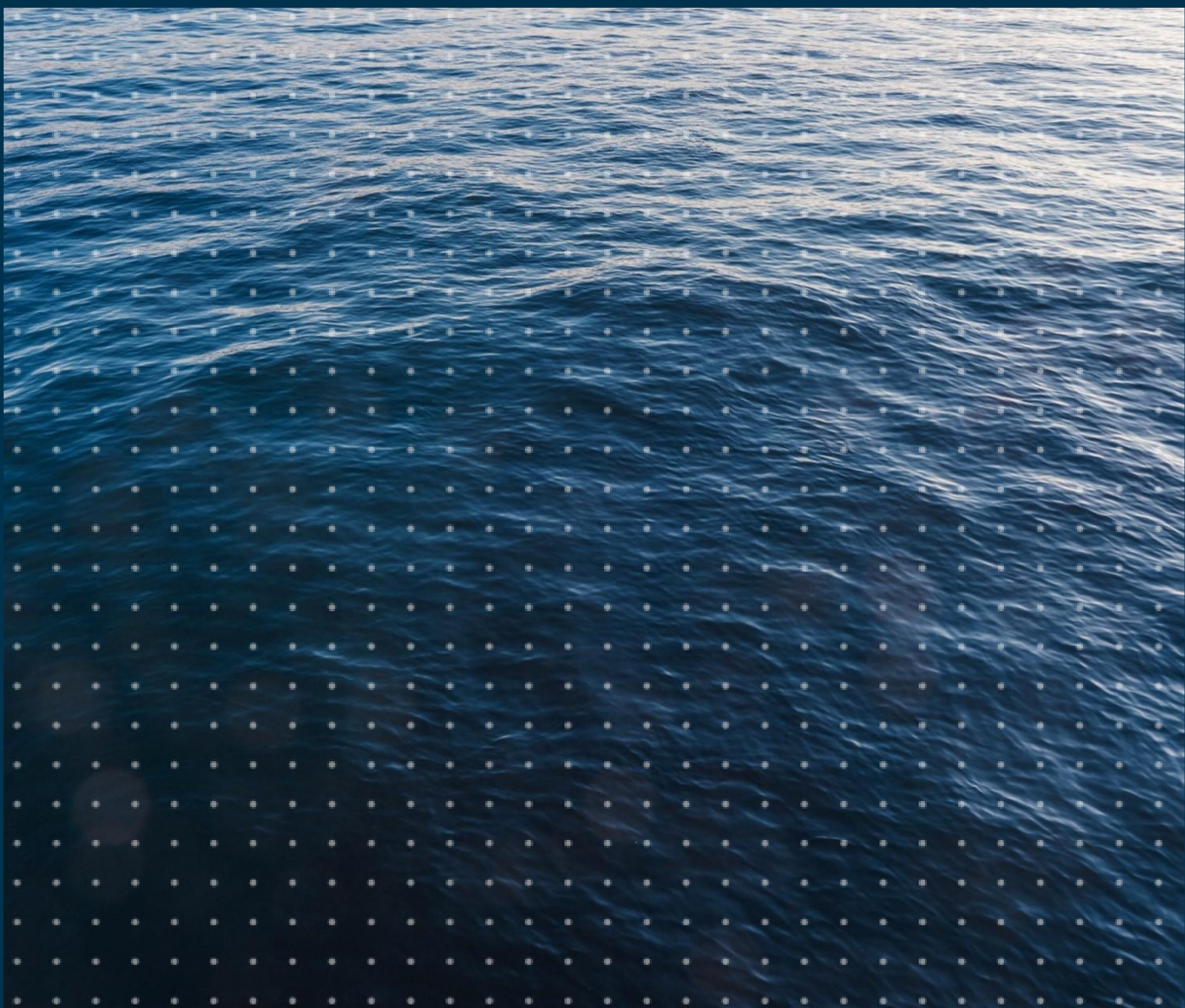
Environment Protection Authority

What's the GO with FOGO?

Study of food and garden composts and other recovered organics in NSW



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The global shift to a circular economy is putting the spotlight on recovering food waste. In the Waste and Sustainable Materials Strategy 2041 the NSW Government has affirmed its commitment to divert organics from landfill by mandating food and garden organics collection for all NSW households and select businesses by 2030.

This study examined composts derived from food organics and garden organics (FOGO) and garden organics (GO) across NSW as well as some dehydrated food waste outputs. The aim was to provide an evidence base to inform any management considerations that may be needed to ensure the sustainable processing and supply of recovered organics in NSW.

Executive summary

The NSW Government has been supporting the better use and recovery of organics in NSW since 2013 through a range of funding and investment initiatives. The *NSW Waste and Sustainable Materials Strategy 2041* (the strategy) was released in July 2021 to further guide this transition with targets for achieving a reduction in waste and emissions, reducing harm to our environment, and boosting innovation to help drive the economy.

The strategy also contributes to the *NSW Net Zero Plan Stage 1: 2020–2030* commitment for net zero emissions from organics waste in landfill by 2030. In addition, it aligns with the aims of the National Food Waste Strategy, which provides a framework to support collective action towards halving Australia's food waste by 2030.

The NSW Environment Protection Authority (EPA) conducted a study, known as *What's the GO with FOGO?* (the study), of recovered organics across NSW, particularly composts generated from **food organics and garden organics** (FOGO) and **garden organics** (GO). A preliminary study was conducted on composts from 10 FOGO facilities during 2019, and extended in 2020–21 to 13 FOGO facilities, five GO composting facilities and outputs from three on-site rapid dehydration food waste units (ORDUs). The study was undertaken in collaboration with the NSW Department of Planning and Environment's (DPE) Contaminants and Risk Team (DPE–C&R) and Chemical Forensics Team.

The study looked closely at the characteristics of several source-separated recovered organic materials with more than 260 parameters analysed. This is a much more extensive examination than 'normal' testing conducted nationally or internationally.

The purposes of the study were to:

- examine the physical, chemical and microbiological composition of FOGO and GO compost to ensure that the regulatory standards are appropriate and support safe and beneficial re-use of organic materials in NSW
- provide sound evidence for any management considerations that may be needed for the continued support and funding for source-separated FOGO collection and the sustainable recovery of organic materials in NSW.

Key findings

While most of the recovered organics met their current regulatory requirements in NSW, a number of chemical contaminants were detected in the composts that are not currently regulated. These have been traced back to seemingly innocent 'scope creep' in the materials that have been accepted as inputs in kerbside collections.

Microbiological findings included the frequent detection of viruses and human intestinal worm eggs. The source of these pathogens remains unknown at present, but ensuring pasteurisation is achieved consistently may require closer attention.

Precautionary measures have already been implemented to reduce the potential sources of chemicals and pathogens being disposed of in kerbside FOGO or food organics (FO) only bins. One measure has been an EPA position statement, *FOGO information for households*, on what can and cannot be placed into FOGO bins: this was released in July 2022. The pathogen risks identified by *What's the GO with FOGO?* can be reduced with good hygiene practices.

Chemical and other attributes identified in the study

Nutrients

Food waste is generally high in nutrients such as nitrogen, potassium and phosphorous that are essential for healthy plant growth. The plant nutrient nitrogen was higher in FOGO than GO compost. This was expected as kitchen and food wastes have a higher concentration of nitrogen than garden waste. ORDU outputs had the highest nitrogen concentrations but also the highest salt content, which limits their application conditions.

Salts

All the recovered organics sampled were moderately to extremely saline, which will increase salts in the soils to which they are applied and may limit plant growth. The source of salt in the samples is predominantly food waste, as demonstrated by the increasing sodium and electrical conductivity (EC) from GO to FOGO to ORDU outputs. Salinity must be considered to guide appropriate use of recovered organics.

Metals

Metals were commonly detected in all FOGO, GO composts and ORDU outputs. The concentrations detected were generally below the upper limits recommended under the voluntary Australian industry standard for composts, soil conditioners and mulches (AS 4454) and the British Standards Institution's Publicly Available Specification 100 for compost (PAS 100).

Pesticides

From a suite of 93 pesticides tested, none were detected in ORDUs and six were detected infrequently in FOGO and GO composts. These were the organochloride pesticides (OCPs) chlordane, dieldrin and DDT, and the herbicides glyphosate, 2-methyl-4-chlorophenoxyacetic acid (MCPA) and clopyralid. Some of the OCPs were above the industry Australian Standard AS4454 for composts, soil conditioners and mulches. Further work is needed to determine if these are sporadic findings.

Phthalates and phenols

The only phthalate detected was diethylhexyl phthalate (DEHP) and it was detected in FOGO, GO composts and ORDU outputs. Review of the literature indicates that the presence of DEHP at the concentrations detected is unlikely to be of concern.

