing compliance. The calibrated dispersion model will then be a valuable tool for the operator to understand how their operation can impact on sensitive receptors under different conditions.

    The performance of the odour dispersion model generated for the actual operating conditions could be evaluated and verified through a series of field ambient odour assessments. A minimum of ten field odour surveys in a period of 30 days should be conducted at different times of the day and in different meteorological conditions. This assessment could be repeated at least once during a different season within the first year of operation. Selection of seasons should be informed by dispersion model results and consider the following:

    - Times of the year when winds are most likely to blow emissions towards key identified sensitive receptor areas,

- Peak odour emissions (e.g. potentially summer time) when ambient and compost temperatures are likely to be at their maximum, thereby generating peak odour emissions. This may also coincide with the period when compost material volumes are at their peak.
- Worst case dispersion conditions (e.g. winter time), particularly at night and around sunrise and sunset, but not limited to these times, and elevated ground-level odour concentrations.

An odour impact assessment technical report of these studies should be prepared by a suitably qualified and experienced person. This level of odour assessment will not be required for all facilities and is not directed at facilities that are demonstrably at low risk of impacting on sensitive receptors.

21. For an existing composting facility that has been the subject of a certain number of complaints (to be determined by the regulator) from the community related to offensive odours that may cause nuisance, the proponent of the facility should be required to conduct an odour impact assessment of its operations. The assessment should include, but not be limited to:
    - An odour emissions audit, with sampling and measurement by the methods prescribed in the Australian standards e.g., AS4323.3 and AS4323.4. The results of the audit should be compiled into an emissions inventory for comparison with the inventory developed after the facility's approval.
    - An odour impact assessment report should be prepared which considers the likely contribution from all sources including:
        - d. all phases of processing (e.g. pre-treatment, decomposition, aeration and maturation),
        - e. raw organics and organic products managed at the premises, including impacts during receipt and storage (i.e. including stockpiling of organics),
        - f. movement of raw organics and organic products at and to/from the premises.
    - An odour dispersion model may be a useful tool to understand the interactions and contributions of different sources / activities. Field ambient odour surveys should be conducted to evaluate odour model performance and provide an actual assessment of odour experienced in the surrounding area.
    - Consideration may also be given to ongoing and routine field ambient odour assessment surveys as an odour management tool. Surveys should be conducted by suitably trained and qualified odour assessors, and preferably independent of the occupier's organisation. Should staff from the occupier's organisation conduct these surveys, they should not be plant operators that spend their time on the site and are desensitised to the odours released. These surveys should be recorded and documented appropriately in order for the regulator to assess compliance upon request.
22. For all facilities, operators should undertake an odour audit or odour balance study, which can be a useful exercise to identify and quantify odour emissions from each stage of the process, resulting in an odour emissions inventory for the site. The sophistication and level of detail of such a study will vary for each site in accordance with the scale or the operation and risk profile (function of waste types, process, proximity to sensitive receptors). It is worth noting the receival area and curing piles can be major odour sources which should not be overlooked, in addition to the mixing and composting stages.
23. Ongoing environmental management of existing and future composting facilities may include, but not be limited to:
    - A site-specific odour management plan, the purpose of which is to identify odour sources and proactively reduce the potential for odour generation as well as to have a reactive plan for managing odour during upset conditions. The complexity of the plan should match the risk posed by the operation but a typical odour management plan may include the following:
        - a. An inventory of all sources of odour,
        - b. Odour sources and controls under normal conditions,

c. Odour monitoring and recording regime,
d. Odour management during upset conditions, and
e. Routine maintenance of odour control equipment (where installed).

- Site-specific meteorological data should be collected and recorded in accordance with the Australian standard AS3580.14 (2014) and EPA NSW (2016). The establishment of meteorological stations at all higher risk composting and related organics processing facilities should be encouraged to help verify odour complaints and evaluate or enhance dispersion model performance. The meteorological monitoring station should be maintained in good working order. Meteorological stations installed at composting and related organics processing facilities should, where practicable, continuously measure and electronically log the following parameters, at a minimum, in accordance with the Australian standard AS3580.14 (2014):
  g. Wind speed at 10 metres (m/s),
  h. Wind direction at 10 metres (°),
  i. Ambient temperature at two levels (2 metres and 10 metres) (°C),
  j. Parameters needed to determine the Pasquill-Gifford stability class—that is, either sigma theta (°) or solar radiation (W/m2).
- All complaints reported to the occupier regarding odour must be considered in the light of meteorological data and/or site activities such as delivery of unusual organics to identify any correlations.

8.2 Contamination Recommendations

A number of recommendations are made to reduce the risk of compost product contamination, primarily by better managing and regulating feedstocks used in composting. The recommendations are set out below.

8.2.1 Composition data and feedstock characterisation

24. The initial contaminant risk assessment has identified 32 feedstocks considered to pose a high risk and 16 ranked as very high risk of leading to contaminants in compost products. Where there is reasonable confidence in the composition of the feedstocks and a high or very high rating is still applied (contamination category 1 materials), these should generally be banned from composting. In many cases though, the high ranking is partly due to uncertainty in composition so could potentially be reduced with better compositional data. The onus should generally be on operators to undertake sufficient analysis to demonstrate that the risk profile of their feedstocks is acceptable.
25. The lack of detailed data on feedstock composition has been a significant barrier in this study and more broadly in understanding and quantifying the scale of the issues. DES should establish a database of feedstock compositional analyses, by collecting data through a number of means such as:
    a. For common and consistently used feedstocks, DES could undertake sampling and analysis and make data available to industry
    b. For less common or more variable feedstocks, require operators to undertake regular sampling and analysis
    c. DES could require operators that need to analyse and characterise feedstocks to satisfy EA conditions, to regularly submit that data to supplement a non-published database.
26. Better analysis and data collection by industry is also needed to characterise and risk assess their own feedstocks, but DES could provide a framework and clear guidance on how to do this.

27. In general, composters should not be accepting wastes which are of unknown origin or composition. Where the composition of a waste is not known, it should conservatively be considered high risk until shown otherwise. If the waste generator or transporter fails to provide this information, there should be a clear mandate for the operator to reject the material and measures to restrict other operators then accepting it.

28. Likewise, it would be advantageous if compost quality data, differentiated into product types (feedstock, end-use based) was collated centrally by industry or a quality assurance organisation, and made available as collated anonymous information for public-interest interrogation.

29. The government should allow an adequate transition period for any regulatory changes which will divert materials away from composting, where there may be a need for industry to develop new infrastructure, to prevent perverse disposal outcomes and worsened environmental outcomes.

30. It would be beneficial to have a standard list of feedstock names which provide a more accurate and descriptive picture of the material, including the source industry or sector and accompanied by a short statement regarding source and composition of each feedstock. This is an important piece of information to record as it will assist in guiding management decisions on the assessment of new feedstocks, and consistency in terminology used across industry will aid in ensuring that incoming feedstocks are classified in a consistent manner upon receipt at composting facilities and that risks are better understood.

31. Further work is also needed to collate data on organic contaminants (and other characteristics) in compost products from a wide variety of sources to establish what proportion of products exceed the AS4454/ Biosolids limits, and which compounds are causing issues. Without sufficient data, it is impossible to have an informed discussion and to make informed decisions.

32. Further investigation is needed to evaluate the risks associated with new ‘emerging’ chemicals of interest, especially PFOS/PFAS. An approach similar to that used by Clarke and Smith (2011) as referenced in this report would be highly valuable, in which emerging contaminants were scored on certain criteria in order to prioritise for further research. This research could be used to reset the proposed suite of Organic Chemicals to be tested. This list may vary a little depending on the waste being composted.

33. Further investigation is needed to assess whether elevated TPH and TRH levels found in the finished compost samples collected by DES in 2017 are widespread and common, and what the specific hydrocarbons are and where they came from. TPH and TRH have been detected in common feedstocks including green waste and grease-trap waste but these do not fully account for the levels detected in finished compost products and the fact that most volatile hydrocarbons are readily biodegradable in a composting process. It is possible that compounds are being formed during the composting process, which are being detected in the TPH / TRH tests, but this needs to be confirmed.

34. There is also a need for improved management procedures for tracking, assessing, and managing contamination risks, which may include:

    - Procedural improvements – develop templated forms and record keeping requirements, including forms to document feedstock sources, volumes, testing done, etc.
    - Procedural improvements – require improved record keeping of composting processes, to ensure biological hazards are being managed (i.e. pasteurisation requirements)
    - Improved guidance on analytical requirements – to be developed following further data collection on current feedstocks.

8.2.2 Regulation of contaminants

35. As with odour regulation, DES should investigate options to harmonise and reduce the inconsistency in EA conditions relating to the management of contamination in feedstocks and compost products. The main focus should be on achieving consistency and there is a case for

more prescriptive conditions to regulate some aspects, such as feedstock characterisation, risk assessment and product testing.

36. There is a strong need to restore consumer confidence in the quality of compost products in the Queensland market and in the ingredients used in composting. Feedstocks which have been rated as high or very high risk of causing product contamination need to be further investigated and characterised to confirm the risk and then consideration given to whether they are appropriate feedstocks, or whether the risks can be adequately controlled with management and regulatory measures.

37. The government should consider whether feedstocks which are confirmed as high or very high risk in terms of contamination, including those processed under ERA’s 55 and 58, should be processed in physically separate composting facilities, or indeed whether other treatment technologies are more appropriate. The combining of ERA 53 composting with ERA 55 activities, and in some cases ERA 58, seems to add to the risk of product contamination and certainly undermines consumer confidence in the product.

38. This review has considered whether there may be a case for differentiation in labelling and permitted end uses of compost products that are derived from low risk organic feedstocks (under ERA 53) versus those which incorporate higher risk feedstocks. The idea may be that only the low risk feedstocks would be permitted to be used in sensitive applications such as food production and horticulture, residential, commercial, institutions and public space landscaping. Higher risk and poorer quality products, whilst still complying with minimum standards, would then be confined to applications that minimise the likelihood and frequency of human contact or environmental impact, such as rehabilitation of mines, landfills and contaminated sites, highway verges and forestry. However, the project team has come to the view that such an approach will be difficult to implement and potentially counter-productive. It is better to aim for one final product standard, which allows use in any application (unrestricted) to avoid potential confusion in the market place. This will be much more practical to implement and enforce / monitor. Industry feedback supports this approach but further consultation with industry on this point is recommended.

39. The government should generally reconsider its current approach of allowing operators to be primarily responsible for determining which feedstocks are suitable for composting as set out in the Composting Guidelines, or at least provide much more specific guidance around assessing feedstock suitability. This approach and the exclusion of waste acceptance criteria from a number of EAs, has undoubtedly allowed the current proliferation of composting feedstocks and the apparent shift from production of beneficial soil products, to low cost treatment of waste streams.

40. Further work is needed to establish the suitability of the AS4454/ Biosolids organic contaminant limits to the current situation with respect to organic waste recycling. Most of these chemicals have been phased out for many years and studies overseas show that they are usually virtually absent in compost products. Conversely, there are numerous contaminants not included in these standards which could be relevant. The NEPM Soil Health Investigation Levels provide a more contemporary and comprehensive list of contaminants that should be considered, although the actual thresholds should be tailored to suit the application of compost to land (rather than the assessment of existing contamination, as the current HILs are designed for).

41. In regulating physical impurities, area-based assessment of impurities should be considered as a superior method (compared to weight or item number based measures) to better account for highly visible light weight impurities such as film plastics, which are likely to break down into microplastics over time.

42. End of Waste codes may provide an effective tool, with minimal regulatory change, to better regulate the contaminant risks associated with specific high risk feedstocks, or to introduce regulatory limits on compost products.

43. The requirement for some composters under their EA conditions to demonstrate that new feedstocks do not have detrimental effects on the composting process or the quality / usability of finished products is good in its intention, but potentially too loosely defined. It could be tightened and industry provided with specific guidance on how to undertake such assessments, including

analysis of contamination risks, which could result in utility and risk scores, that determine whether new feedstock enhance or detract from the composting process and the generated product.