For the phenol group of chemicals, phenol, m-cresol and p-cresol were detected in FOGO composts only. There is limited terrestrial ecotoxicity data for phenols; however, they have low persistence and degrade readily in aerobic soils, which means they are likely to pose low long-term risks.

PFAS and PBDE chemicals

Per- and polyfluoroalkyl substances (PFAS) and polybrominated diphenyl ethers (PBDEs) were identified in both FOGO and GO composts. PFAS was not detected in the ORDU samples but PBDEs were detected very close to the limit of detection.

A human health risk assessment was conducted for PFAS and PBDEs by DPE–C&R, which identified potential risks to human health for some exposure pathways relevant to FOGO and GO compost use.

Potential risks identified with PFAS and PBDEs in both FOGO and GO compost were related to the consumption of milk and meat from a person's own property where compost is surface-applied to land without incorporation.

Risks from the consumption of homegrown fruit and vegetables grown in surface-applied compost, without incorporation, were low and acceptable for the assumption that a person's fruit and vegetable consumption from homegrown produce is 10%. Exposures may be higher where there is greater consumption of home produce grown in soils where compost has been surface-applied without incorporation.

Some manufactured chemicals, such as PFAS and PBDEs, are likely to be introduced from sources placed into GO or FOGO collections. These sources may include fibre-based food contact materials that consumers have been innocently encouraged to view as suitable inputs for FOGO bins. To ensure risks are managed and reduced, precautionary measures have already been implemented. The EPA released a position statement on FOGO inputs in July 2022 which clarifies what can and cannot go into FOGO bins.

While potential risks have been identified in composts sampled in the study, a food survey led by Food Standards Australia New Zealand (FSANZ) in 2021 confirmed the safety of the general Australian food supply with regards to PFAS levels.[1] Another study by FSANZ, published in 2007, concluded that the Australian public health risk arising from dietary exposure to PBDEs in food is unlikely to be of public health and safety significance.[2] The precautionary measures proposed by the EPA in this report aim to reduce contaminants at various stages along the pathway from FOGO collection through processing to end use as soil amendments.

Chemicals not detected in any sample

The chemicals that were not detected in any sample were:

- organophospate pesticides (OPPs)
- glufosinate (herbicide)
- multi-residue pesticides (mix of 38 herbicides, insecticides and fungicides)
- polycyclic aromatic hydrocarbons (PAHs)
- bisphenol A
- triclosan.

Physical contaminants

All facilities except one FOGO and one GO facility complied with the physical contaminant limits in the Compost Order 2016. Those that failed did so for the absolute maximum concentration for plastics: light, flexible or film > 5 mm.

There is currently little information about microplastics in recovered resources that have plastic as known inputs. Precautionary measures have already been implemented to reduce the potential sources of physical contaminants disposed of into kerbside FOGO or food organics (FO) bins with the release of the EPA position statement on FOGO inputs.

Pathogens

Pathogens including adenovirus, *Ascaris* and *Taenia* ova (intestinal parasitic worms affecting humans) and spore-forming bacteria (*Clostridium perfringens* and *Bacillus cereus*) were identified in both FOGO and GO composts. *Taenia* ova and *Bacillus cereus* were detected in the ORDU

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[1] FSANZ 2021, 27th Australian Total Diet Study (ATDS), https://www.foodstandards.gov.au/publications/Documents/27th%20ATDS%20report.pdf

[2] FSANZ 2007, Polybrominated diphenyl ethers (PBDE) in Food in Australia, Study of concentrations in foods in Australia including dietary exposure assessment and risk characterisation, https://www.foodstandards.gov.au/science/surveillance/documents/PBDE_Report_Dec_07.pdf

samples. The bacteria *Salmonella* spp., *Campylobacter* spp. and *Legionella* spp. and the viruses reovirus and norovirus were not detected in any sample.

As there are no guideline limits for some of these pathogens, a quantitative microbial risk assessment (QMRA) was conducted for adenovirus and *Ascaris*. QMRA modelling developed by the DPE–C&R team is considered a novel approach internationally.

The QMRA identified potentially unacceptable risks associated with adenovirus for all exposure scenarios involving surface application and soil-incorporated FOGO and GO composts. The potentially unacceptable risks with *Ascaris* ova in domestic scenarios were associated with handling FOGO and GO composts when potting plants and consuming unwashed homegrown vegetables. In the agricultural scenarios risks were associated with farmworkers handling FOGO composts. The risk associated with *Ascaris* ova is marginal to minor compared to that posed by adenovirus. The risks identified can be reduced with good hygiene practice – for example, wearing a mask and gloves, and washing hands.

Recommended measures to support sustainable composting in NSW

The learnings from the study indicate that certain measures can ensure that compost derived from FOGO and GO is of high quality and safe for humans and the environment.

Better control on inputs and initial processing is needed to reduce the likely sources of contaminants

This can be achieved by:

1. ensuring that physical contaminants such as plastics, glass, metals and paper-based food contact materials are kept out of food and garden waste bins. The EPA's position statement released in July 2022 says that only food and garden waste should be placed in the FOGO bins, the only exceptions being fibre or compostable-plastic kitchen caddy liners
2. ensuring that any physical contaminants are removed before composting begins.

Improved process monitoring and record keeping are needed to manage pathogens

Better record keeping and monitoring of processing practices is needed to determine why pathogens have been detected in composts and how to remove or reduce them.

It can also help establish whether compost is being consistently pasteurised to inactivate pathogens and/or whether pathogens are being added at a later stage of the composting process.

Anyone handling compost should be encouraged to follow good hygiene practices, to minimise risks from pathogens.

Amendments to current monitoring requirements for final composts may be required

The EPA will further consider whether pathogens and key chemicals need to be monitored.

Introduction

The NSW Government is committed to net zero emissions of organics waste in landfill by 2030, halving organics waste to landfill by 2030 and recovering 80% of all waste by 2030.

Methane production from food, garden and textile waste accounts for 3.1 million tonnes of carbon dioxide equivalent (CO_2-e) generated each year from landfills in NSW, accounting for 56% of the total waste emissions from landfill. Collected at the kerbside and processed into compost or used to generate energy, food and garden waste is a valuable resource. Composted organics reduce emissions and return carbon to soils.

Since 2013 the NSW Environment Protection Authority (EPA) has been supporting organics recovery through the $105.5 million Waste Less Recycle More (WLRM) Organics Infrastructure Fund. This program has resulted in 70% of NSW households with a general waste red-lid bin now having access to an organics collection service (up from 56% in 2010–11), and an additional organics processing capacity of 800,000 tonnes a year.

The NSW Government has allocated an additional $69 million to 2027 to deliver on the commitments under the Net Zero Plan Stage 1 and the *NSW Waste and Sustainable Material Strategy 2041*. These commitments include requirements for all households and certain large businesses that generate the highest volumes of food waste to source-separate organic waste for processing by 2030 and 2025 respectively. The source-separation requirements will divert up to 800,000 tonnes more organics waste from landfill per year by 2030, significantly increasing **food organics and garden organics** (FOGO) volumes.

This report presents the findings of an EPA study, *What's the GO with FOGO?*, of composts generated from FOGO, **garden organics** (GO) and outputs from **on-site rapid food waste dehydration units** (ORDUs) across NSW. The purpose of the study was to examine the physical, chemical and microbiological composition of these composts and other recovered organic wastes, to ensure that the regulatory standards are appropriate and support safe and sustainable resource recovery in NSW.

The study provides the evidence base to support a food-waste recovery pathway that is sustainable and which will deliver economic, employment and environmental benefits for NSW communities. This will be a circular-economy outcome for organics.

1. Scope of the study

The study focused on recovered organics, particularly composts generated from FOGO and GO, across NSW. It was done in collaboration with the Contaminants and Risk Team and the Chemical Forensics Team in the NSW Department of Planning and Environment (DPE).

The study's purpose was to examine the characteristics of composts and other recovered organics produced from source-separated food and garden wastes. This in turn was to generate a sound base of evidence for any management considerations that may be needed for the expansion of FOGO collections across NSW under the mandated targets of the *NSW Waste and Sustainable Materials Strategy 2041* (WaSM).

Under the EPA's Compost Order 2016, compost must be tested for three microbial organisms (*Salmonella*, *Escherichia coli* and thermotolerant (faecal) coliforms) and physical contaminants (light and rigid plastics, metal and glass). Little information has been available on many chemical and microbiological characteristics of compost produced in NSW. To address this knowledge gap, compost samples were analysed for approximately 260 attributes including chemicals, physical contaminants and microbiological pathogens that are relevant to human health. The range of attributes tested are in the study's data (a separate document, available on the EPA website).