SOURCES

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APPENDIX A

Qualitative Risk Assessment Scoring Summary

Table 54: Contamination Risk Ranking of Current Feedstocks

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Beer	Food & Food processing waste	Food waste residues from beer brewing	Pathogens	1	1	1	1	Low
Food Organics	Food & Food processing waste	Food wastes, assumed no other products such as cleaning residues etc.	None	1	1	1	1	Low
Grain Waste	Food & Food processing waste	Assumed unprocessed grains	Trace pesticides etc, but likely negligible amounts in food streams	1	1	1	1	Low
Vegetable waste	Food & Food processing waste	Food wastes, assumed no other products such as cleaning residues etc.	None	1	1	1	1	Low
Cypress chip	Plant matter	Assumed untreated wood chips	None	1	1	1	1	Low
Forest mulch	Plant matter	Assumed untreated wood product	None	1	1	1	1	Low
Green waste	Plant matter	Assumed untreated green wastes	None	1	1	1	1	Low
Pine bark	Plant matter	Assumed untreated wood product	None	1	1	1	1	Low
Lime	Earthworks waste and additives	Assumed quarry or mining waste of calcium carbonate, with no additives or industrial by-products	high pH	1	1	1	2	Low

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Sand	Earthworks waste and additives	Assumed untreated or from greenfield source	Metals	1	1	1	2	Low
Beer	Food & Food processing waste	Food waste residues from beer brewing	Pathogens	1	1	1	2	Low
Grain Waste	Food & Food processing waste	Assumed unprocessed grains	Trace pesticides etc, but likely negligible amounts in food streams	1	1	1	2	Low
Cane residues	Plant matter	Assumed unprocessed and processed sugar cane wastes	Pesticides, herbicides	1	1	1	2	Low
Animal manures, including livestock manure	Animal Matter	Animal waste only, no other products such as cleaning residues, 'sheep dip', etc.	Pathogens	1	1	1	4	Low
Animal processing waste	Animal Matter	Animal / meat waste only, no other products such as cleaning residues etc.	Pathogens	1	1	1	4	Low
Animal Waste, including egg waste and milk waste	Animal Matter	Animal waste only, no other products such as cleaning residues, etc.	Pathogens	1	1	1	4	Low

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Crusher dust	Earthworks waste and additives	By-product of quarrying or mining, assumed natural unprocessed rock with no additives	Metals	2	1	1	4	Low
Lime Slurry	Earthworks waste and additives	Assumed construction or industrial by-product, with a mix of lime, sand and water	High pH, metals or trace cross-contamination	2	1	1	4	Low
Brewery effluent	Food & Food processing waste	Food waste residues from beer brewing, assumed no contamination by cleaning products, etc.	Pathogens	2	1	1	4	Low
Food processing effluent and solids	Food & Food processing waste	Food wastes, potential for minor residues from cleaning products or other industrial processing inputs.	Detergents	2	1	1	4	Low
Food processing treatment tank or treatment pit liquids, solids or sludges	Food & Food processing waste	Food wastes, potential for minor residues from cleaning products or other industrial processing inputs.	Detergents	2	1	1	4	Low
Grease trap - treated grease trap waters and dewatered	Food & Food processing waste	Greases and food by-products from grease traps	Fatty acids, detergents, TRH / TPH	2	1	1	4	Low

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
grease trap sludge								
Grease trap waste	Food & Food processing waste	Greases and food by-products from grease traps	Fatty acids, detergents, TRH / TPH	2	1	1	4	Low
Molasses Waste	Food & Food processing waste	Waste products from sugar processing and molasses manufacture	High BOD	2	1	1	4	Low
Soft Drink Waste	Food & Food processing waste	Food manufacturing wastes, potential for minor residues from cleaning products or other industrial processing inputs	Detergents	2	1	1	4	Low
Starch Water Waste	Food & Food processing waste	Assumed food or industrial waste product with high starch content and minor residues from processing	Pathogens, others?	2	1	1	4	Low
Sugar and sugar solutions	Food & Food processing waste	Waste products from sugar processing with high sugar content and minor residues from processing	High BOD, others?	2	1	1	4	Low
Vegetable oil wastes and starches	Food & Food processing waste	Greases and food by-products from food industry	Fatty acids, detergents	2	1	1	4	Low

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Yeast Waste	Food & Food processing waste	Assumed to be beer or food manufacturing waste product	Pathogens	2	1	1	4	Low
Cement Slurry	Industrial residues	Mix of cement, sand, water and additives	Potential for small proportion to comprise unknown additives	2	1	1	4	Low
Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Plant matter	Assumed majority is untreated wood product, although some treatment residues (e.g. ACC) may be present	Metals, pesticides	2	1	1	4	Low
Tub ground mulch	Plant matter	Fine to medium mulch products, assumed majority is untreated wood product, although some treatment residues (e.g. ACC) may be present	Metals, pesticides	2	1	1	4	Low
Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs	Plant matter	Assumed to largely be untreated wood product, however inclusion of manufactured wood products (e.g. pallets) may introduce contaminants into feedstock stream	Metals, pesticides	2	1	1	4	Low

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Worm castings suitable for unrestricted use	Plant matter	Assumed to be comprised of largely organic worm castings, minor potential for some contaminants	Microplastics, metals	2	1	1	4	Low
Mushroom compost (substrate)	Plant matter	Mushroom growth medium and residues, generally comprised of straw, manure, lime/chalk, etc	Pathogens, potential pesticide residues	2	1	1	4	Low
Ammonium Nitrate	Chemical residues	Assumed pure ammonium nitrate	Ammonia, nitrate, pH, explosive / combustible	1	1	1	5	Low
Paunch material	Animal Matter	Partially digested gut contents of slaughtered animals from abattoir, consists mainly of undigested grass, hay, other feed products such as grain, and water as well as body fluids, including saliva	Pathogens	2	1	1	6	Low
Brine Water	Wastewater & washwaters	Unknown sources, assumed hyper-saline water from industrial or food processes	high pH, others?	3	1	1	6	Low
Calcium Water	Wastewater & washwaters	Unknown sources, assumed calcium containing water ('hard' water) is from industrial or food processes	high pH, others?	3	1	1	6	Low

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Abattoir waste	Animal Matter	Animal / meat waste only, with some minor potential for cleaning residues etc.	Pathogens, detergents	2	1	1	8	Medium
Tallow Waste	Animal Matter	Rendered meat fat residues or wastes	Pathogens	2	1	1	8	Medium
Fertiliser water and fertiliser washings	Chemical residues	By-product from fertiliser production, assumed no other waste materials cross-contaminate the stream.	Ammonia, nitrate, other fertilisers, pH, explosive / combustible	2	1	1	8	Medium
Dewatered fertiliser sludge	Chemical residues	By-product from fertiliser production, assumed no other waste materials cross-contaminate the stream.	Ammonia, nitrate, other fertilisers, pH, potentially explosive / combustible	2	1	1	10	Medium
Pot ash	Chemical residues	Potassium compounds, most commonly used as a fertilizer but also used in industry. Unknown whether pot ash feedstock is from the manufacture of pot ash or includes by-products from industrial uses.	Unknown	2	1	2	12	Medium

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Soil	Earthworks waste and additives	Unknown sources, potentially contaminated?	Metals, asbestos, TRH, others?	2	1	2	16	Medium
Acid Sulphate Sludge	Earthworks waste and additives	Naturally generated from ASS	low pH, sulphates, metals	3	1	2	18	Medium
Wood molasses	Industrial residues	Waste products from wood processing to manufacture molasses	Potential PAHs / hydrocarbons, VOCs, high BOD, low pH	3	1	2	18	Medium
Amorphous silica sludge	Industrial residues	Concrete additive made from silica	Silica, metals	3	1	1	18	Medium
Waterbased glue	Industrial residues	Potentially undiluted glue comprised of polymers and solvents	VOCs, solvents, PVA (or other polymers such as latex)	3	1	2	18	Medium
Coolant Waste	Industrial residues	Waste water with coolant, by-product from industry or small scale mechanics.	TRH, anti-freeze (e.g. ethylene glycol), metals	3	1	2	18	Medium
Polymer Water	Industrial residues	Unknown. Potentially associated with coagulants added to process water	VOCs, others?	3	1	2	18	Medium
Ash	Industrial residues	Industrial by-product (e.g. coal power generation), may be wood, coal, or other sources of ash	PAHs, TRH, metals, VOCs, high pH	2	1	3	18	Medium

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Coal ash	Industrial residues	Industrial by-product (e.g. coal power generation)	PAHs, TRH, metals, VOCs, high pH	2	1	3	18	Medium
Fly ash	Industrial residues	Industrial by-product (e.g. coal power generation), may be wood, coal, or other sources of ash.	PAHs, TRH, metals, VOCs, high pH	2	1	3	18	Medium
Soapy water	Wastewater & washwaters	Unknown	Unknown, likely detergents, oils, low concentrations of other residues, etc.	3	1	2	18	Medium
Ground Water	Wastewater & washwaters	Unknown source or composition	Unknown	3	1	2	18	Medium
Low level organically contaminated stormwaters or groundwaters	Wastewater & washwaters	Unknown source or composition	Unknown	3	1	2	18	Medium
Bentonite	Earthworks waste and additives	Mined clay waste, no other products from use of bentonite (e.g. drilling fluids).	Metals	2	1	2	24	Medium
Mud and Dirt Waste	Earthworks waste and additives	Unknown sources, potentially contaminated	Metals, PFAS, others?	3	1	2	24	Medium

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Quarantine waste treated by an AQIS approved facility	Food & Food processing waste	Assumed to be food and organic material treated by irradiation or similar. May include chemical additives, treatment chemicals, or unknown materials.	Pesticides, herbicides, others?	2	1	2	24	Medium
Abrasive blasting sand (excluding heavy metal contaminated sands)	Industrial residues	Industry waste from sand blasting, may contain traces of paint etc from sand blasting process	Silica, metals, trace paints	2	1	2	24	Medium
Compostable PLA plastics	Industrial residues	Plastics made from plant products such as corn starch	Microplastics, dyes, VOCs, additives	2	1	2	24	Medium
Paper mulch	Industrial residues	Assumed solid paper wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	Metals, dyes, dioxins, VOCs, others?	2	1	2	24	Medium
Paper pulp effluent	Industrial residues	Assumed mix of solid and liquid paper wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	Metals, dyes, dioxins, VOCs, others?	2	1	2	24	Medium

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Paper sludge dewatered	Industrial residues	Assumed solid paper wastes from paper manufacturing, potentially containing dyes, solvents and chemical residues	Metals, dyes, dioxins, VOCs, others?	2	1	2	24	Medium
Plaster board	Industrial residues	Assumed to be comprised of gypsum with potential for multiple additives - plasticisers, fire retardants, water repellents, 'foaming agents', etc.	VOCs, phthalates, PFAS, emerging contaminants, others?	2	1	2	24	Medium
Natural textiles	Plant matter	Assumed by-product of fabric manufacturing, including wool, cotton, bamboo, etc.	Pathogens, metals, dyes, dioxins (from bleaching), others?	2	1	2	24	Medium
GPT Waste	Plant matter	Gross pollutant trap wastes, including rubbish, leaf litter, stormwater runoff, etc, assumed that wastes such as plastics are mechanically removed prior to composting.	TRH, metals, microplastics, others?	2	1	2	24	Medium
Mill mud	Plant matter	Mix of mud and ash from sugar can processing	Metals, high pH, PAHs	2	1	2	24	Medium
Muddy Water	Wastewater & washwaters	Unknown sources, potentially contaminated	Metals, PFAS, others?	3	1	2	24	Medium

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Soil treated by indirect thermal desorption	Earthworks waste and additives	Assumed that soils were contaminated prior to thermal desorption treatment	Metals, PFAS, asbestos, others?	3	1	2	36	High
Drilling Mud / Slurry (Coal Seam Gas)	Earthworks waste and additives	Drilling fluids, may contain surfactants or other additives	Metals, TRH, surfactants	3	1	2	36	High
Bauxite sludge	Industrial residues	Alumina refinery by-product	Metals, high pH	3	1	2	36	High
Water blasting washwaters	Industrial residues	Assumed dilute concentration contaminants may be present from cleaning ('water blasting') process	Metals, TRH, PAHs, solvents, others?	3	1	2	36	High
Carbon Pellets	Industrial residues	Unknown source - may be spent or unused pellets from a range of sources or industries	TRH, PAH, metals, VOCs, contaminants (if spent)	3	1	2	36	High
Paint Wash	Industrial residues	Assumed wash down water with some paint residues, potentially with solvents, surfactants, oils, etc.	Metals, dyes, TRH, VOCs, others?	3	1	2	36	High

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Total Petroleum Hydrocarbon Water	Industrial residues	Assumed run-off from hard surfaces, or industrial waste water, with potential for other contaminants to be present	TRH, PAHs, metals, VOCs, others?	3	1	2	36	High
Waterbased Lacquer Waste	Industrial residues	Waste liquid lacquers from manufacture or use, potentially undiluted	VOCs, solvents, metals, polymers	3	1	2	36	High
Latex Washing	Wastewater & washwaters	Rubber and ash from sugar canelatex processing	Latex, detergents, others?	3	1	2	36	High
Sullage waste (greywater)	Wastewater & washwaters	Wastewater from domestic or commercial buildings excluding sewage, includes waters drained in showers, sinks, laundries, etc.	Detergents, surfactants, oils, pharmaceuticals, pathogens, others?	3	1	2	36	High
Bilge waters	Wastewater & washwaters	Sea and fresh water from ship pump outs, may contain oil, sludge and other chemicals.	TRH, PAHs, antifoulants, metals, VOCs, emerging contaminants	3	1	2	36	High
Boiler blow down water	Wastewater & washwaters	Waste water from boilers to remove suspended solids, scale, contaminants, etc.	Metals, TRH, VOCs, treatment chemicals, others	3	1	2	36	High
Car Wash Mud & Sludge	Wastewater & washwaters	Waste slurry captured in drains at car washes	TRH, PAHs, VOCs, detergents, exhaust residues	3	1	2	36	High

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Oily Water	Wastewater & washwaters	Assumed run-off from forecourts or hard surfaces, with water collected from areas with high potential for oils	TRH, PAHs, metals, VOCs, others?	3	1	2	36	High
Stormwater Waste	Wastewater & washwaters	Assumed run-off from roads and hard surfaces, with water potentially collected from areas with high potential for oils or wastes	TRH, PAHs, metals, VOCs, others?	3	1	2	36	High
Vehicle wash down waters	Wastewater & washwaters	Waters collected at car wash facilities	TRH, PAHs, metals, VOCs, detergents, exhaust residues	3	1	2	36	High
Wash Bay Water	Wastewater & washwaters	Waters collected at wash down areas	TRH, PAHs, VOCs, detergents, exhaust residues	3	1	2	36	High
Carpet cleaning washwaters	Wastewater & washwaters	Wastewater from domestic and commercial carpet cleaning	Surfactants, detergents, PFAS, dyes, others?	3	1	2	36	High
Dye Waste (water based)	Industrial residues	By-product from industrial dying processes.	Pigments, detergents, surfactants, metals, VOCs, fixing agents (formaldehyde), others?	3	1	2	48	High
Water based inks	Industrial residues	Assumed liquid wastes from ink use or manufacture	Metals, VOCs, solvents, others?	3	1	2	48	High