1.1. Selected sites to represent facilities in NSW

The study assessed compost from a range of geographic locations and process types. In 2019, the EPA conducted a preliminary study by sampling FOGO composts from 10 facilities receiving food and garden organics waste from metropolitan, regional and rural areas of NSW. In 2020–21 the study was expanded to a total of 18 composting facilities processing GO and FOGO across NSW (including nine of the 2019 facilities). This represents approximately 26% of EPA licensed facilities in NSW that compost either GO or FOGO wastes. Facilities composting biosolids (or taking any waste other than FOGO or GO) and anaerobic digestates were excluded from the study.[3] On-site rapidly dehydrated food-waste units (ORDUs) were added to provide further data for food-only wastes. The sites selected are shown in Figure 1 and comprise:

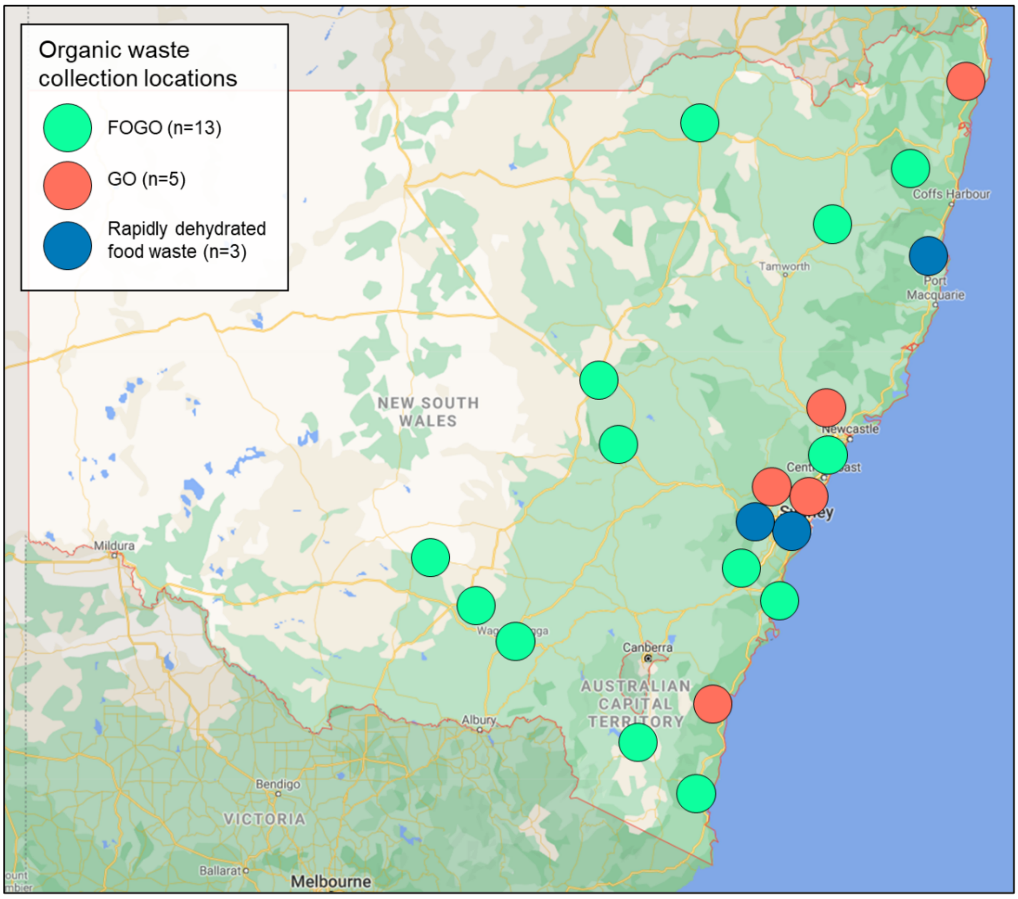
- 13 FOGO composting facilities – process food and garden organic waste
- 5 GO composting facilities – process garden waste only and do not accept food waste
- 3 ORDUs – these produce, not a compost, but a dehydrated food waste generated from cafes and similar businesses.[4]

A range of processing technologies was represented in the study. The study included FOGO compost generated using a mobile aerated floor (MAF) as part of an open windrow process; tunnel composting followed by windrow processing; and conventional windrow composting (with minor site-specific variations such as the use of covers and/or microbiological cultures). The GO compost was generated using MAF followed by conventional windrows; static aerated windrows with covers; and conventional windrows. The EPA also tested outputs from two types of ORDUs. ORDUs dehydrate food wastes by mechanical mixing and heating of food wastes for periods of up to 24 hours.

[3] Anaerobic digesters processing FOGO waste were not available for sampling at the time of this study.

[4] Composts are produced through managed biological transformations as defined in the *Compost Order 2016*.

Figure 1 The 2020–21 samples in the study were taken from a range of recovered organics facilities from metropolitan, regional and rural areas of NSW.



1.2. Sampling

Three independent replicate samples were collected from each facility in 2020–21 and two in 2019 for analysis of chemical and physical contaminants.

- Each replicate was a composite of five discrete (grab) samples.
- The only exceptions to this sampling design were due to errors on the sampling days, where only one independent composite sample was collected. The exceptions were:
  - one FOGO and one GO facility during the 2020–21 round
  - one FOGO facility during the 2019 round.

Discrete (grab) samples were taken for microbiological analysis (bacteria, viruses and helminths) for both rounds of sampling in 2019 and 2020–21.

- In the 2020–21 sampling round, three discrete samples were taken randomly across the FOGO and GO compost piles with one taken at 30 cm depth and two at 60 cm depths.
- The only exception to this sampling design was at one GO facility where only two samples were taken for virus and helminth testing and three samples were taken for testing of bacteria. These exceptions were due to errors at the time of sampling.
- For the 2019 round, discrete samples were taken for microbiological analysis at both surface (30 cm below surface) and at depth (60 cm below surface). Sample numbers collected were:
  - between two and four for virus and helminth analysis from all 10 facilities sampled

- between two and four for bacterial analyses from six of the 10 facilities sampled.[5]

Samples for bacterial analysis were delivered to the laboratories within 24 hours of collection. Samples for virus, helminth, chemical and physical contaminants analyses were kept refrigerated and delivered within a few days of collection.

Questionnaires were done at the time of sample collection and included information on the sources of inputs, contaminants observed by facilities, type of processing and time frame required to produce final product, monitoring and testing conducted by the facility.

1.3. Wide range of attributes

A total of 266 chemical, microbiological and physical parameters were analysed for the groupings in Table 1**.** Two laboratories were engaged for the analysis of the chemical and physical attributes and two laboratories for the microbiological attributes. The full list of attributes analysed is provided in the study's data (a separate document, available on the EPA website). Each attribute group is discussed separately in this report.

Table 1 General grouping of attributes analysed for all samples collected in this study

Chemicals	Microorganisms	Physical contaminants
• Metals • Pesticides (incl. OCPs, OPPs and herbicides) • Per- and polyfluoroalkyl substances (PFAS) • Polybrominated diphenyl ethers (PBDEs) • Petroleum hydrocarbons (incl. PAHs and phenols) • Phthalates • Salts, pH and electrical conductivity (EC) • Nutrients	• Bacteria • Helminths • Viruses	• Glass • Metal • Rigid plastics • Flexible plastics

[5] Four of the 10 sites sampled during 2019 were omitted for bacteriological testing because samples could not be delivered to laboratories within the 24-hour sample holding times.

2. Chemical findings

The findings for each chemical group are reported separately in this section.

2.1. Nutrients

Sources of plant nutrients

Nitrogen, potassium and phosphorous are essential nutrients that plants need for healthy growth, and these are made available through microbiological breakdown of organic materials such as food and garden waste. These nutrients are also available to plants by adding inorganic fertilisers.