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Forecourt Water	Wastewater & washwaters	Run off from service station forecourts	TRH, metals, PAHs	3	1	2	48	High
Organics extracted from mixed household waste / MSW	Food & Food processing waste	Assumed similar to NSW 'MWOO' grade waste stream, which studies showed can contain contaminants	Metals, microplastics, PFAS, pharmaceuticals, emerging contaminants, others?	3	1	3	72	High
Foundry sands	Industrial residues	Sand used in foundry mouldings, stabilised with phenol compounds	Heavy metals, phenols	2	2	3	72	High
Biosolids	Sewage & STP residues	Sewerage and treatment plant residues.	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	3	2	2	72	High
Nightsoil	Sewage & STP residues	Sewerage and treatment plant residues	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	3	2	2	72	High
Sewage sludge	Sewage & STP residues	Sewerage and treatment plant residues	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	3	2	2	72	High
Sewage treatment tank or treatment pit liquids,	Sewage & STP residues	Sewerage and treatment plant residues	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	3	2	2	72	High

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
solids or sludges								
Septic wastes	Sewage & STP residues	Sewerage and treatment plant residues	Pathogens, metals, pharmaceuticals, microplastics, potential emerging contaminants	3	2	2	72	High
Activated sludge and lime sludge from wastewater treatment plants	Sewage & STP residues	Waste material from WTPs, known to commonly be contaminated	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	3	2	2	72	High
Hide curing effluent	Animal Matter	Effluent and wastes from tanneries	Chromium, metals, pathogens, low pH, dyes, others?	3	1	3	90	Very High
Filter cake and presses	Industrial residues	Concentrated waste streams from water treatment in a filter press	Unknown, could contain a large number of toxins, such as metals, PFAS, microplastics, emerging contaminants, etc.	3	1	3	90	Very High
Water based paints	Industrial residues	Assumed liquid waste paint, potentially undiluted	Metals, VOCs, solvents, others?	3	1	3	90	Very High

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Filter/ion exchange resin backwash waters	Industrial residues	Concentrated waste streams from water treatment using exchange resins	Unknown, could contain a large number of toxins, such as metals, PFAS, microplastics, emerging contaminants, etc.	3	1	3	90	Very High
Waste Water	Wastewater & washwaters	Unknown	Unknown	3	1	3	90	Very High
Leachate Waste	Wastewater & washwaters	Landfill leachate, potentially contains complex mix of contaminants	Ammonia, sulphides, pathogens, metals, PFAS, pharmaceuticals, potential emerging contaminants	3	1	3	90	Very High
Treated timber waste	Industrial residues	Timber treated with either CCA, ACQ, CuAz or other chemical treatment	Heavy metals (copper, chrome, arsenic), creasote, organic solvents, boron, methyl bromide	3	1	4	96	Very High
Treatment tank sludges and residues	Wastewater & washwaters	Unknown, potentially highly variable industrial wastes	Unknown	3	2	3	144	Very High
Process Fluid	Industrial residues	Unknown	Unknown	3	2	3	180	Very High
Effluent Waste	Wastewater & washwaters	Assumed to comprise either industrial or domestic effluent streams	Pathogens, metals, PFAS, pharmaceuticals, microplastics, potential emerging contaminants	3	2	3	180	Very High

Feedstock	Type	Assumed Composition	Assumed Contaminants	Uncertainty regarding composition	Degrades to toxic daughter compound?	Hazard Score of Composted Feedstock	Risk Ranking Score	Risk Rating
Leachate Waste	Wastewater & washwaters	Landfill leachate, potentially contains complex mix of contaminants	Ammonia, sulphides, pathogens, metals, PFAS, pharmaceuticals, potential emerging contaminants	2	5	2	20	Very High
Waste Water	Wastewater & washwaters	Unknown	Unknown	2	5	2	20	Very High

Table 55: Odour Contribution Potential Risk Ranking of Current Feedstocks

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Abrasive blasting sand (excluding heavy metal contaminated sands)	Industrial residues	- none, assumed inert	0	1	1	1	1	0	None
Ash	Industrial residues	- none, inert	0	1	1	1	1	0	None
Boiler blow down water	Wastewater & washwaters	- none, inert	0	1	1	1	1	0	None
Brine Water	Wastewater & washwaters	- assume no organic content, so minimal	0	1	1	1	1	0	None
Calcium Water	Wastewater & washwaters	- assume no organic content, so minimal	0	1	1	1	1	0	None
Cement Slurry	Industrial residues	- none, inert	0	1	1	1	1	0	None
Coal ash	Industrial residues	- none, inert	0	1	1	1	1	0	None
Dye Waste (water based)	Industrial residues	- assume none	0	1	1	1	1	0	None
Fly ash	Industrial residues	- none, inert	0	1	1	1	1	0	None

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Ground Water	Wastewater & washwaters	- unknown content, but should be inert	0	1	1	1	1	0	None
Lime Slurry	Earthworks waste and additives	- none, inert	0	1	1	1	1	0	None
Mud and Dirt Waste	Earthworks waste and additives	- assume inert, none	0	1	1	1	1	0	None
Muddy Water	Wastewater & washwaters	- assume inert, none	0	1	1	1	1	0	None
Natural textiles	Plant matter	- assume dry and stable	0	1	1	1	1	0	None
Pot ash	Chemical residues	- Minimal	0	1	1	1	1	0	None
Soil treated by indirect thermal desorption	Earthworks waste and additives	- assume inert	0	1	1	1	1	0	None
Water based inks	Industrial residues	- assume none	0	1	1	1	1	0	None
Water based paints	Industrial residues	- assume none	0	1	1	1	1	0	None
Waterbased glue	Industrial residues	- assume none	0	1	1	1	1	0	None
Waterbased Lacquer Waste	Industrial residues	- assume none	0	1	1	1	1	0	None

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Amorphous silica sludge	Industrial residues	- none, assumed inert	0	1	1	1	1	0	None
Bauxite sludge	Industrial residues	- none, in	0	1	1	1	1	0	None
Bentonite	Earthworks waste and additives	- none, inert	0	1	1	1	1	0	None
Crusher dust	Earthworks waste and additives	- none, inert	0	1	1	1	1	0	None
Lime	Earthworks waste and additives	- none, inert	0	2	1	1	1	0	None
Sand	Earthworks waste and additives	- none, inert	0	1	1	1	1	0	None
Soil	Earthworks waste and additives	- assume inert	0	1	1	1	1	0	None
Foundry sands	Industrial residues	- dry, low or no organics / nutrients	0	1	1	1	1	0	None
Cane residues	Plant matter	- high carbon	1	1	1	1	1	3	Low
Grain Waste	Food & Food processing waste	- assume dry, high carbon - potentially fermented?	1	1	1	1	1	3	Low

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Cypress chip	Plant matter	- high carbon	1	1	1	1	1	3	Low
Forest mulch	Plant matter	- high carbon	1	1	1	1	1	3	Low
Pine bark	Plant matter	- high carbon	1	1	1	1	1	3	Low
Sawmill residues (inc. sawdust, bark, wood chip, shavings etc.)	Plant matter	- high carbon	1	1	1	1	1	3	Low
Wood chip	Plant matter	- high carbon	1	1	1	1	1	3	Low
Wood waste (excluding chemically treated timber) including pallets, offcuts, boards, stumps and logs	Plant matter	- high carbon	1	1	1	1	1	3	Low
Car Wash Mud & Sludge	Wastewater & washwaters	- assume low	1	1	1	1	1	3	Low
Carbon Pellets	Industrial residues	- assume dry and stable, so low but depends on usage	1	1	1	1	1	3	Low

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Compostable PLA plastics	Industrial residues	- none, assumed inert	1	1	1	1	1	3	Low
Coolant Waste	Industrial residues	- volatile alcohols	1	1	1	1	1	3	Low
Forecourt Water	Wastewater & washwaters	- VOCs / light hydrocarbons - likely very dilute	1	1	1	1	1	3	Low
Latex Washing	Wastewater & washwaters	- assume dilute, natural rubber	1	1	1	1	1	3	Low
Low level organically contaminated stormwaters or groundwaters	Wastewater & washwaters	- unknown content, but should be inert	1	1	1	1	1	3	Low
Oily Water	Wastewater & washwaters	- VOCs / hydrocarbons	1	1	1	1	1	3	Low
Paint Wash	Industrial residues	- minimal assuming water based	1	1	1	1	1	3	Low
Paper mulch	Industrial residues	- high carbon content, assume relatively dry	1	1	1	1	1	3	Low
Polymer Water	Industrial residues	- unknown content / source	1	1	1	1	1	3	Low

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Process Fluid	Industrial residues	- unknown content / source	1	1	1	1	1	3	Low
Soapy water	Wastewater & washwaters	- assume low	1	1	1	1	1	3	Low
Stormwater Waste	Wastewater & washwaters	- unknown content / source	1	1	1	1	1	3	Low
Vehicle wash down waters	Wastewater & washwaters	- unknown content / source	1	1	1	1	1	3	Low
Wash Bay Water	Wastewater & washwaters	- unknown content / source	1	1	1	1	1	3	Low
Water blasting washwaters	Industrial residues	- unknown content / source	1	1	1	1	1	3	Low
Carpet cleaning washwaters	Wastewater & washwaters	- VOCs, high pH	1	1	1	1	1	3	Low
Treated timber waste	Industrial residues	- dry, high carbon	1	1	1	1	1	3	Low
Worm castings suitable for unrestricted use	Plant matter	- assume mostly matured	1	1	2	1	1	4	Low
Bilge waters	Wastewater & washwaters	- potential hydrocarbon / oil vapours	1	1	1	1	2	4	Low

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Drilling Mud / Slurry (Coal Seam Gas)	Earthworks waste and additives	- assume inert - some may contain sulphate compounds although the draft EoW requires drill muds to be free from detectable offensive odours	1	1	1	2	1	4	Low
Fertiliser water and fertiliser washings	Chemical residues	- may contain volatile ammonia, assume dilute	1	1	3	1	1	5	Low
Filter/ion exchange resin backwash waters	Industrial residues	- unknown composition / source - assume organic content	1	1	2	2	1	5	Low
Total Petroleum Hydrocarbon Water	Industrial residues	- VOCs / light hydrocarbons	1	1	1	1	3	5	Low
Soft Drink Waste	Food & Food processing waste	- assume high sugar content	2	1	1	1	1	6	Low
Sugar and sugar solutions	Food & Food processing waste	- assume high sugar content	2	1	1	1	1	6	Low
Starch Water Waste	Food & Food processing waste	- high starch / sugar content	2	1	1	1	1	6	Low
Sullage waste (greywater)	Wastewater & washwaters	- may contain food / organics - potentiall anaerobic on arrival	2	1	1	1	1	6	Low

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Green waste	Plant matter	- moisture content will vary - potentially moderate nitrogen (grass) - depends on age / storage	2	1	2	1	1	8	Medium
Tub ground mulch	Plant matter	- high carbon	2	1	2	1	1	8	Medium
Beer	Food & Food processing waste	- wet, potentially anaerobic?	2	1	2	1	1	8	Medium
Brewery effluent	Food & Food processing waste	- wet, potentially anaerobic?	2	1	2	1	1	8	Medium
Mushroom compost (substrate)	Plant matter	- assume composted but not mature - composting odours	2	1	2	1	1	8	Medium
Vegetable waste	Food & Food processing waste	- high nitrogen / moisture	2	1	2	1	1	8	Medium
GPT Waste	Plant matter	- mostly vegetation and sludge, wet	2	1	2	1	1	8	Medium

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Mill mud	Plant matter	- organic / sugar content - moderate nutrient content	1	2	2	1	1	8	Medium
Waste Water	Wastewater & washwaters	- unknown content / source - could contain organic waste / anaerobic	2	1	2	1	1	8	Medium
Molasses Waste	Food & Food processing waste	- highly biodegradable - potentially anaerobic on arrival?	3	1	1	1	1	9	Medium
Effluent Waste	Wastewater & washwaters	- unknown composition / source	2	1	2	2	1	10	Medium
Vegetable oil wastes and starches	Food & Food processing waste	- high carbon - wet, could be anaerobic on arrival	2	1	1	1	3	10	Medium
Filter cake and presses	Industrial residues	- unknown composition / source - assume organic content	1	2	2	2	1	10	Medium
Paper pulp effluent	Industrial residues	- depends on process - may contains sulphate, chlorine?	2	1	2	2	1	10	Medium

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Paper sludge dewatered	Industrial residues	- depends on process - assume mostly fibres - may contains sulphate, chlorine?	1	2	2	2	1	10	Medium
Plaster board	Industrial residues	- sulphate content	1	2	1	3	1	10	Medium
Gypsum	Earthworks waste and additives	- sulphate content	1	2	1	3	1	10	Medium
Dewatered fertiliser sludge	Chemical residues	- unknown composition, may contain volatile ammonia	1	3	3	1	1	15	High
Acid Sulphate Sludge	Earthworks waste and additives	- sulphide content	1	3	1	3	1	15	High
Ammonium Nitrate	Chemical residues	- soluble ammonium form - potential release of ammonia vapour - very concentrated form of nitrogen	1	3	3	1	1	15	High
Wood molasses	Industrial residues	- potential VOCs / ammonia, acidic	2	2	2	1	1	16	High
Yeast Waste	Food & Food processing waste	- fermented, yeast odour - potentially anaerobic	2	2	2	1	1	16	High
Animal manures, including livestock manure	Animal Matter	- wet and high nitrogen content - potentially anaerobic on arrival	3	1	3	1	2	18	High