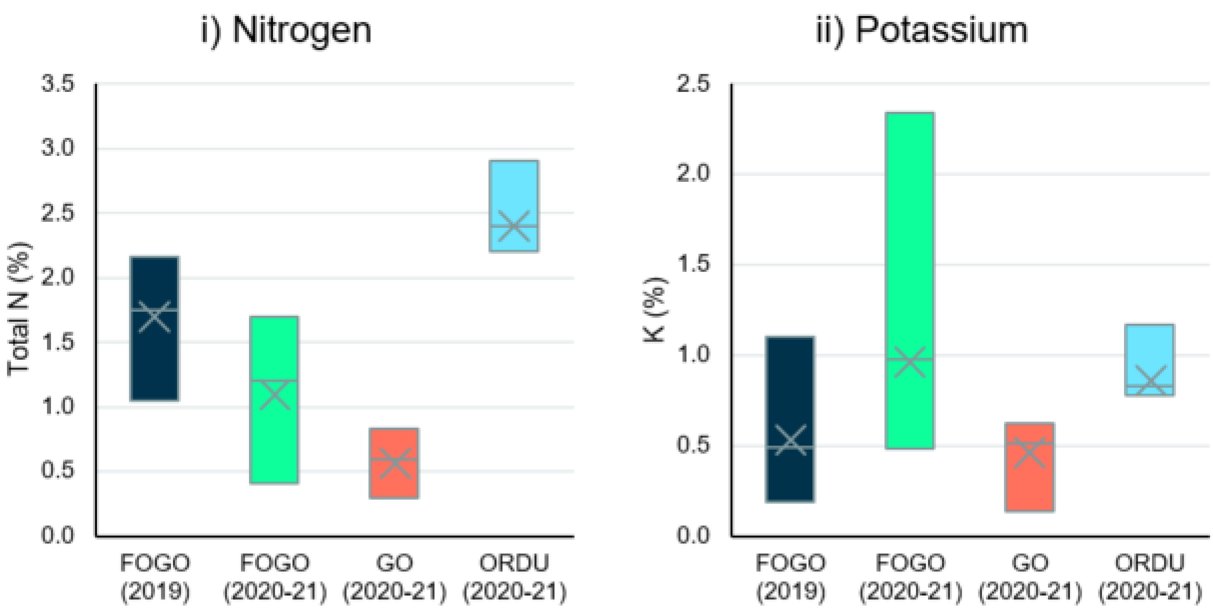
Study findings

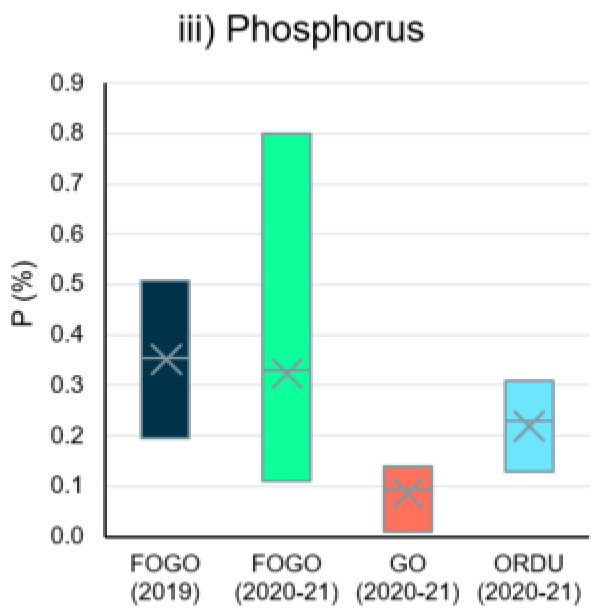
Figure 2 provides a visual comparison for the range of concentrations found for the nutrients nitrogen, potassium and phosphorus in FOGO, GO and ORDU samples collected in the study. ORDUs had the highest concentrations of nitrogen followed by FOGO then GO. This is not surprising as kitchen and food wastes have higher concentrations of nitrogen than garden waste. ORDUs also had the highest salinity (see Section 2.2).

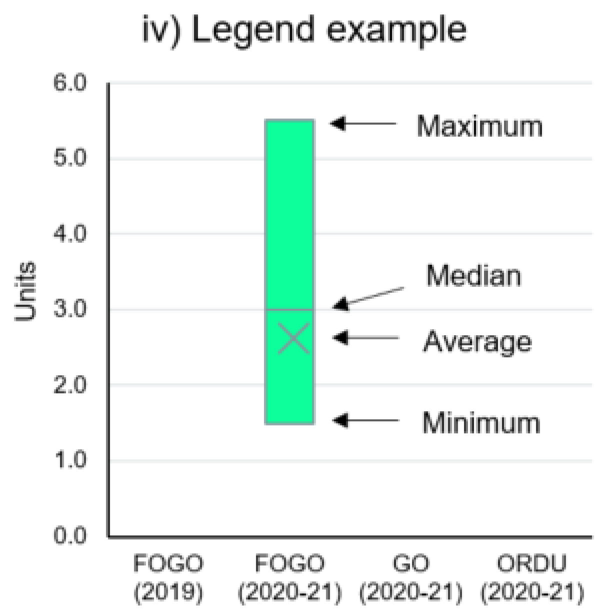
As expected, all of these amendments are a source of nitrogen, with increasing quantities of food waste inputs contributing to increased nitrogen in the output. Plants use nitrogen in the form of nitrate and ammonium. Nitrogen in compost is not immediately available and needs to mineralise before plants can access it. Mineralisation rates of approximately 15–20% are generally expected for composts in the first year after application.

Figure 2 Range of concentrations of the nutrients nitrogen, potassium and phosphorus in FOGO and GO composts, and ORDU outputs in samples from both the 2019 and 2020–21 sampling rounds

All measured values are presented as percentages.







2.2. Salts

Sources and significance of salinity and sodicity

Salinity is defined as the amount of soluble salts in soil or water, or in this case recovered organics. Where there is too much soluble salt, plant growth is affected. Where the cation composition in soil is dominated by sodium (known as sodicity), soil degradation can occur. All soil contains sodium, but it should be in proportion to other soil cations, including calcium, magnesium and potassium.

Sodium chloride can have severe adverse effects on soil by (a) raising the electrical conductivity (EC) and (b) changing the physical condition of the soil. Raising the EC leads to an increase in the osmotic potential of soil water, which can result in plants being unable to access soil water. The physical condition of the soil can also be affected by sodium, which can exchange with other cations (e.g. calcium, magnesium and potassium) on clay particles, leading to a greater propensity for soil dispersion. This in turn leads to soil structural degradation and a decrease in infiltration rate, hydraulic conductivity and air-filled porosity. The organic amendments (GO, FOGO, ORDU) do not contain clay and so the risk of physical problems such as clay dispersion is unlikely if they are used as a growing medium. Even when applied to land the application rates assumed for composts (25 tonnes/hectare) are low enough that dispersion is unlikely to be an issue. However, there are likely to be adverse effects on plant growth before soil structural decline becomes a problem. There is also a relationship between EC and sodium such that sodic soil with a high EC will stay flocculated (clumped).

Food waste contains salts, including sodium chloride from table salt. Food waste as an input to composting or other recovered wastes will increase the salinity and sodium concentration in the final recovered organic destined for land application. It is therefore important to consider salinity and sodium to guide appropriate use of recovered organics.

Findings

Table 2 summarises the results for the major cations (sodium, calcium, magnesium and potassium), electrical conductivity and pH of the FOGO, GO and ORDUs sampled. Figure 3 provides a visual comparison of sodium, electrical conductivity and pH between the FOGO, GO and ORDU outputs.

In the study, both the total cation concentration (TCC) and EC measurements have many extreme values, and show that all three amendments are too saline for crop growth. In soil, TCC values above 7 mmol (+)/L (i.e. millimoles of positive charge per litre) indicate saline conditions. All but one facility had TCCs above 7 (ranging from 14.7 to 121.6).

Interpretation of soil EC is dependent on clay content. Critical threshold values for EC (1:5) range from <0.07 to 1.87 dS/m, dependent on clay. This has limited relevance here because this is a non-soil matrix, however it is a guide to plant response to salts. The EC 1:5 values range from 6 to 9 dS/m for ORDUs, 1.1-5 dS/m for FOGO and 0.23-2.1 dS/m for GO. Using conversion factors to express EC1:5 as ECe and comparing the data to other critical thresholds for plant growth indicates that all samples except one will cause some limitation to plant growth with many in the extremely saline range.

The pH of ORDU outputs was acidic ranging from 4.4 to 5.1 with an average of 4.8. GO composts tended toward neutral pH with a range from 5.7 to 7.6 and an average of 6.7. The pH of FOGO composts ranged from 6.4 to 8.8 and averaged above neutral at 7.5 to 7.9 in the two sampling rounds.