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Food Organics	Food & Food processing waste	- may contain meat / fat - high moisture / nitrogen - likely anaerobic on arrival	3	1	2	2	2	18	High
Food processing effluent and solids	Food & Food processing waste	- wet / high nitrogen - likely anaerobic on arrival	3	1	3	1	2	18	High
Quarantine waste treated by an AQIS approved facility	Food & Food processing waste	- potentially contains meat / food	3	1	2	2	2	18	High
Treatment tank sludges and residues	Wastewater & washwaters	- unknown content / source - could be high organics / anaerobic	2	2	2	2	1	20	High
Paunch material	Animal Matter	- partially digested / fermented grass - likely anaerobic on arrival	3	2	3	1	1	30	High
Activated sludge and lime sludge from wastewater treatment plants	Sewage & STP residues	- biomass from sewage treatment - wet and likely anaerobic on arrival	3	2	3	1	1	30	High
Biosolids	Sewage & STP residues	- high moisture and nitrogen content - potentially anaerobic depending on storage	3	2	3	1	1	30	High
Food processing treatment tank or	Food & Food processing waste	- wet / high nitrogen - likely anaerobic on arrival	3	2	3	1	1	30	High

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
treatment pit liquids, solids or sludges									
Organics extracted from mixed household waste / MSW	Food & Food processing waste	- may contain meat / fat - high moisture / nitrogen - likely anaerobic on arrival	3	2	3	1	2	36	Very high
Leachate Waste	Wastewater & washwaters	- likely high ammonia, sulphides, methane - will be anaerobic	3	2	3	3	1	42	Very high
Abattoir waste	Animal Matter	- decomposing meat and fat content, high protein - wet and potentially anaerobic on arrival	3	2	3	1	3	42	Very high
Animal processing waste	Animal Matter	- wet and high nitrogen content - decomposing meat / fat content, high protein - potentially anaerobic on arrival	3	2	3	1	3	42	Very high
Hide curing effluent	Animal Matter	- decomposing meat and fat content, high protein - potentially anaerobic on arrival	3	2	3	1	3	42	Very high
Tallow Waste	Animal Matter	- high fat and protein content - likely anaerobic on arrival	3	2	3	1	3	42	Very high

Feedstock	Type	Odour Factors	Putrescible	Concentrated form	Nitrogen content	Sulfur content	Fat, oil, protein content	Risk score	Risk Rating
Nightsoil	Sewage & STP residues	- from sewage / septic tanks - high organic / nitorgen content - likely anaerobic	3	2	3	2	2	42	Very high
Septic wastes	Sewage & STP residues	- from sewage / septic tanks - high organic / nitrogen content - likely anaerobic	3	2	3	2	2	42	Very high
Sewage sludge	Sewage & STP residues	- from sewage treatment - high organic / nitrogen content - likely anaerobic	3	2	3	2	2	42	Very high
Sewage treatment tank or treatment pit liquids, solids or sludges	Sewage & STP residues	- from sewage treatment - high organic / nitrogen content - likely anaerobic	3	2	3	2	2	42	Very high
Grease trap - treated grease trap waters and dewatered grease trap sludge	Food & Food processing waste	- wet, food and grease content - likely anaerobic on arrival	3	2	3	1	3	42	Very High
Grease trap waste	Food & Food processing waste	- wet, food and grease content - likely anaerobic on arrival	3	2	3	1	3	42	Very High
Animal Waste, including egg waste and milk waste	Animal Matter	- high fat and protein content -wet and likely anaerobic on arrival	3	2	3	2	3	48	Very high

APPENDIX B

Specific feedstock contaminant risk assessment template

Composting Feedstock Contaminant Risk Assessment

Feedstock material:	**Green waste**
Proportion in the compost mix (dry wt)	**70%**
Is the feedstock homogenous	Yes
Degree or variability in composition	Moderate
Proposed end use	Unrestricted

Components beneficial to compost:	
Contains degradable carbon?	Yes
Contains nitrogen?	Yes
Contains other macro-nutrients (potassium, phosporous)?	Yes
Contains beneficial metals / trace elements (e.g. copper, zinc, iron, nickel)?	Yes
Will add structure / porosity?	Yes

The operator should undertake sufficient sampling to fully characterise the full range of variability of the feedstock, including any seasonal effects

This assessment only calculates the contribution of each individual feedstock. Contributions from other feedstocks in the mix need to be summed together to estimate the final product concentration

		Raw material concentrations			**Expected reduction factor** (degradation / decomposition / volatilisation in compost process)		**Final Compost - contribution** (accounting for dilution and degradation)		**Final Product Max Concentration**	
Parameter	**Units**	**Typical**	**Min**	**Max**		**Notes**	**Typical**	**Max**		
Moisture content	% by wt	0.35	0.25	0.45	-					
pH	pH scale				-					
Electrical Conductivity	mS									
Total degradable carbon	mg / kg dm									
Total nitrogen	mg / kg dm									
Ammonia	mg / kg dm									
Nitrate	mg / kg dm									
Sulphate	mg / kg dm									
Chloride	mg / kg dm									
Calcium	mg / kg dm									
Magnesium	mg / kg dm									
Potassium	mg / kg dm									
Sodium	mg / kg dm									
Physical Impurities										
Glass	% dm				0%				0.005	
Metal fragments	% dm				0%					
Rigid plastics	% dm				0%					
Lightweight plastics	% dm				0%				0.0005	*AS 4454 Limit*
Pathogens										
Faecal coliforms	MPN/g				100%	*Assuming pasteurisation requirements are met*			< 1000	*AS 4454 Limit*
Salmonella spp	-				100%	*Assuming pasteurisation requirements are met*			absent in 50 g dry weight ec	*AS 4454 Limit*

Final concentration contribution of each contaminant in the compost is calculated as: *Raw conc x Proportion in mix (%) x (100%- Expected reduction factor(%))*

Expected reduction factor(%) should be conservative and assume normal composting conditions, based on literature

Final product max limits to be determined - AS4454 values included to demonstrate

Metals										
Arsenic	mg / kg dm	15			0%		10.5		20	*AS 4454 Limi*
Boron	mg / kg dm	10			0%		7.0		100	*AS 4454 Limi*
Cadmium	mg / kg dm	1			0%		0.7		3	*AS 4454 Limi*
Chromium (Total)	mg / kg dm	10			0%		7.0		100	*AS 4454 Limi*
Copper	mg / kg dm	100			0%		70.0		100 (150)**	*AS 4454 Limi*
Lead	mg / kg dm	30			0%		21.0		150	*AS 4454 Limi*
Mercury	mg / kg dm	0			0%		-		1	*AS 4454 Limi*
Nickel	mg / kg dm	10			0%		7.0		60	*AS 4454 Limi*
Selenium	mg / kg dm	2			0%		1.4		5	*AS 4454 Limi*
Zinc	mg / kg dm	250			0%		175.0		200 (300)**	*AS 4454 Limi*
Organochlorine Pesticides										
DDT/DDE/DDD	mg / kg dm								0.5	*AS 4454 Limi*
Aldrin	mg / kg dm								0.02	*AS 4454 Limi*
Dieldrin	mg / kg dm								0.02	*AS 4454 Limi*
Chlordane	mg / kg dm								0.02	*AS 4454 Limi*
Heptachlor	mg / kg dm								0.02	*AS 4454 Limi*
HCB	mg / kg dm								0.02	*AS 4454 Limi*
Lindane	mg / kg dm								0.02	*AS 4454 Limi*
BHC	mg / kg dm								0.02	*AS 4454 Limi*
PCBs^	mg / kg dm								Not detected	*AS 4454 Limi*
Herbicides										
2,4,5-T	mg / kg dm									
2,4-D	mg / kg dm									
MCPA	mg / kg dm									
MCPB	mg / kg dm									
Mecoprop	mg / kg dm									
Picloram	mg / kg dm									
Other Pesticides										
Atrazine	mg / kg dm									
Chlorpyrifos	mg / kg dm									
Bifenthrin	mg / kg dm									

Not every compound will need to be tested for every feedstock

Typical value is based on typical raw concentration, likewise for Max value. For highly variable feedstocks, assessment should focus on the Max expected values

Polycyclic Aromatic Hydrocarbons (PAHs)									
8 Carcinogenic PAHs (as BaP TEQ)	mg / kg dm								
Total PAHs (16)	mg / kg dm								
Phenols									
Phenol	mg / kg dm								
Pentachlorophenol	mg / kg dm								
Cresols	mg / kg dm								
Total Recoverable Hydrocarbons (NEPM 2013 Fractions)									
C10 - C16 Fraction	mg / kg dm	60			60%		16.8		
C16 - C34 Fraction	mg / kg dm	300			60%		84.0		
C34 - C40 Fraction	mg / kg dm	100			60%		28.0		
Total Petroleum Hydrocarbons									
C10 - C14 Fraction	mg / kg dm	50			60%		14.0		
C15 - C28 Fraction	mg / kg dm	150			60%		42.0		
C29 - C36 Fraction	mg / kg dm	250			60%		70.0		
BTEX									
Benzene	mg / kg dm								
Toluene	mg / kg dm								
Ethylbenzene	mg / kg dm								
meta- & para-Xylene	mg / kg dm								
PFAS / PFOS									
Sum of PFAS	mg / kg dm								
Sum of PFHxS and PFOS	mg / kg dm								

APPENDIX C

International Contamination Regulatory Guidelines

Data Annexes

A. Thresholds for health-based Soil Investigation Levels compared to unrestricted use limits for compost (AS 4454 – 2012)

B. Impurity limits for compost in European countries in 2014

C. PFAS compounds in garden organics and FOGO compost at 0.001 mg/kg dm detection limit

D. National approaches and criteria to define whether compost produced from waste may be marketed as product or is still within the waste regime in European countries

E. Heavy metal limits (mg/kg dm) in European compost/digestate standards

F. Compost use regulations in European countries

G. Admissible maximum dosage (g/ha*y) of heavy metals to the soil in European national legislation and standards

H. Compost quality assurance schemes in European countries

Annex A Thresholds for health-based Soil Investigation Levels compared to unrestricted use limits for compost (AS 4454 – 2012)

Chemical	AS4454 - 2012 Compost Standard	Health-based investigation levels (mg/kg)			
		Residential[1] A	Residential[1] B	Residential[1] C	Commercial / industrial[1] D
Arsenic	20	100	500	300	3,000
Beryllium		60	90	90	500
Boron	100	4,500	40,000	20,000	300,000
Cadmium	1	20	150	90	900
Chromium (VI)	100 (all Cr)	100	500	300	3,600
Cobalt		100	600	300	4,000
Copper	150	6,000	30,000	17,000	240,000
Lead [3]	150	300	1,200	600	1,500
Manganese		3,800	14,000	19,000	60,000
Mercury (inorganic) [5]	1	40	120	80	730
Methyl Mercury [4]		10	30	13	180
Nickel	60	400	1,200	1,200	6,000
Selenium	5	200	1,400	700	10,000
Zinc	300	7,400	60,000	30,000	400,000
Cyanide (free)		250	300	240	1,500
	Polycyclic Aromatic Hydrocarbons (PAHs)				
Carcinogenic PAHs (as BaP TEQ)[6]		3	4	3	40
Total PAHs[7]		300	400	300	4,000
	Phenols				
Phenol		3,000	45,000	40,000	240,000
Pentachlorophenol		100	130	120	660
Cresols		400	4,700	4,000	25,000
	Organochlorine Pesticides				

DDT+DDE+DDD	0.5	240	600	400	3,600
Aldrin and dieldrin	0.02 (each)	6	10	10	45
Chlordane	0.02	50	90	70	530
Endosulfan		270	400	340	2,000
Endrin		10	20	20	100
Heptachlor	0.02	6	10	10	50
HCB	0.02	10	15	15	80
Methoxychlor		300	500	400	2,500
Mirex		10	20	20	100
Toxaphene		20	30	30	160
	Herbicides				
2,4,5-T		600	900	800	5,000
2,4-D		900	1,600	1,300	9,000
MCPA		600	900	800	5,000
MCPB		600	900	800	5,000
Mecoprop		600	900	800	5,000
Picloram		4,500	6,600	5,700	35,000
	Other Pesticides				
Atrazine		320	470	400	2,500
Chlorpyrifos		160	340	250	2,000
Bifenthrin		600	840	730	4,500
	Other organic contaminants				
PCBs[8]		1	1	1	7
PBDE Flame Retardants (Br1-Br9)		1	2	2	10
	Notes:				
	(1) Generic land uses are described in detail in Section 3. HIL A: Residential with garden/accessible soil (home-grown produce <10% fruit and vegetable intake (no poultry)), also includes childcare centres, preschools and primary schools HIL B: Residential with minimal opportunities for soil access; includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments HIL D: Commercial/industrial includes premises such as shops, offices, factories and industrial sites				

HIL C: Public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. This does not include areas of undeveloped open space where the potential for exposure is lower and where a site-specific assessment may be more appropriate.

(2) Arsenic: HIL for arsenic assumes 70% oral bioavailability. Site-specific bioavailability may be important and should be considered where appropriate (refer Schedule B7).