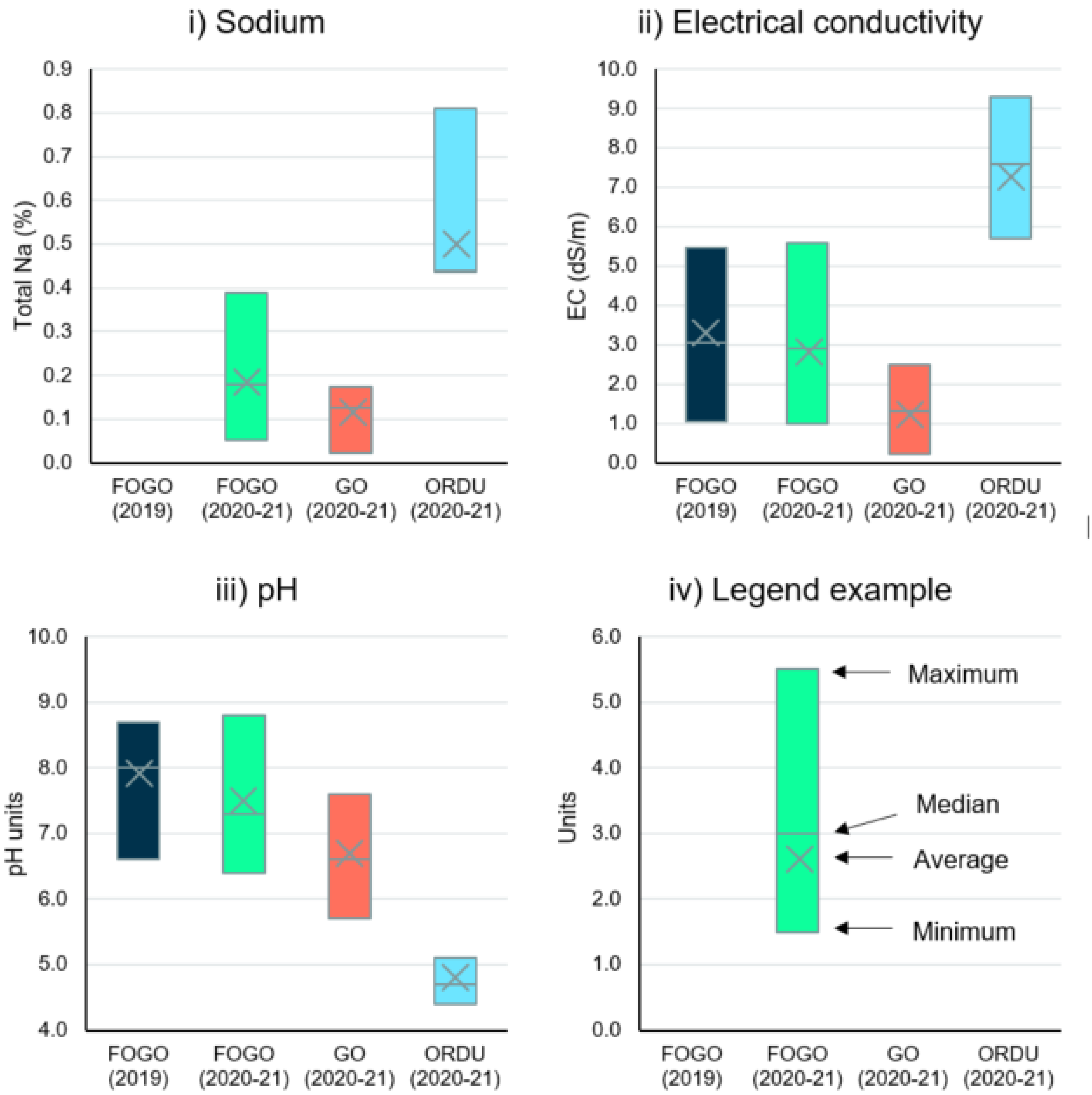
All FOGO, GO and ORDU samples analysed in the study were moderately to extremely saline, which could increase salts in the soils to which they are applied and limit plant growth. The increasing sodium and electrical conductivity (EC) in samples from GO to FOGO to ORDUs supports the premise that food waste is predominately the source of sodium and salinity. The salinity of the GO, FOGO and ORDU samples analysed was at a level detrimental to plant growth. Therefore, the material could not be used as a growing medium alone but rather as a soil amendment. The negative effects of high salt content need to be balanced against other beneficial properties of the recovered material to ensure the benefits outweigh the risks.

Table 2 **Range of salt concentrations, electrical conductivity and pH found in the study**

Salt concentrations are not available for the 2019 FOGO sampling event. Note that the concentrations of salts are based on an acid digest and are larger than the soluble fraction.

Chemical or parameter	Dataset	No. of samples	Minimum	Median[1]	Maximum	Average[1]
Calcium (mg/kg)	FOGO (2020–21)	37	10,700	22,000	44,800	23,100
	GO (2020–21)	13	5490	13,100	18,900	12,300
	ORDU (2020–21)	7	1620	10,400	25,700	11,500
Magnesium (mg/kg)	FOGO (2020–21)	37	2580	4400	8730	4630
	GO (2020–21)	13	1130	2020	3840	2440
	ORDU (2020–21)	7	980	1200	1310	1210
Potassium (mg/kg)	FOGO (2020–21)	37	4800	9780	23,400	9660
	GO (2020–21)	13	1330	5130	6210	4560
	ORDU (2020–21)	7	7700	8270	11,700	8690
Sodium (mg/kg)	FOGO (2020–21)	37	520	1790	3880	1870
	GO (2020–21)	13	240	1260	1730	1140
	ORDU (2020–21)	7	4370	4400	8100	5010
Electrical Conductivity (dS/m)	FOGO (2019)	17	1.1	3.1	5.5	3.3
	FOGO (2020–21)	37	1.0	2.9	5.6	2.8
	GO (2020–21)	13	0.23	1.3	2.5	1.3
	ORDU (2020–21)	7	5.7	7.6	9.3	7.2
pH (pH units)	FOGO (2019)	17	6.6	8.0	8.7	7.9
	FOGO (2020–21)	37	6.4	7.3	8.8	7.5
	GO (2020–21)	13	5.7	6.6	7.6	6.7
	ORDU (2020–21)	7	4.4	4.7	5.1	4.8

Figure 3 Comparison of sodium, electrical conductivity and pH findings between FOGO, GO and ORDU samples from sampling rounds in 2019 and 2020–21



2.3. Metals

Sources of metals

Metals occur naturally, and vary in concentration in soils according to regional geology. Metals are considered persistent chemicals that can cycle in the environment: even if they change in form, they remain in the environment. Increased metal concentrations following land application of recovered materials are of concern as they can affect plant and animal health and reproduction, and soil function; they may also contaminate the food chain and water supplies.

All samples collected in both sampling rounds of this study were analysed for the same metals: antimony, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, tin, vanadium and zinc.

Findings

Metals were detected in all FOGO, GO composts and ORDU outputs. Table 3 shows their concentrations. Most were generally below the upper limits set in the Australian voluntary industry standard AS 4454-2012, *Composts, soil conditioners and mulches*, or the British Standards Institution's *Publicly Available Specification (PAS) 100* for compost, or within background concentration ranges in soils where other limits were not available.[6,7] Most samples met the AS 4454 upper limits for metals: the exceptions were one sample of FOGO that exceeded the arsenic upper limit of 20 mg/kg (the concentration was 25 mg/kg) and eight samples of FOGO that exceeded the zinc upper limit of 300 mg/kg (330–980 mg/kg).

Some metals (arsenic, boron, chromium, cobalt, copper, lead, manganese, molybdenum, nickel, tin, vanadium and zinc) were detected more frequently than others (antimony, beryllium, cadmium, mercury and selenium) in both FOGO and GO composts. Fewer metals were detected in the ORDU samples (boron, chromium, copper, manganese, nickel, tin and zinc) than in the composts; however, it must be noted that the ORDU data is from a smaller sample size of seven samples from three units.

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[6] Berkman DA 1989 (3rd edition), *Field Geologist's Manual*, Australasian Institute of Mining & Metallurgy

[7] South Australian Health Commission 1995, *Contaminated Sites Monograph No.4: Trace Element Concentrations in Soils from Rural & Urban Areas of Australia*

Table 3 **Range of metal concentrations found in the NSW EPA study**

Chemical	Dataset	No. of samples	No. (%) of detections	Minimum (mg/kg)	Median[1] (mg/kg)	Maximum (mg/kg)	Average[1] (mg/kg)	AS4454 upper limit criterion (mg/kg)	No. (%) of samples above upper limit criterion
Antimony	FOGO (2019)	17	0 (0)	<5	-	<5	-	-	-
	FOGO (2020–21)	37	9 (24)	<0.5	0.25	1.1	0.39	-	-
	GO (2020–21)	13	4 (31)	<0.5	0.25	1	0.38	-	-
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Arsenic	FOGO (2019)	17	11 (65)	<5	8.0	25	7.4	20	1 (6)
	FOGO (2020–21)	37	37 (100)	3.9	6.7	17	7.7	20	0 (0)
	GO (2020–21)	13	13 (100)	3.1	4.9	11	6.4	20	0 (0)
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Beryllium	FOGO (2019)	17	0 (0)	<1	-	<1	-	-	-
	FOGO (2020–21)	37	7 (19)	<0.5	0.25	0.83	0.32	-	-
	GO (2020–21)	13	5 (38)	<0.5	0.25	0.88	0.46	-	-
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Boron	FOGO (2019)	17	2 (12)	<50	25	80	31	100	0 (0)
	FOGO (2020–21)	37	37 (100)	10	20	75	22	100	0 (0)
	GO (2020–21)	13	13 (100)	4.5	17	20	15	100	0 (0)
	ORDU (2020–21)[3]	7	7 (100)	6.3	7.5	8.1	7.3	-	-
Cadmium	FOGO (2019)	17	1 (6)	<1	0.5	1	0.5	1	0 (0)
	FOGO (2020–21)	37	5 (14)	<0.5	0.25	0.73	0.30	1	0 (0)
	GO (2020–21)	13	0 (0)	<0.5	-	<0.5	-	1	0 (0)
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Chromium	FOGO (2019)	17	17 (100)	10	15	34	18	100	0 (0)
	FOGO (2020–21)	37	37 (100)	11	20	80	25	100	0 (0)