(3) Lead: HIL for lead is based on blood lead models (IEUBK for HILs A, B and C and adult lead model for HIL D) where 50% oral bioavailability has been considered. Site-specific bioavailability may be important and should be considered where appropriate.

(4) Methyl mercury: assessment of methyl mercury should only occur where there is evidence of its potential source. It may be associated with inorganic mercury and anaerobic microorganism activity in aquatic environments. In addition, the reliability and quality of sampling/analysis should be considered.

(5) Elemental mercury: HIL does not address elemental mercury. A site-specific assessment should be considered if elemental mercury is present or suspected to be present.

(6) Carcinogenic PAHs: HIL for carcinogenic PAHs is based on the 8 carcinogenic PAHs and their respective TEFs (potency relative to BaP) adopted by CCME 2008. The BaP TEQ is calculated by multiplying the concentration of each carcinogenic PAH in the sample by its BaP TEF, given below, and summing these products. Where the BaP occurs in bitumen fragments it is relatively immobile and does not represent a significant health risk.

PAH Species	TEF	PAH Species	TEF
Benzo(a)anthracene	0.1	Benzo(g,h,i)perylene	0.01
Benzo(a)pyrene	1	Chrysene	0.01
Benzo(b+j)fluoranthene	0.1	Dibenz(a,h)anthracene	1
Benzo(k)fluoranthene	0.1	Indeno(1,2,3-c,d)pyrene	0.1

(7) Total PAHs: HIL for total PAH is based on the sum of the 16 PAHs most commonly reported for contaminated sites (WHO 1998). The application of the total PAH HIL should consider the presence of carcinogenic PAHs and naphthalene (the most volatile PAH). Carcinogenic PAHs reported in the total PAHs should meet the BaP TEQ HIL. Naphthalene reported in the total PAHs should meet the relevant HSL.

(8) PCBs: HIL for PCBs relates to non-dioxin-like PCBs only. Where a PCB source is known, or suspected, to be present at a site a site-specific assessment of exposure to all PCBs (including dioxin-like PCBs) should be undertaken

Annex B Limits for impurities in compost in various European countries [Saveyn and Eder 2014]

Country	Impurities	Mesh size (mm)	Limit values weight % d.m.
Austria Compost ordinance	Total; agriculture	>2	≤ 0.5%
	Total; land reclamation	>2	< 1.0%
	Total; technical use	>2	< 2.0%
	Plastics; agriculture	>2	< 0.2%
	Plastics; land reclamation	>2	< 0.4%
	Plastics; technical use	>2	< 1.0%
	Plastics; agric. excl. arable land	>20	< 0.02%
	Plastics; technical use	>20	< 0.2%
	Metals; agriculture	-	< 0.2%
	Glass; agriculture	-	< 0.2%
Belgium Royal Decree for fertilisers, soil improvers and substrates	Total	>2	< 0.5%
	Stones	>5	< 2.0%
Czech Republic Act on fertilisers Biowaste Ordinance	Total, agriculture	>2	< 2.0%
	Total, land reclamation	>2	< 2.0%
Germany Biowaste Ordinance	Glass, plastics, metal	>2	< 0.5%
	Stones	>5	< 5.0%
Estland	Total impurities (glass, metals, plastic)	>2	< 3.0%
Finland Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 12/07	Refuse (glass, metal, plastics, bones, rocks)	-	
	In packaged products		
	Sold in bulk		
France NF U44-051	Plastic films	>5	< 0.3%
	Other plastics	>5	< 0.8%
	Metals	>2	< 2.0%
Hungary	No restrictions	-	-

Country	Impurities	Mesh size (mm)	Limit values weight % d.m.
Ireland EPA waste license	Total; compost class 1 & 2	>2	≤ 0.5%
	Total; low grade compost/MBT	>2	≤ 3.0%
	Stones	>5	≤ 5.0%
Italy Fertiliser law d.lgs. 75/2010	Glass, plastics, metals	>2	< 0.5%
	Stones	>5	< 5.0%
Latvia Cabinet Regulation No. 530, 25.06.2006	Total (glass, metal, plastics)	>4	< 0.5%
Netherlands Fertiliser act + various certification systems	Total	>2	< 0.5%
	Glass	>2	< 0.2%
	Stones	>5	< 2.0%
	Biodegradable parts	>50	0
	Non-soil based, non-biologically degradable parts		< 0.5%
Slovenia Decree on the treatment of biodegradable waste (Official Gazette of the Republic of Slovenia, no. 62/08)	Glass, plastics, metal		
	1st class	<2	< 0.5%
	2nd class	<2	< 2.0%
	Stabilized biodegradable waste	<2	< 7.0%
	Minerals, stones		
	1st class	<5	< 5.0%
	2nd class	<5	< 5.0%
	Stabilized biodegradable waste	<5	-
United Kingdom PAS 100 voluntary standard	Total	>2	< 0.5%
	herein included plastic		<0.25%
	Stones: other than ‘mulch’	>4	< 0.8%
	Stones: in ‘mulch compost’	>4	< 10%

Annex C Concentration (mg/kg dm) of 18 PFAS compounds in compost made from garden organics and FOGO at detection limit of 0.001 mg/kg dm [modified from Kehres 2015]

Compound*	Abbreviation	Garden Organics Compost N=5	FOGO Compost N=5
Perfluorbutanoat	PFBA	n.d.	1 x 0.004
Perfluorpentanoat	PFPA	n.d.	1 x 0.001
Perfluorhexanoat	PFHxA	n.d.	n.d.
Perfluorheptanoat	PFHpA	n.d.	n.d.
Perfluoroctanoat	PFOA	n.d.	n.d.
Perfluornonanoat	PFNA	n.d.	n.d.
Perfluordecanoat	PFDA	n.d.	n.d.
Perfluorundecanoat	PFUnA	n.d.	n.d.
Perfluordodecanoat	PFDoA	n.d.	n.d.
Perfluorbutansulfonat	PFBS	n.d.	3 x 0.001
Perfluorhexansulfonat	PFHxS	n.d.	n.d.
Perfluoroctansulfonat	PFOS	1 x 0.002 1 x 0.003	1 x 0.001 2 x 0.002
Perfluordekansulfonat	PFDS	n.d.	n.d.
Perfluoroktansulfonsäureamid	PFOSA	n.d.	n.d.
7H-Dodecafluorheptanoat	HPFHpA	n.d.	n.d.
2H,2H-Perfluordecanoat	H2PFDA	n.d.	n.d.
2H,2H,3H,3H-Perfluorundecanoat	H4PFUnA	n.d.	n.d.
1H,1H,2H,2H-Perfluoroctansulfonat	H4PFOS	1 x 0.002	1 x 0.002

* some compound names might be in German
n.d. = not detected

Annex D National approaches and criteria to define whether compost produced from waste may be marketed as product or is still within the waste regime in European countries [Saveyn and Eder 2014]

Country	Compost = PRODUCT or WASTE	Legal basis or standard	Main criteria for 1) compost ceasing to be waste and/or 2) placing on the market and use of compost even under the WASTE regime
Austria	PRODUCT	Compost Ordinance BGBl. I 291/2001	• Central registration of compost plant • Positive list of input materials • Comprehensive documentation of - Waste reception - Process management and material movement - Compost quality criteria - Product designation, declaration, labelling and selling of compost • External sampling and product certification by acknowledged institute. If all criteria are met and approved by the external certification system, all types of compost can be marketed as PRODUCT.
Belgium Flanders	PRODUCT (secondary raw material)	VLAREA Flemish Regulation on waste prevention and management (B.S. 1998-04-16)	Total quality control of the VLACO-certificate includes: • Input criteria, • Process parameters, • Standards for end-product • Correct use If conditions are met, compost loses the status of waste material and becomes raw material. User certificate by OVAM is necessary only for the application of sewage sludge compost
Belgium Wallonia	WASTE	Decree on compost and digestates (currently being examined by the Walloon Government)	Compost does not cease to be waste Four classes (A, B, C, D) and two subclasses (B1, B2) are defined in the classification system proposed by the administration for all materials. Composts belong to class B, and are distributed between class B1 and B2 according to the type or origin of the material Material of class D cannot be used on or in the soils; Material of class C cannot be used on or in agricultural soils; Material of class A of B can be used on or in agricultural soils. Norms of subclass B2 are those applied for treatment plant sludge that can be recovered in agriculture in accordance with European legislation, i.e. a

			management at the field level together with a preliminary soil analysis must be undertaken (field level traceability with soil analysis). In order to protect soils from metallic element traces, a maximum quantity of material spreading is defined, and the soil is preliminary analysed for metallic element traces (in order to avoid exceeding a defined level) Norms of subclass B1 are less restrictive than subclass B2 due to the lower concentration in metallic element traces and in organic compound traces of certain material (such as wastes from food processing industry, green wastes compost, decarbonation sludge, etc), and due to criteria, that must be followed within the Water Code on sustainable nitrate management in agriculture. Therefore, preliminary soil analyses are not needed for subclass B1, which simplifies the use of these materials on or in agricultural soils. The presence of a quality management system allows the traceability to be at the farm/firm level, otherwise the field level traceability is maintained.
Bulgaria	-	-	-
Cyprus	-	-	-
Czech Republic	PRODUCT	Act on fertilisers 156/1998 Sb. by the Public Ministry of Agriculture ČSN 46 5735 Průmyslové komposty Czech Compost Standard	Fertiliser Registration System; Central Institute for Supervising and Testing in Agriculture, the Czech Environmental Inspectorate. One Compost Class; Quality requirements correspond to Class 1 of the Czech Compost Standard but with less quality parameter compared to the waste composts. The use is not restricted to agriculture. Compost has only to be registered for this group and the inspection/control of samples is done by the Control and Test Institute for Agriculture which is the Central Institute for Supervising and Testing in Agriculture.
	PRODUCT	Bio-waste Ordinance (In preparation)	All 3 Classes foreseen in the new draft Compost Ordinance are defined as end-of-waste criteria.
Germany	WASTE	Fertiliser Ordinance (26. November 2003) Circular Economy Management and Waste Act (KrW/AbfG); Bio-waste Ordinance (BioAbfV, 1998)	Compost also from source separated organic waste is seen as WASTE due to its waste properties and its potential to pose negative impacts to the environment. (risk of contamination) • Positive list for input materials • Hygienically harmless • Limit value for heavy metals • Requirements for environmentally sound application • Soil investigation • Official control of application by the waste authority

			• Documented evidence of approved utilisation All classes and types of compost, which are produced from defined source materials under the Bio-waste Ordinance remain WASTE
	WASTE product (!)	RAL Gütesicherung RALGZ 251	When participating in a voluntary QA scheme regulatory requirements are relaxed with respect to the regular control and approval protocols under the waste regime. Though, legally spoken compost remains WASTE quality assured and labelled compost can be extensively treated and handled like a product. The relaxations are: • No soil investigation • No official control of application by the waste authority • No documented evidence of approved utilisation In principle all classes and types of compost, which are produced from defined source materials under the Bio-waste Ordinance remain WASTE, but in practice, if certified under QAS of the RALGZ 251 compost can be marketed and used quasi like a PRODUCT.
Denmark	WASTE	Stat. Order 1650 of 13.12.06 on the use of waste (and sludge) for agriculture	The use of compost based on waste is under strict regulation (maximum of 30 kg P/year/ha etc. and the concentration of heavy metals in the soil were applied must not exceed certain levels. For this reason, the authorities want to know exactly where the compost ends up which is only possible if handled as waste and not as a product (for free distribution). Compost from garden waste is not formally regarded as a product but is treated according to the general waste regulation for which the municipalities are responsible.
Estonia	WASTE	Environmental Ministry regulations 2002.30.12 nr. 78 and in Environmental Ministry regulation 2002.01.01 nr. 269.	Heavy metal limits in compost (sludge compost). No specific regulation on compost from bio-waste and green waste.
Spain	PRODUCT	Real Decree 506/2013 on Fertilisers Products	• Input list (Annex IV) • Documentation (Art. 16): declaration of raw materials, description of production processes, certification to declare the fulfilment of all legal requirements • Minimum criteria for fertilizer products to be used on agriculture or gardening (Annex I): raw materials, how it shall be obtained, minimum nutrient contents and other requirements, parameters to be included on the label.

			• Quality criteria for final compost (Annex V): heavy metals content, nitrogen %, water content, Size particle, maximum microorganism content, limitations of use.
Finland	WASTE PRODUCT	Jätelaki (Waste Act) Fertiliser Product Act 539/2006 Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 12/07	WASTE status changes to PRODUCT if compost fulfils the criteria of fertiliser regulation and is spread to land or mixed into substrate. But there is no external approval or inspection scheme. Samples can be taken by compost producer! Waste can be used in fertiliser product, if compost fulfils the criteria of the national fertiliser product legislation. The fertiliser product must be produced in an approved establishment which has self-supervision. The fertilisers products have to full fill the general requirements and type designation requirement before marketing
France	PRODUCT	NF U44-051 Standard	Mixed waste compost – no positive list 4 Product types • “Organic soil improvers - Organic amendments and supports of culture” • “Organic soil improvers - Composts containing substances essential to agriculture, stemming from water treatment (sludge compost)” • “Organic amendments with fertiliser” • “supports of culture” Further following quality criteria: • Limit values for: trace metal concentrations and loads (g/ha*y), impurities, pathogens, organic micro-pollutants • Labelling requirements There is no regular external approval or inspection scheme. Samples can be taken by compost producer. However, there exists a legal inspection by the competent authority based on the IPPC procedure which in FR is also applied to composting facilities. Compost which is not produced according to the standard is WASTE and has to follow a spreading plan and may apply for a temporary product authorisation. By this way the standard can easily be bypassed.
Greece	PRODUCT	Common Ministerial Decision 114218, 1016/B/17- 11-97. Fertiliser law (Law 2326/27-6-1995, regulating the types of licenses	Compost is considered as product and may be sold, provided it complies with the restrictions of the frame-work of Specifications and General Programs for Solid Waste Management. No sampling protocol and analysis obligations/ organisations are defined. Composts produced from materials of agricultural origin (olive-mill press cake, fruit stones, tree

		for selling fertilisers).	trimmings, manures etc) are considered products and sold under the fertilisers law
Hungary	PRODUCT	36/2006 (V.18.) Statutory rule about licensing, storing, marketing and application of fertiliser products	Composts are in waste status as long as they are not licensed under the Statutory rule Nr. 36/2006 (V.18.). After the licensing composts may become a PRODUCT. To achieve the product status needs to be in accordance with the Statutory rule Nr. 36/2006 (V.18.). Criteria: • Input-List, • External quality approval by acknowledged laboratories, • physical, chemical and biological quality parameter for final compost.
Ireland	PRODUCT	EPA Waste license or Local Authority waste permit	Product status is based on site specific waste licence or waste permit; compliance with all operational and product requirements laid down in the consent document must be shown by producer. There is NO legal standard or QAS or quality protocol in Ireland at the moment which will say when waste becomes a product.
Italy	PRODUCT	L. 748/84 (law on fertilisers); D.M. 05/02/98 (Technical Regulation on simplified authorization procedures for waste recovery)	Criteria for product status are based on National Law on Fertilisers, which comprises: • Qualitative input list source segregated organic waste • Quality parameters for final compost • Criteria for product labelling Compost from MBT/mixed waste composting plants may still be used under the old Decree DPR 915/82 - DCI 27/7/84 as WASTE for restricted applications (brown fields, landfill reclamation etc).
Lithuania	PRODUCT	Decree of the Ministry for Environment (D157/Jan 2007)	According to environmental requirements for composting of bio-waste the compost producer must provide a certificate on the compost quality • Compost sampling is done by the PRODUCER (!) • NO external approval or plant inspection
Luxembourg	PRODUCT	Waste licence	The Product Status is achieved only when a QAS is applied. QAS is an obligatory element of the waste licensing of composting plants. The further criteria are: • Positive list for input materials • Hygienically harmless (Process requirements and indicator pathogens) • Limit value for heavy metals • Requirements for environmentally sound application (labelling)

Latvia	PRODUCT	Licensing as organic fertiliser (Cabinet Regulation No. 530 “Regulations on identification, quality, conformity and sale of fertilisers” 25.06.2006)	Quality of the compost, its composition. The Product Status is achieved only when it is registered and tested by certificated laboratory. The further criteria are: • Hygienically harmless • Limit value for pollutants
Malta	WASTE	-	NO provisions for compost
Netherlands	PRODUCT	Fertiliser act (2008)	One or more organic components, but no animal manure, broken down by micro-organisms into such a stable end product that the composting process is slowed down considerably. Key criteria: • The composting process (hygienisation) and its documentation • stability (no value) and • the absence of animal manure. • heavy metal limits • minimum organic matter content • declaration & labelling
Poland	WASTE	Waste law	Ministerial Approval by Min. of Environment
	PRODUCT	Fertiliser law	Ministerial Approval by Min. of Agriculture and Rural Development Criteria: • Limit values for heavy metals (3 classes; also coarse and fine compost) Test on Pathogens
Portugal	PRODUCT	NP 1048 – Standard for fertilisers Portaria 672002 pg 436	Compost is interpreted as organic soil amendment “*Correctivo organico”* There are no specific regulations available.
Romania	-	-	NO provisions for compost
Sweden	WASTE	Private QAS and SPRC 152 (compost standard)	Waste Criteria: Definition according to European court of justice. The compost standard is managed by the Swedish Standardisation Institute SP)
Slovenia	PRODUCT	Decree on the treatment of biodegradable waste (Official Gazette of the Republic of Slovenia, no. 62/08)	If compost meets the requirements of this Decree, compost is a PRODUCT. If limit values are not met the compost can be used as WASTE. Provided risk assessment is carried out by an accredited laboratory. Criteria: Limit values for heavy metals (3 classes) and AOX, PCBs

			Maximum levels for glass, plastics, metals But: Compost sampling is done by the producer (!); no QAS certification!
Slovakia	PRODUCT	Act No. 223/2001 Col. on waste as amended Slovak technical standard (STS) 46 57 35 Industry composts Act No. 136/2000 Col. on fertilisers Act No. 264/1999 Col. about technical requests for products Regulation of the Government No. 400/1999 Col. which lays down details about technically requirements for products	After bio-waste has gone through recovering process it is considered as compost, but such product cannot be marketed Compost may be marketed in case it is certified by an authorised person according to Act No. 264/1999 Col. Key criteria for the PRODUCT status: • Quality parameter for final compost – STS 46 57 35 • Process parameter (sanitisation) – STS 46 57 35§ • Quality approval by acknowledged laboratory or quality assurance organisation – Act No. 264/1999 Col.
United Kingdom	WASTE	Waste Management Licensing Regulations Animal By-Products Regulations	England, Wales, Scotland and Northern Ireland: Compost must be sold/supplied in accordance with the Waste Management Licensing Regulation rules for storing and spreading of compost on land (these rules apply whether or not the compost is derived from any animal by-products). There are not any quality criteria / classes but in the application form and evidence (test results for the waste) sent to the regulator, 'agricultural benefit' or 'ecological improvement' must be justified. The regulator makes an evaluation taking account of the characteristics of the soil / land that is intended to receive the waste, the intended application rate and any other relevant issues. Compost derived in whole or in part from animal by-products must be placed on the market and used in accordance with the animal by-products regulations.
	PRODUCT	BSI PAS 100:2005 BSI PAS 100:2005 + Quality Compost Product	Scotland: requires certification to PAS 100 (or an equivalent standard), that the compost has certainty of market, is used without further recovery, is not be subjected to a disposal activity and is not be mixed with other wastes, materials, composts, products or additives. Northern Ireland: similar position as Scotland's. England & Wales: both, the Standard and the Protocol have to be fulfilled to sell/supply/use "Quality Compost" as a PRODUCT. Key criteria: • Positive list of allowed input types and source types • QM system including HACCP assessment; standard process including hygienisation

- Full documentation and record keeping
- Contract of supply per consignment
- External quality approval
- Soil testing on key parameters
- Records of compost spreading by land manager who receives the compost (agriculture and land-based horticulture

N.B.: In each country of the UK, if compost ‘product’ is derived in whole, or in part from animal by-products, placed on the market, stored, used and recorded as required by the Animal By-Products Regulations.

Annex E Heavy metal limits (mg/kg dm) in Australia vs European compost/digestate standards [adapted from Saveyn and Eder 2014]

Country	Regulation	Type of standard	Cd	Cr_{tot}	Cr^{VI}	Cu	Hg	Ni	Pb	Zn	As
Australia	AS 4454 - 2012	Voluntary standard	1	100		100 (150)	1	60	150	200 (300)	20
Austria	Compost Ord.: Class A+ (organic farming)	Statutory Ordinance	0.7	70	-	70	0.4	25	45	200	-
	Compost Ord.: Class A (agriculture; hobby gardening)		1	70	-	150	0.7	60	120	500	-
	Compost Ord.: Class B limit value (landscaping; reclam.) (guide value) *		3	250	-	500 (400)	3	100	200	1800 (1200)	-
Belgium	Royal Decree, 07.01.1998, case by case authorisation, Compost	Statutory decree	2	100	-	150	1	50	150	400	20
	Royal Decree, 07.01.1998, case by case authorisation, DIGESTATE	Statutory decree	6	500	-	600	5	100	500	2000	150
Bulgaria	No regulation	-	-	-	-	-	-	-	-	-	-
Cyprus	No regulation	-	-	-	-	-	-	-	-	-	-
Czech Republic	Use for agricultural land (Group one)	Statutory	2	100	-	100	1	50	100	300	10
	Landscaping, reclamation (draft Bio-	Statutory Class 1	2	100	-	170	1	65	200	500	10
		Statutory Class 2	3	250	-	400	1.5	100	300	1200	20

	waste Ordinance) (group two)	Statutory Class 3	4	300	-	500	2	120	400	1500	30
	Fertilizer law 156/1998, ordinance 474/2000 (amended)	DIGESTATE with dry matter > 13%	2	100		150	1	50	100	600	20
		DIGESTATE with dry matter < 13%	2	100		250	1	50	100	1200	20
Germany	Quality assurance RAL GZ - compost / digestate products	Voluntary QAS	1.5	100	-	100	1	50	150	400	1
	Bio waste Ordinance	Statutory decree (Class I)	1	70	-	70	0.7	35	100	300	-
		Statutory decree (Class II)	1.5	100	-	100	1	50	150	400	-
Denmark	Statutory Order Nr.1650; Compost after 13 Dec. 2006	Statutory decree	0.8	-	-	1000	0.8	30	120/60 for private gardens	4000	25
Estonia	Env. Ministry Re. (2002.30.12; m° 87) Sludge regulation	Statutory	-	1000	-	1000	16	300	750	2500	-
Spain	Real decree 506/2013 on fertilisers: Class A	Statutory	0.7	70	0	70	0.4	25	45	200	-
	Class B		2	250	0	300	1.5	90	150	500	-
	Class C		3	300	0	400	2.5	100	200	1000	-
Finland	Decree of the Ministry of Agriculture and Forestry	Statutory decree	1.5	300	-	600	1	100	100	1,500	25

	on Fertiliser Products 12/07										
France	NF U44-051	Standard	3	120		300	2	60	180	600	
Greece	KYA 114218, Hellenic Government Gazette, 1016/B/17- 11-97 [Specifications framework and general programmes for solid waste management]	Statutory decree	10	510	10	500	5	200	500	2,000	15
Hungary	Statutory rule 36/2006 (V.18)	Statutory Co: 50; Se: 5	2	100	-	100	1	50	100	-	10
Ireland	Licensing/permitting of treatment plants by competent authority stabilised MBT output or compost not meeting class I or II	Statutory	5	600	-	600	5	150	500	1500	-
	(Compost – Class I)	Statutory	0.7	100	-	100	0.5	50	100	200	-
	(Compost – Class II)	Statutory	1.5	150	-	15	1	75	150	400	-
Italy	Law on fertilisers (L 748/84; and: 03/98 and 217/06) for BWC/GC/SSC	Statutory decree	1.5	-	0.5	230	1.5	100	140	500	-
Luxembourg	Licensing for plants		1.5	100	-	100	1	50	150	400	-
Lithuania	Regulation on sewage sludge Categ. I (LAND 20/2005)	Statutory	1.5	140		75	1	50	140	300	-

Latvia	Regulation on licensing of waste treatment plants (n° 413/23.5.2006) – no specific compost regulation	Statutory = threshold between waste/product	3			600	2	100	150	1,500	50
Netherlands	Amended National Fertiliser Act from 2008	Statutory	1	50		90	0.3	20	100	290	15
Poland	Organic fertilisers	Statutory	5	100		-	2	60	140	-	-
Portugal	Standard for compost is in preparation	-	-	-	-	-	-	-	-	-	-
Sweden	Guideline values of QAS	Voluntary	1	100	-	100	1	50	100	300	-
	SPCR 152 Guideline values	Voluntary	1	100	-	600	1	50	100	800	-
	SPCR 120 Guideline values (DIGESTATE)	Voluntary	1	100	-	600	1	50	100	800	-
Slovenia	Decree on the treatment of biodegradable waste (Official Gazette of the Republic of Slovenia, no. 62/08)	Statutory: 1st class*	0.7	80	-	100	0.5	50	80	200	-
		Statutory: 2nd class*	1.5	200	-	300	1.5	75	250	1200	-
		Statutory: stabilized biodegradable waste*	7	500	-	800	7	350	500	2500	-
		* normalised to an organic matter content of 30%									
Slovakia	Industrial Standard STN 46 5735 Cl. 1	Voluntary (Mo: 5)	2	100		100	1	50	100	300	10

	Cl. 2	Voluntary (Mo: 20)	4	300		400	1.5	70	300	600	20
United Kingdom	UKROFS fertil. org. farming, ‘Composted household waste'	Statutory (EC Reg. 889/2008)	0.7	70	0	70	0.4	2	45	200	-
	Standard: PAS 100	Voluntary	1.5	100	-	200	1	50	200	400	-
	Standard: PAS 110 (DIGESTATE)	Voluntary	1.5	100	-	200	1	50	200	400	-
EU ECO Label	COM Decision (EC) n° 64/2007 eco-label to growing media COM Decision (EC) n° 799/2006 eco-label to soil improvers	Voluntary [Mo: 2; As: 10; Se: 1.5; F: 200 [only if materials of industrial processes are included]	1	100	-	100	1	50	100	300	10
EU Regulation on organic agriculture	EC Reg. n° 889/2008. Compliance with limits required for compost from source separated bio-waste only	Statutory	0.7	70	-	70	0.4	25	45	200	-

Annex F Compost use regulations in European countries [adapted from Saveyn and Eder 2014]

Country	Regulation	Requirements or restriction for the use of compost
Austria	Compost Ordinance	• Agriculture: 8 t d.m. /ha*y on a 5-year basis • Land reclamation: 400 or 200 t d.m. /ha*y within 10 years depending on quality class • Non-food regular application: 20 or 40 t d.m. /ha*y within 3 years dep. on quality class • El. Conductivity > 3 mS/cm: excluded from marketing in bags and for private gardening
	Water Act	1 Specific application requirements pursuant to the Action Programme following the EU Nitrate Directive (e.g. limitation to 210 or 170 kg total N per hectare an year)
Belgium Flanders Wallonia	Royal decree for fertilisers, soil improvers and substrates Fertiliser Regulation (nitrate directive) VLAREA waste regulation Arrêté du Gouvernement wallon favorisant la valorisation de certains déchets	• An accompanying document with user information is obligatory. • Fertiliser Regulation limits N and P, partly more compost use possible because of beneficial soil effects compared to manure. • VLAREA require VLACO Certificate for use and limits max. level of pollutants and show conditions for max application rates • Not specifically for organic waste, so all the conditions are laid down in the certificate of use
Bulgaria	No data available	n.d.
Cyprus	No data available	n.d.
Czech Republic	Bio -waste Ordinance, Waste Act (2008)	According to the coming Bio-waste Ordinance (2008) for the first class there are restrictions according to Ordinance on hygienic requirements for sport areas, the 2nd best can be used with 200 t dm/ha. in 10 years.
	Fertiliser law	Fertiliser law requires application according to good practice.
Germany	Bio -waste Ordinance (BioAbfV 1998) Soil Protection Ordinance (BbodSchV 1999) Fertiliser Ordinance (DÜMV, 2003)	• The Bio-waste Ordinance regulates agricultural use with compost Class I 20 t dm in 3 years, Class II 30 t dm in 3 years.