Chemical	Dataset	No. of samples	No. (%) of detections	Minimum (mg/kg)	Median[1] (mg/kg)	Maximum (mg/kg)	Average[1] (mg/kg)	AS4454 upper limit criterion (mg/kg)	No. (%) of samples above upper limit criterion
	GO (2020–21)	13	13 (100)	7.4	12	16	12	100	0 (0)
	ORDU (2020–21)[3]	7	5 (71)	<0.5	0.82	1.8	0.8	-	-
Cobalt	FOGO (2019)	17	17 (100)	2.0	6.0	12	5.8	-	-
	FOGO (2020–21)	37	37 (100)	2.3	5.3	16	6.3	-	-
	GO (2020–21)	13	12 (92)	<0.5	3.9	14	4.2	-	-
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Copper	FOGO (2019)	17	17 (100)	24	38	138	50	150[2]	0 (0)
	FOGO (2020–21)	37	37 (100)	20	42	140	48	150	0 (0)
	GO (2020–21)	13	13 (100)	10	29	47	28	150	0 (0)
	ORDU (2020–21)[3]	7	7 (100)	4.3	12	12	11	-	-
Lead	FOGO (2019)	17	17 (100)	10	41	62	37	150	0 (0)
	FOGO (2020–21)	37	37 (100)	11	40	59	38	150	0 (0)
	GO (2020–21)	13	13 (100)	7.4	21	26	20	150	0 (0)
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Manganese	FOGO (2019)	17	17 (100)	166	377	783	398	-	-
	FOGO (2020–21)	37	37 (100)	170	350	4690	518	-	-
	GO (2020–21)	13	13 (100)	94	230	360	223	-	-
	ORDU (2020–21)[3]	7	7 (100)	13	24	31	25	-	-
Mercury	FOGO (2019)	17	0 (0)	<0.1	-	<0.1	-	1	0 (0)
	FOGO (2020–21)	37	0 (0)	<0.2	-	<0.2	-	1	0 (0)
	GO (2020–21)	13	0 (0)	<0.2	-	<0.2	-	1	0 (0)
	ORDU (2020–21)[3]	7	0 (0)	<0.2	-	<0.2	-	-	-
Molybdenum	FOGO (2019)	17	0 (0)	<2	-	<2	-	-	-
	FOGO (2020–21)	37	35 (95)	<0.5	0.89	1.3	0.9	-	-

Chemical	Dataset	No. of samples	No. (%) of detections	Minimum (mg/kg)	Median[1] (mg/kg)	Maximum (mg/kg)	Average[1] (mg/kg)	AS4454 upper limit criterion (mg/kg)	No. (%) of samples above upper limit criterion
	GO (2020–21)	13	10 (77)	<0.5	0.89	1.4	0.8	-	-
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Nickel	FOGO (2019)	17	17 (100)	4.0	11	16	10	60	0 (0)
	FOGO (2020–21)	37	37 (100)	5.1	12	42	15	60	0 (0)
	GO (2020–21)	13	13 (100)	3.7	5.7	13	7.2	60	0 (0)
	ORDU (2020–21)[3]	7	7 (100)	0.59	0.83	1.4	0.9	-	-
Selenium	FOGO (2019)	17	0 (0)	<5	-	<5	-	5	0 (0)
	FOGO (2020–21)	37	4 (11)	<0.5	0.25	0.65	0.3	5	0 (0)
	GO (2020–21)	13	1 (8)	<0.5	0.25	0.85	0.3	5	0 (0)
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Tin	FOGO (2019)	17	3 (18)	<5	2.5	14	3.8	-	-
	FOGO (2020–21)	37	36 (97)	<0.5	2.1	8.8	2.6	-	-
	GO (2020–21)	13	12 (92)	<0.5	1.4	13	2.4	-	-
	ORDU (2020–21)[3]	7	4 (57)	<0.5	0.8	1.5	0.76	-	-
Vanadium	FOGO (2019)	17	17 (100)	7.0	22	41	23	-	-
	FOGO (2020–21)	37	37 (100)	9.9	22	980	52	-	-
	GO (2020–21)	13	11 (85)	<0.5	11	15	8.7	-	-
	ORDU (2020–21)[3]	7	0 (0)	<0.5	-	<0.5	-	-	-
Zinc	FOGO (2019)	17	17 (100)	84	231	493	237	300[2]	3 (18)
	FOGO (2020–21)	37	37 (100)	93	210	980	236	300	5 (14)
	GO (2020–21)	13	13 (100)	36	120	160	113	300	0 (0)
	ORDU (2020–21)[3]	7	7 (100)	13	16	20	15	-	-

Notes

1. Where concentrations were <LOR, half the LOR was used to calculate median and average values.

2. Note on Table 3.1(C) in AS4454 states: A product that contains levels of copper (Cu) greater than 100 mg/kg but less than 150 mg/kg and/or total zinc (Zn) greater than 200 mg/kg but less than 300 mg/kg (dry weight), whilst not exceeding the limit values for all other contaminants listed in Table 3.1(C), shall provide a warning label in accordance with the labelling requirements of Clause 5.3 (of AS4454).

3. Outputs from ORDUs are not composts but dehydrated food wastes, hence AS4454 limits do not apply.

2.4. Pesticides

Source of pesticides

Pesticides are chemicals that control pests by physically, chemically or biologically interfering with their metabolism or behaviour. Pesticides include herbicides, fungicides, insecticides, fumigants, bactericides, rodenticides, baits, lures and repellents.

Findings

Table 4 provides a summary of the pesticides detected and the number of sites at which each pesticide was detected. The full set of analytical results for the study is in the study's data (a separate document, available on the EPA's website).

A total of 47 organochlorine and organophosphate pesticides were tested in FOGO compost samples collected during the 2019 sampling round. One herbicide, MCPA, was detected in two samples of FOGO compost collected from one site during this round.[8] There were no other detections above the laboratory reporting limit for this sampling round. However, the laboratory limit of reporting for the 2019 round was less sensitive than for the 2020–21 round.

An expanded set of 93 pesticides was tested during the 2020–21 sampling round. Substances tested for included organochlorine and organophosphate pesticides, phenoxy acid herbicides, glyphosate, AMPA and glufosinate. A mix of 38 herbicides, insecticides and fungicides was also analysed, using a multi-residue method.

In the 2020–21 sampling round, six pesticides were detected in FOGO and GO composts, and none were detected in ORDUs. The pesticides detected were the organochloride pesticides (OCPs) chlordane, dieldrin and DDT and the herbicides glyphosate, MCPA and clopyralid. Most were at concentrations near the laboratory reporting limits.

No pesticides were detected in the dehydrated food waste samples from the three ORDUs included in the study.

Organochloride pesticides (OCPs)

Two pesticides (chlordane and dieldrin) were infrequently found at concentrations above the upper limits of 0.02 mg/kg set in the industry standard for composts, AS 4454-2012. The laboratory limit of reporting for these OCPs was <0.02 mg/kg. The OCPs chlordane and dieldrin were banned in Australia during the mid-1990s and the late 1980s respectively. They are known to persist in the environment for decades.

Chlordane was detected only as trans-chlordane isomer in three FOGO samples from one facility (minimum 0.025 mg/kg, average 0.029 mg/kg, maximum 0.032 mg/kg) and in one GO sample (0.03 mg/kg). All four samples exceeded the upper limit for chlordane in AS4454-2012, which is 0.02 mg/kg.

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[8] MCPA was detected in both FOGO compost samples collected from the same site in 2019 at 0.15 mg/kg and 0.1 mg/kg (limit of reporting was <0.04 mg/kg).

Dieldrin was detected in 17 of 54 samples collected from nine FOGO facilities (minimum 0.021 mg/kg, average 0.050 mg/kg, maximum 0.120 mg/kg) and in three of 13 GO samples taken from two GO facilities (min 0.025 mg/kg, average 0.030 mg/kg, maximum 0.039 mg/kg). All detected concentrations were at or above the 0.02 mg/kg upper limit in AS4454-2012.

DDT was detected in four FOGO samples from two facilities (minimum 0.02 mg/kg, average 0.05 mg/kg, maximum 0.098 mg/kg). All the detected values were below the upper limit for DDT/DDD/DDE in AS4454-2012, which is 0.5 mg/kg. DDT pesticides were banned in Australia in the mid-1990s and are known to persist in the environment for decades.

Herbicides

The herbicides glyphosate, MCPA and clopyralid were detected infrequently in FOGO and GO composts at concentrations of less than 4 mg/kg. None were detected in the ORDU samples. Further work may be needed to determine the relevance of these findings – for example, whether the findings are sporadic or if detections would continue over time.

Glyphosate was detected in 7 FOGO samples at three facilities (minimum 0.52 mg/kg, average 1.07 mg/kg, max 1.80 mg/kg) and in three GO samples from one facility (min 1.70 mg/kg, average 1.97 mg/kg, max 2.10 mg/kg).

Glyphosate strongly sorbs onto soil minerals and is readily degraded by soil microbes to aminomethylphosphonic acid (AMPA). AMPA was not detected in any samples. Glyphosate's half-life in soil ranges between two and 197 days, with a typical soil half-life of 47 days.[9] The carcinogenic potential of glyphosate has been very much debated internationally and currently there are no institutions or agencies in the world that have established screening levels in soils.

In the 2020–21 sampling round, MCPA was detected in three FOGO samples (minimum 0.2 mg/kg, average 0.27 mg/kg, max 0.35 mg/kg) and in one GO sample (0.14 mg/kg). The concentrations detected at one FOGO site in 2019 were 0.15 mg/kg and 0.1 mg/kg. MCPA has moderate persistence in the environment with a soil degradation half-life reported to range from 15 to 50 days.[10] It has the potential to leach from solid material and be transported with water. A screening criterion of 2.67 mg/kg was established for MCPA as part of the risk assessment conducted for mixed-waste organic outputs, indicating that the concentrations detected in these samples are unlikely to be of concern.[11]

Clopyralid was detected in three FOGO samples from two facilities (0.10 mg/kg, 0.11 mg/kg and 0.12 mg/kg). These detections are very close to the laboratory limit of reporting at 0.1 mg/kg. There are no screening criteria for clopyralid in soils and the U.S. Environmental Protection Agency (US EPA) classifies this herbicide with toxicity class III (low toxicity to human and animal health).[12] While clopyralid does not accumulate in animal tissues, it can be very toxic at low concentrations to plants in the bean family, the potato/tomato family and the sunflower family. It resists breakdown in compost and soil and may be present in animal manures. Concentrations of 0.003 mg/kg in soils

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[9] National Pesticide Information Center 2010 (revised March 2019), *Glyphosate technical fact sheet*, http://npic.orst.edu/factsheets/archive/glyphotech.html

[10] Health Canada 2022, *Guidelines for Canadian Drinking Water Quality MCPA*, https://www.canada.ca/content/dam/hc-sc/documents/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-2-methyl-4-chlorophenoxyacetic-acid-mcpa/27-21-3021-Guidelines-Water-Quality-MCPA-EN-02.pdf

[11] NSW Office of Environment and Heritage 2015, *Alternative waste treatment research program: Project 3: Assessing the toxicity of mixed waste organic output leachates*, https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/recycling/mwoo/0486-resource-recovery-inw-awt-project3.pdf?la=en&hash=462A2F7E4962DC1D1FF3640B1A574D96E2689943

[12] U.S. EPA classifies Transline (the herbicide product with clopyralid as the sole active ingredient) as toxicity class III (low toxicity) with a signal word of CAUTION.

are considered as ‘plant safe’ to these sensitive plant families.[13] However, the laboratory limit of reporting for this herbicide was 0.1 mg/kg, hence it is unknown if clopyralid may be present in other samples that returned a non-detected result.

[13] Michel FC & Doohan D (n.d.), *Clopyralid and other pesticides in composts*, Ohio State University Extension, https://www.global2000.at/sites/global/files/Clopyralid_Factsheet.pdf

Table 4 Summary of pesticides detected in FOGO and GO facilities in 2020–21 sampling round

Chemical	Dataset	No. of samples	No. (%) of detections	Minimum (mg/kg)	Maximum (mg/kg)	No. (%) of facilities with detections	AS4454 upper limit criterion (mg/kg)	No. (%) of samples above upper limit criterion
Trans-Chlordane	FOGO (2020–21)	37	3 (8)	<0.02	0.032	1 (8)	0.02	3 (8)
	GO (2020–21)	13	1 (8)	<0.02	0.03	1 (20)	0.02	1 (8)
Dieldrin	FOGO (2020–21)	37	17 (46)	<0.02	0.12	9 (69)	0.02	16 (43)
	GO (2020–21)	13	3 (23)	<0.02	0.039	2 (40)	0.02	3 (23)
DDT	FOGO (2020–21)	37	4 (11)	<0.02	0.098	2 (15)	0.5	0 (0)
	GO (2020–21)	13	0 (0)	<0.02	-	0 (0)	0.5	0 (0)
MCPA	FOGO (2020–21)	37	3 (8)	<0.1	0.35	1 (8)	-	-
	GO (2020–21)	13	1 (8)	<0.1	0.14	1 (20)	-	-
Glyphosate	FOGO (2020–21)	37	7 (19)	<0.5	1.8	3 (23)	-	-
	GO (2020–21)	13	3 (23)	<0.5	2.1	1 (20)	-	-
Clopyralid	FOGO (2020–21)	37	3 (8)	<0.1	0.12	2 (15)	-	-
	GO (2020–21)	13	0 (0)	<0.1	-	0 (0)	-	-

Note: No pesticides were detected in the FOGO (2019) sampling round, except for two detections of MCPA (0.1 mg/kg, 0.15 mg/kg) from one facility. No pesticides were detected in the ORDU samples.

2.5. Phthalates

Sources of phthalates

Phthalates are a group of chemicals used to make plastics more flexible and harder to break. They are often called plasticisers. They are found in TVs, furniture, computers and vinyl flooring, and also in adhesives, detergents, lubricating oils, plastic clothes and personal-care products such as soaps, shampoos, hair sprays and nail polishes.

Findings

Phthalates were not detected in FOGO compost during the 2019 sampling round. Bis(2-ethylhexyl) phthalate (DEHP) was infrequently detected during the 2020–21 sampling round in FOGO, GO and ORDU outputs.

In the 2020–21 round, DEHP was detected in 12 FOGO samples from six facilities (average concentration of 3.9 mg/kg and maximum of 21 mg/kg), in two GO samples from one facility (average 1.5 mg/kg, max 1.7 mg/kg), and in three ORDU samples from one unit (average 2.9 mg/kg, max 4.7 mg/kg). The highest concentration was found in one FOGO compost sample, with the remaining samples at significantly lower concentrations of less than 4.4 mg/kg. Ecological and human health screening criteria are available for DEHP as 13 mg/kg and 30 mg/kg respectively.[14] Other than the single detection of 21 mg/kg at one facility, all other samples have concentrations below the ecological and human health screening criteria, indicating that these samples are unlikely to be of concern.

DEHP may be present in plastics and can leach into food from plastic packaging (particularly foods with a higher fat content). The surveys received from the facilities sampled as part of this study and the discussions held with the facility operators indicate plastic food packaging is commonly found in feedstocks used for composting. This may be a potential source of the DEHP found in these samples.

2.6. Phenols

Sources of phenols

Phenols may be present in herbicides, food waste (via flavouring agents), wood (via incomplete combustion, phenolic resins) and human excretions. They are also produced through the degradation of organic matter such as that found in composts. These chemicals can originate from both anthropogenic and natural sources.

Findings

Phenols (phenol and 2-methylphenol (o-cresol)) were detected infrequently in FOGO composts in the 2020–21 sampling round. None were detected in the 2019 samples.

Phenol was detected in two FOGO samples from two facilities (average 1.2 mg/kg, max 1.5 mg/kg).

2-Methylphenol (o-cresol) was detected in seven FOGO samples from three facilities (average 2.0 mg/kg, max 4.8 mg/kg).

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[14] These screening criteria were used in a previous risk assessment undertaken for a report on mixed-waste organic outputs by the NSW Office of Environment and Heritage, Environment Protection Science Branch 2019, *Alternative waste treatment research program: Project 3: Assessing the toxicity of mixed waste organic output leachates* (Table 6, page 47). (Available on the EPA website.)

Detections were infrequent: just four facilities detected either or both of the two phenolic chemicals.