		• Soil Protection Ordinance for non-agricultural areas between 10 and 65 t dm compost depending on use. • Fertilising with compost according to good practice
Denmark	Stat. Order 1650 0f 13.12.06 of the use of waste (and sludge) in agriculture	• 7 t d.m. /ha*y on a 10-year basis • Restriction of nitrogen to 170 kg /ha*y • Restriction of phosphorus to 30 kg /ha*y average over 3 years • The levels for heavy metals and organic compounds are restricted in the INPUT material for the composting process
Estonia	No compost restrictions	Only restrictions for the use of stabilized sludge "sludge compost"
Spain	Real Decree 506/2013 on Fertiliser Products	Class C compost (mixed waste compost) 5t d.m./ha*y
Finland	Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 12/07	• Maximum Cd load/ha 6 g during 4 years (crop growing area), 15 g during 10 years (landscape gardening), 60 g during 40 years (forestry); • Soluble phosphorus load per 5 years 400 kg (farming), 600 (horticulture) and 750 (landscape gardening); soluble nitrogen load during 5 years in landscape gardening max. 1250 kg.
France	Organic soil improvers - Organic amendments and supports of culture NF U44-051	From the moment a compost meets the standard NF U44-051 there is no rule for the use. In the standard, flows in heavy metals, and elements are restricted to the maximum loading limits: Per year g/ha: As 270, Cd 45, Cr 1,800, Cu 3,000, Hg 30, Ni 900, Pb 2,700, Se 180, Zn 6,000 Over 10 years g/ha: As 900, Cd 150, Cr 6,000, Cu 10,000, Hg 100, Ni 3,000, Pb 9,000, Se 600, Zn 30,000 Application should follow good agrarian practices, and agronomical needs which are taken into account for the use of composts.
Greece	Common National Ministerial Decision 114218/1997 Hellenic Ministerial Decision	Upper limits for amounts of heavy metals disposed of annually in agricultural land Cd 0,15, Cu 12, Ni 3, Pb 15, Zn 30, Cr 5, Hg 0,1, kg/ha/y
Hungary	49/2001 Statutory Rule about the protection of the waters and groundwaters being affected by agricultural activities	• Compost application on agricultural land is limited by the amount of nutrient with 170 kg/ha Nitrogen. • Dosage levels depending on background contamination and nutrient content level in the soil laid down in the

	10/2000. (VI. 2.) KöMEüM-FVM-KHVM - Water protection rule	National Statutory Rule about the threshold values for the protection of the ground- and subsurface waters and soils.
Ireland	Statutory Instruments SI No. 378/2006 Good agricultural practice for protection of waters: Statutory instrument 253 of 2008	IE Nitrate regulation: Compost has to be included in the Nutrient Management Plan. Availability of nutrients calculated like cattle manure. There are specific waiting periods to consider for animal access to land fertilised with bio-waste compost based on the Animal-By-Product Regulations. • Catering waste: 21 d for ruminant animals; 60 d for pigs; • Former foodstuff & fish waste compost: 3 years (under revision)
Italy	National law on fertilisers L. 748/84 (revised in 2006 with the new law on fertilisers, D.lgs. 217/06) Regional provisions	• Compost has to be considered a product to be used according only to Good Agricultural Practice as long as it meets the standards. No restriction is set on loads for unit area • Some regions have codified approaches for low grade materials applications and landfill reclamation, building on the old regulation on “mixed MSW compost” (DCI 27/7/84)
Lithuania	Environmental Requirements for Composting of bio-waste, approved by the Ministry of the Environment on 25 January 2007, No. D1-57 Standards for sewage sludge use for fertilising and redevelopment LAND 20-2005 (Gaz., 2005, No. 142-5135)	• When compost used for improving the quality of the soil, the annual quantity of the heavy metals cannot exceed norms according LAND 20-2005. • Compost application in agriculture and or soil reclamation purposes, is restricted by contamination with pathogenic microorganisms, organic micropollutants and heavy metals (according to LAND 20-2005) • Compost application on agricultural land is limited by the amount of nutrient with 170 kg/ha Nitrogen and 40 kg/ha Phosphorous per year
Luxembourg	EU Nitrate Directive	• No specific regulations; advise (voluntary): 15 t d.m. /ha *y • Only record keeping about the compost use and send to the Ministry
Latvia	No regulations	only for sewage sludge compost
Malta	No data available	
Netherlands	Fertiliser Act (2008)	• Compost has to meet the national standard (heavy metals) • In the new fertiliser legislation limitations for application are only based on the nutrient content for

		agriculture, so called standard values of max. 80 kg P2O5 /ha*y, 100 kg N /ha*y, 150 K2O /ha*y, 400 kg neutralizing value /ha*y or 3000 kg organic matter /ha*y • For some crops which grow in the soil (e.g. potatoes) compost needs certification and a low glass content < 0.2 %
Poland	The Act of 10 July 2007 on fertilisers and fertilisation (Journals of Laws No. 147, item 1033, as amended)	• Organic fertilisers and plant conditioners containing compost can be marketed and used on the Polish territory on the basis of a license from the Agricultural Ministry; • Products containing compost are used exactly as given in the instructions for using and storing the product, which is an integral part of the license; • A limit for nitrogen use of 170 kg of nitrogen (N) in the pure ingredient per ha and per year only applies to natural fertilizers
Portugal	No regulations available	-
Romania	No data available	n.d.
Sweden	The Swedish Board of Agriculture: SJV 1998:915 (sewage sludge regulation)	Fixed maximum heavy metal load Maximum heavy metal load (g/ha*y): Pb 25; Cd 0.75; Cu 300; Cr 40; Hg 1.5; Ni 25; Zn 600
	Nitrate directive	Agriculture: nitrogen: 150 kg/ha*y and phosphorus: 22 – 35 kg/ha*y
Slovenia	Decree on the treatment of biodegradable waste (Official Gazette of the Republic of Slovenia, no. 62/08)	Class I can be used without any restrictions. Class II can be spread with a special permission with a limited application rate considering the heavy metal content and load after an evaluation and risk assessment performed by a lab (but not more than 10 t d.m./ha /year).
	Decree concerning the protection of waters against pollution caused by nitrates from agricultural sources (Official Gazette of the Republic of Slovenia, no. 113/09)	Application of organic fertilizer on agricultural land is limited by the amount of nutrient with 250 kg/ha Nitrogen.
Slovakia	Act No. 220/2004 Col. on protection and using of agricultural soils	Lays down limit concentrations of risk elements in agricultural soils

	Ministry of Agriculture Decree No. 26/2000, on fertilisers.	Lays down fertiliser types, max. concentration of risk elements in organic fertilisers, substrates and commercial fertilisers, storage and take-off conditions, and methods of fertiliser testing
United Kingdom	Each country of the UK has different requirements Here is an example of parts of the regulations applicable for England and Wales	• Use in agriculture and applications to soil other than land restoration: A Waste Management Licence Exemption, Paragraph 7A, must be obtained by the land owner/manager before accepting and storing then spreading compost. The compost must be made from source segregated bio-waste. Per Paragraph 7A exemption: • ‘Benefit to agriculture’ or ‘ecological improvement’ must be demonstrated, which is done by spreading compost as per Nitrate Vulnerable Zone regulations if within a NVZ, and following the Codes of Good Agricultural Practice for the Protection of Soils and Water. Given the typical total nitrogen content of ‚Green compost ‘, the application rate would be approximately; • 30 - 35 fresh tonnes per hectare per year where a field NVZ limit of 250 kg total nitrogen per hectare applies, • 30 fresh tonnes per hectare per year if ‚Not NVZ‘ but as per good agricultural practice, or • 60 – 70 fresh tonnes per hectare once per two years if ‚Not NVZ‘ but as per good agricultural practice. • If the compost is classed as a waste, the Environmental Permitting Regulations apply (paragraph 7 exemption, U10 exemption or Standard Rules Permit) and a permit or exemption will be required by the land owner/manager before storing or spreading the compost. If the compost has ceased to be waste • Voluntary Code of Good Agricultural Practice for the Protection: limitation of nitrogen of 250 kg /ha/y (for all types of ‘organic manure’ used, including composts); compost can also be applied at a rate of 500 kg/ha once per two years

Annex G Admissible maximum annual heavy metal dosage (g/ha*y) to soil in European national legislation and standards [adapted from Saveyn and Eder, 2014] and in the United States of America

Country			Cd	Cr_{tot}	Cr^{VI}	Cu	Hg	Ni	Pb	Zn	As	Se
United States	Sewerage sludge		1,900			75,000	850	21,000	15,000	140,000	2,000	5,000
European Community	Sewerage sludge[1]	10 y basis	150	3,000	-	12,000	100	3,000	15,000	30,000	-	-
Austria	Sewerage sludge [2]		20	1,250	-	1,250	20	250	1,000	5,000	-	-
	Fertiliser. Ord.	2 years basis	5	300	-	350	5	200	300	1,500	-	-
Cyprus	No data available		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Czech Republic	Sewage sludge max. 5 t d.m./3y in agriculture	yearly	5	200		500	4	100	200	2,500	30	
Germany [1]	Sewage sludge		16	1,500	-	1,300	13	300	1,500	4,100	-	-
Denmark	7 t d.m. basis / calculated		5.6	700		7,000	5.6	210	840	28,000	-	-
	related to 30 kg P2O5/ha / calculated		3	-	-	-	6	75	300	-	-	-
Estonia	No data available		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Spain	RD 1310/1990 (SS)	10 years basis	150	3,000		12,000	100	3,000	15,000	30,000	-	-
Finland	Sewage sludge		3	300		600	2	150	150	1,500	-	-
	Decree of the Ministry of Agriculture and Forestry on Fertiliser Products 12/07 (average		1.5									

	based on 4,10 or 40 years application)											
France	NF U 44 51 (comp.)	10 years basis	15	600		1,000	10	300	900	3,000	90	60
	NF U 44 51 (comp.)	yearly	45	1,800		3,000	30	900	2,700	6,000	270	180
Greece	No data available		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hungary	Sewage sludge (under Nr. 50/2001.)		150	10,000	-	10,000	100	2,000	10,000	30,000	500	1,000
Ireland	SI 148/1998 [use of sewage sludge in agriculture]		10	1,000	-	1,000	10	300	750	2,500	-	-
Italy	DCI 27/07/84 - MWC from mixed waste		15	2,000	15	3,000	15	1,000	500	10,000	100	-
Lithuania	No data available		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Luxembourg	No regulation		-	-	-	-	-	-	-	-	-	-
Latvia	Sewage sludge		30	600		1,000	8	250	300	5,000		
Malta	No data available		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Netherlands	Nutrient loads (N,P) are the dosage limiting factor		-	-	-	-	-	-	-	-	-	-
Poland	Sewage sludge		20	1,000		1,600	10	200	1,000	5,000	-	-
Portugal [1]	Sewage sludge /10 y basis		150	4,500		12,000	100	3,000	15,000	30,000	-	-
Romania	No data available		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sweden	SNFS 1992:2 (sewage sludge)		0.75	40		300	1.5	25	25	600	-	-

Slovenia	Sewage sludge use in agriculture on 10-year basis	15	2,000	-	3,000	15	750	2,500	12,000	-	-
Slovakia	No regulation	-	-	-	-	-	-	-	-	-	-
United Kingdom	Sludge (use in agriculture) Regulations 3) sewage sludge average annual loading over 10 years	150	?	-	7,500	100	3,000	15,000	15,000	-	-

1) Directive 86/276/EEC; average within 10 years

2) Sew. Sludge Ordinance, Lower Austria (Class III)

3) S (UiA) regulations: Statutory Instrument 1989 No. 1263, The Sludge (Use in Agriculture) Regulations 1989 The QCP (England and Wales) sets maximum allowable concentrations for PTEs in soils that receive Quality Composts, as specified in the Sludge (Use in Agriculture) Code; these are more stringent than the soil PTE maximum allowable concentrations allowed in the regulations.

SS: Sewage Sludge

Annex H Compost quality assurance schemes in European countries [adapted from Saveyn and Eder, 2014]

Country (Quality label)	Status of quality assurance activities and certification/quality assurance organisation
Austria	Fully established quality assurance system based on Austrian Standards ÖNORM S2206 Part 1 and 2 and Technical Report ONR 192206 published by the Austrian ÖNORM Standardisation Institute. Up to now two non-profit associations have adopted these standards for granting a compliance certification with the QAS: 1 the Compost Quality Society of Austria KGVÖ (Kompostgüteverband Österreich) 2 the Compost & Biogas Association – Austria (ARGE Kompost & Biogas – Österreich) The certification schemes comprise both, operational process and quality management and final product approval. Thereby the most important references are the requirements set by the Austrian Compost Ordinance which provides for a comprehensive documentation and monitoring programme. Compost can get product status if it meets one of the 3 classes based on precautionary requirements (class A+ (top quality for organic farming), class A "Quality compost"(suitable for use in agriculture, horticulture, hobby gardening and Class B (minimum quality for "compost" restricted use in nonagricultural areas). Under the roof of **Compost Quality Society of Austria (KGVÖ)** large scale compost producers supplemented by experts, grant an additional quality seal for the marketing of high-quality composts on the basis of the officially acknowledged quality assurance system. External labs collect the samples and analyses. Evaluation of the results, documentation and granting of the label is carried out by an independent quality committee with expert members of the KGVÖ. (16 members - 300.000 t capacity) **Compost & Biogas Association Austria (ARGE** Kompost & Biogas) was founded to establish the decentralised composting of separately collected bio-waste in cooperation with agriculture (on-farm composting). Nowadays the association has grown to a full-scale quality assurance organisation on the basis of the common Austrian standards. ARGE uses external auditors for sample taking, plant inspection, evaluation, documentation and certification of the plants. (370 members - 300.000 t capacity),
Belgium	Fully established statutory quality assurance system for compost in the Flanders region operated by the non-profit **Flemish compost organisation VLACO vzw** with its members from municipalities, government and composting plants. (Around 40 green and bio-waste plants with 840.000 t of capacity). Based on the Flemish Regulation on Waste Prevention and Management VLAREA act VLACO vzw show a very unique but effective integrated approach and a broad range of tasks. The organisation executes: 1. Waste prevention and home composting programmes 2. Consultation and advice for process management incl. co-composting and co-digestion 3. Sampling, organisation of the analysis and evaluation of the results 4. Organisation of field trials and development of application information 5. Marketing and Public Relation for organic waste recycling and first of all for the compost. So by means of this integrated approach the whole organic loop from source material to the use of the final product is in one hand. Nevertheless, some modifications are made lately in order to include elements of ISO 9000 and the Total Quality Management TQM the quality assurance of anaerobic digestion residuals and of manure into the system. Not only the end-product is controlled but the whole process is followed up. In TQM the input (the bio or green waste), the process and

	the output are monitored and analysed. The reason to put standards on the input is that this allows no dilution. Depending on source materials and product characteristics up to 15 different products can be certified (statutory) and labelled (voluntarily) by VLACO vzw.
Czech Republic	Voluntary quality assurance scheme proposed by the **regional Environmental and Agricultural Agency ZERA** is in preparation for a quality assurance scheme for 2008 after new bio-waste Ordinance is in force. Main task is to create a compost market by certifying compost products and organise a practical inspection and control of compost. The certification scheme is based on requirements of the Czech institute of accreditation in the agreement with international norm CSN EN ISO/ IEC 45011:1998
Germany	Fully established voluntary quality assurance system for compost and anaerobic digestion residuals in which the **Compost Quality Assurance Organisation (Bundesgütegemeinschaft Kompost BGK)** organisation is the carrier of the RAL compost quality label. It is recognised by RAL, the German Institute for Quality Assurance and Certification, as being the organisation to handle monitoring and controlling of the quality of compost in Germany. The BGK was founded as a non-profit organisation in order to monitor the quality of compost. Through consistent quality control and support of the compost producers in the marketing and application sectors, the organisation promotes composting as a key element of modern recycling management. 425 composting and 67 digestion plants with 5.9 mio t capacity plants take part in the quality assurance system and have applied for the RAL quality label. Besides the central office, a quality committee works as the main supervision and expert body in the quality assurance system. In addition, BGK runs a database with all indicators of the composting plants and analyses results of the products. Meanwhile it includes more than 35.000 data sets. The BGK has defined a general product criteria quality standard (the RAL quality label GZ 251 for fresh and mature compost as well as for compost for potting soil compost and for different types of digestion residuals RAL GZ 245 (new since 2007 RAL GZ 246 for digestion products residuals from treatment renewable resources (e.g. energy crops)) and established a nationwide system for external monitoring of plants and of compost and digestion products. The quality assurance system comprises the following elements: Definition of suitable input in accordance with bio-waste and fertiliser regulation. 1 Operation control by plant visits of independent quality managers. 2 External and internal monitoring □ Quality criteria and quality label do demonstrate the product quality; 3 Compulsory declaration and information on correct application; 4 Documentation for the competent authorities. The successful work is respected by the authorities in Germany by exempting member plants from some control requirements which are subject to the waste legislation. By means of that procedure quality assured compost show a "quasi" product status in Germany.

Denmark	A quality assurance system for compost (quality criteria, standardised product definition, analysing methods) is prepared by **DAKOFA (Danish Association on waste management)** but is not applied. No further progress expected for the moment because separate collection of kitchen waste will not increase before the present legal background. Green waste collection and composting is very well diffused but not subject to any waste and quality standards regulation in Denmark.
Spain	Draft statutory Spanish standard on compost legislation, laying down standardised, nationwide rules concerning the production, marketing and labelling of compost as a product prepared by the Ministry of Environment. A lot of studies confirmed for Spain the need to improve the compost quality in order to open up markets. This was in the outcome of a LIFE Project too deemed to investigate the production and use of quality compost in Andalusia. Based on the results **the Andalusia´s Regional Ministry of Environment** has designed and registered a trademark “Environmental Accreditation of Compost” that allows - on a voluntary basis - companies producing compost to show its quality. The Order 20/07/07 Environmental Accreditation of Compost Quality. BOJA nº 156 8/8/2007 explains how to get and use it. Compost should fulfil some limits according to the Real Decree 506/2013, 8/7/05, about fertilisers. It is the Andalusia´s Regional Ministry of Environment who will control the label use and define accredited laboratories to analyse compost samples. There is no independent sample taking.
Hungary	Voluntary Hungarian Compost Quality Assurance System is prepared (but not implemented) by the Hungarian Compost Association and waiting for the revision of the existing regulations which are intended for sewage sludge and fertilisers and are not applicable for composting. The **Hungarian Compost Association** has completed in 2006 the framework of the assurance system (similar to the German BGK and Austrian KGVÖ examples) and is now waiting for the new Hungarian Statutory rule about production, nominating, marketing and quality assurance for composts. Basic elements of the future Compost Quality Assurance Systems (implementation in 2009) are: 1. Raw material list (permissive list) 2. Compost Classes The Ordinance will define three different quality classes for compost based on the contaminant content. Will also define ways of utilisation. The classes (similar to the Austrian ones) will be: 3 Class A - top quality (suitable for organic farming use) 4 Class B - high quality (suitable for agricultural use) 5 Class C - minimum quality (not suitable for agricultural use) 3. Quality control End-product controlling and process controlling. Independent sample taking and analysis is intended.
Ireland	A first draft for a voluntary compost quality standard was presented in Ireland (2007). This task and the follow up establishment of a quality assurance system are elements of the national Market Development Plan - intended to create market for recyclables - have recently started. The **Irish Composting Association CRE** supports is involved in these developments. Limits for pollutants, stability, etc. are specified in waste authorisations (e.g. EPA Waste licences and Local Authority waste permits).
Italy	Voluntary quality assurance on operated by the **Italian Compost Association CIC**, the Italian National Association for the compost industry. It started as certification system for compost products in order to show compliance with the national fertiliser

	regulation and the statutory quality standards for green and mixed compost are laid down there. No monitoring of the standard is proposed. Basically, the quality label ensures fulfilment of statutory standards (assessment of compliance is usually an issue due to the rather poor performance of controlling authorities, hence CIC aims to reinforce the “declaration of compliance”). Within the scheme samplings are made by certificated personnel from the Italian Composting Association (CIC) and analyzed at a single accredited laboratory. Now the scheme turns step by step into a quality assurance system e.g. with preparation of certifying the entire production process and above all (as requested by consumers) the traceability of compost. The CIC Quality Label is considering this to be a very important initiative for the industry because it provides an independent element of security upon which consumers and operators can make their choices. Currently, the quantities of compost that can be certified amount to approx. 250,000 tons /y, which represents approximately 20% of the Italian production
Luxembourg	Statutory system which relies on the German Quality Assurance System and on the German Organisation (**Bundesgütegemeinschaft Kompost e.V. BGK**). The request to execute a "quality assurance system like the one of BGK or similar" is part of the licensing procedure for every composting plant. Missing alternatives have established the BGK system in Luxembourg as the one and only. All independent sampling, control functions and documentation functions will be executed by the BGK representatives. (5 compost plants with around 50.000 t/y total capacity are part of the scheme)
Latvia	On the starting stage (from Nov. 2006), quality assurance organization Environmental Agency.
Netherlands	After 10 years of experiences the Dutch Government decided that not the quality, but the nutrients are the primary precautionary problems with compost. Less strict heavy metal thresholds and no obligations for control any more is one result. In addition, no longer is the applied amount of compost but the nutrient load limited. All compost which is used for crops which grow in the soil must be independently certified with a very strict threshold for glass. Because the sales area of compost is not predictable while the production, more or less all bio-waste composts, will be certified in future and compost certification will become quasi statutory. As of 2012, there is one certification type for both VFG and green waste. The BVOR Dutch Association of Compost Plants and Dutch Waste Management Association DWMA/VA manage the certification system in both the green waste and VFG sectors which doesn't require external sampling but independent institutes/auditors for the evaluation of the process and the analysis results.
Poland	Quality Assurance refers only to the final product. The Ministry of Agriculture and Rural Development gives the certificate of organic fertiliser based on its chemical properties and pathogen status after the compost receives a positive expertise from the designated institution (depending on planned application area).
Sweden	Voluntary quality assurance system for compost and digestion products is operated by the **Swedish Waste Management Association Avfall Sverige** together with Swedish Standardisation Institute SP. For the moment Sweden has no statutory standard, but the necessity of standards is seen clearly by involved parties and the government. Producers and users are of the opinion that sustainable recycling of organic wastes demands clear regulations

CERTIFIERAD ÅTERVINNING	regarding what is suitable to be recycled and how it should be managed and controlled. A well-founded quality assurance programme definitely increases sustainable recycling of organic wastes. The regulations for the voluntary Swedish certification of compost and digestion residues are based on purely source-separated organic waste, with special emphasis on the acceptability of raw materials for input, the suppliers, the collection and transportation, the intake, treatment processes, and the end product, together with the declaration of the products and recommendations for use. 6 digestion and 1 composting plant are included in the certification system and have applied for the certificate.
United Kingdom COMPOSTING ASSOCIATION CERTIFIED	Voluntary standard BSI PAS 100 and the supplementing Quality Compost Protocol (QCP) set criteria for the production and minimum quality of quality composts. The **UK Composting Association** owns a certification scheme aligned to BSI PAS 100, which has been upgraded to incorporate the additional requirements of the QCP. Composting plants and compost particle size grades that meet all the requirements can get their composts certified and use the Composting Association's quality mark. Around 150 composting producers are under assessment, treating more than 2 mio t of source segregated bio and green waste, and 40 % of the compost they produce is already certified. BSI PAS 100:2005 specifies the minimum requirements for the process of composting, the selection of materials from which compost is made, minimum compost quality, how compost is labelled and requires that it is traceable. It also requires Hazard Analysis and Critical Control Point assessment, the implementation of a compost Quality Management System and correct compost labelling and marking. Compliance with requirements of the QCP is considered sufficient to ensure that the recovered bio-waste may be used without risk to the environment or harm to human health and therefore without the need for waste regulatory control. In addition, The Quality Compost Protocol requires compost certification to PAS 100 and also imposes restrictions on materials from which quality composts can be made and in which markets they can be used as ‘product’. The QCP also requires the producer to supply customers with contracts of supply, and if Quality Compost is stored and used in agriculture or field horticulture, this must be done in accordance with the Codes of Good Agricultural Practice and that soil PTE concentrations do not exceed the Sludge Use in Agriculture Code’s limits. The Quality Protocol further aims to provide increased market confidence in the quality of products made from bio-waste and so encourage greater recovery of source-segregated bio-waste. In England and Wales, compost must be independently certified compliant with both PAS 100 and the Quality Compost Protocol for it to be supplied to the designated market sectors as a ‘product’. In Scotland, for compost to be supplied as a ‘product’ it must be certified to PAS 100 (or an equivalent standard), have certainty of market, be used without further recovery, not be subjected to a disposal activity and not be mixed with other wastes, materials, composts, products or additives. Northern Ireland’s position is currently similar to Scotland’s. Compost can be placed on the market as a recovered waste material in any of the countries of the UK; in this circumstance, waste management licensing regulation requirements must be adhered to. A number of local authorities have required PAS 100 certification in contracts with compost producers, and in England and Wales in particular, may start requiring certification to the Quality Compost Protocol as well.

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