Microbial biodegradation is the dominant pathway for degradation of phenol in the environment. Phenols have a low bioaccumulation potential and under aerobic conditions degrade readily in soils (e.g. ECHA reports that the aerobic biodegradation half-life (DT50) in soil is 7 days). Degradation in anaerobic soils can be much slower. The ecological 'predicted no-effect concentration' (PNEC) for phenol in soil is 0.136 mg/kg, according to the European Chemicals Agency (ECHA).[15] While the concentrations of phenols detected in the composts sampled are higher than the PNEC, there is also some uncertainty in the PNEC value due to limited ecotoxicity data. The low persistence of these phenols and their likely rapid degradation under aerobic field conditions means they are likely to pose a low long-term risk.

2.7. PFAS and PBDEs

PFAS and PBDEs are persistent chemicals that bioaccumulate, do not easily break down in the environment, and can adversely impact the environment and human health. These chemicals are not found in the environment from natural sources, only from anthropogenic sources.

All Australian governments have agreed that further release of PFAS into the environment from ongoing use should be prevented where practicable: see the National per- and polyfluoroalkyl substances (PFAS) Position Statement.

Several PBDE chemicals are listed under the Stockholm Convention on Persistent Organic Pollutants (POPs), to which Australia is a signatory. The Stockholm Convention requires its parties to take measures to eliminate or reduce the release of POPs into the environment.

Sources of PFAS: PFAS are a large group of chemicals used for their fire-retardant, waterproofing and stain-resistant properties and are found in products such as paints, roof treatments, hardwood floor protectant, surface protection products (e.g. carpet and clothing treatments) and coatings for cardboard and packaging, including containers and packaging used for food. Some PFAS chemicals were also used historically in firefighting foams.

Sources of PBDEs: PBDEs are also a large group of chemicals and are used as flame retardants in a wide variety of products, including plastics, furniture, upholstery, electrical equipment, textiles and other household products. Such household items can release PBDEs, and so they can be present in house dust and become concentrated in household vacuum-cleaner dust.

Study findings

The 2019 study of NSW FOGO compost identified the presence of some PFAS and PDBE chemicals. Both groups of chemicals have the potential to bioaccumulate and biomagnify in agricultural food chains and no soil guidelines are available for these pathways. Therefore, a preliminary human health risk assessment of the 2019 data was undertaken. This assessment identified potential risks that required additional investigation. Further sampling in the extended study conducted in 2020–21 found these chemicals in all FOGO and GO composts analysed. PFAS were not detected in samples from the ORDUs, while PBDEs were detected at considerably lower concentrations than in FOGO and GO composts.

Each sample collected in this study was analysed for 35 individual PFAS compounds in 2020–21 and for 16 individual compounds in 2019. The PFAS compounds detected most frequently were perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonate (PFHxS) and perfluorohexanoic acid (PFHxA). For PBDEs, 34 individual chemical compounds were analysed in both sampling rounds. The non-fully brominated diphenyl ethers (Br1-9) and the

[15] European Chemicals Agency, *Phenol*, https://echa.europa.eu/registration-dossier/-/registered-dossier/15508/6/1

fully brominated (Br-10) are discussed separately, as these have different transfer factors and toxicity reference values.

The range of concentrations of PFAS and PBDE chemicals detected in FOGO, GO and ORDU samples analysed in this study are presented in Table 5 and Table 6, respectively.

The complete analytical results for PFAS and PBDE chemicals are presented in the study's data (a separate document, available on the EPA's website).

Table 5 Range of PFAS concentrations found in the study

Chemical	Dataset	No. of samples	No. (%) of detections	Minimum (µg/kg)	Median (µg/kg)	Maximum (µg/kg)	Average (µg/kg)
PFOS[1]	FOGO (2019)	20	16 (80)	<0.2	0.9	3.3	1.0
	FOGO (2020–21)	37	37 (100)	0.4	1.3	6.0	1.7
	GO (2020–21)	13	11 (85)	<0.1	1.3	2.5	1.2
	ORDU (2020–21)	7	0 (0)	<1	-	<1	-
PFHxS[1]	FOGO (2019)	20	7 (35)	<0.2	0.2	0.5	0.2
	FOGO (2020–21)	37	37 (100)	0.1	0.3	0.9	0.4
	GO (2020–21)	13	10 (77)	<0.1	0.2	0.8	0.3
	ORDU (2020–21)	7	0 (0)	<1	-	<1	-
PFOA[1]	FOGO (2019)	20	15 (75)	<0.2	0.5	4.9	0.9
	FOGO (2020–21)	37	37 (100)	0.1	0.6	2.6	0.8
	GO (2020–21)	13	8 (62)	<0.1	0.3	0.5	0.3
	ORDU (2020–21)	7	0 (0)	<1	-	<1	-
PFHxA[1]	FOGO (2019)	20	17 (85)	<0.5	1.1	8.2	2.0
	FOGO (2020–21)	37	37 (100)	0.3	1.7	18	3.2
	GO (2020–21)	13	11 (85)	<0.1	0.6	1.2	0.7
	ORDU (2020–21)	7	0 (0)	<1	-	<1	-
Total PFAS[2,3]	FOGO (2019)	20	17 (85)	<0.5	3.9	12	4.9
	FOGO (2020–21)	37	37 (100)	2.6	7.5	24	8.9
	GO (2020–21)	13	12 (92)	<0.1	5.2	15	6.3
	ORDU (2020–21)	7	0 (0)	<1	-	<1	-

Notes

1. Where concentrations were <LOR for PFHxS, PFOS, PFHxA and PFOA, half the LOR was used to calculate median and average values.

2. Due to the large number of individual PFAS chemicals measured, when concentrations were reported as <LOR, these data were excluded from the summed concentration for total PFAS (i.e., <LOR was assumed to be zero, and total PFAS is a summed value of all detected PFAS concentrations). LOR are not presented for 'Total PFAS' due to variation of individual PFAS LORs – refer to the study's data (separate document) for PFAS LORs.

3. For 2019 samples, total PFAS calculated reflects the measurement of the minimum recommended analysis suite for PFAS (WA DER List).

Table 6 Range of PBDE concentrations found in the study

Chemical	Dataset	No. of samples	No. (%) of detections	Minimum (µg/kg)	Median (µg/kg)	Maximum (µg/kg)	Average (µg/kg)
PBDE Br1–9[1]	FOGO (2019)	17	17 (100)	1	18	123	23
	FOGO (2020–21)	37	37 (100)	2.1	11	30	12
	GO (2020–21)	13	13 (100)	1.1	3.9	186[3]	37
	ORDU (2020–21)	7	3 (43)	<1	0.4	0.4	0.3
PBDE Br10[2]	FOGO (2019)	17	16 (94)	<2	29	1010	87
	FOGO (2020–21)	37	29 (78)	<6	22	80	29
	GO (2020–21)	13	5 (38)	<7	15	460	61
	ORDU (2020–21)	7	0 (0)	-	-	-	-

Notes

1. Due to the large number of individual compounds in the Br1–Br9 range, when concentrations were reported as <LOR, these data were excluded from the summed concentration (i.e., <LOR was assumed to be zero). This was done as use of half the LOR (as done for other compounds) can lead to unrealistically elevated estimated concentrations due to the large number of compounds in the Br1–Br9 range.

2. Where concentrations were <LOR for Br10, half the LOR was used to calculate median and average values.

3. One GO facility (facility O) had considerably elevated concentrations of Br1–Br9 (99, 169 and186 µg/kg) compared to the other facilities, which had typical concentrations of less than 20 µg/kg.

Risk assessments for PFAS and PBDEs

PFAS and PBDEs have the potential to bioaccumulate and biomagnify in agricultural food chains; however, there are no soil guidelines available for these pathways. Therefore, as there are limited environmental guideline values for PFAS and PBDEs for the exposure pathways relevant for compost use, DPE–C&R undertook a human health risk assessment to help interpret the data.

The risk assessment considered several potential exposure pathways associated with the use of FOGO and GO composts. The ORDU data was not considered in the risk assessments due to the low or no detections of PFAS and PBDEs.

Three land-application scenarios were assessed for the composts:

1. no incorporation (no-dig surface application) into soil
2. incorporation to 2 cm (representing cattle trampling compost into the soil)
3. incorporation to 10 cm into soils.

The key exposure pathways of egg, meat (beef) and milk consumption were assessed. For meat and milk consumption scenarios, these were assessed further as exposure to grazing animals from soil and pasture, and from fodder (i.e. pasture only). Repeated applications of compost were not considered in the assessment.

Although a number of PFAS compounds were detected in FOGO and GO composts, the risk assessment focused only on PFOS, PFHxS, PFOA and PFHxA. The summed PFAS chemicals PFOS+PFHxS and PFOA+PFHxA were assessed. There are currently only human health toxicity reference values available in Australia for PFOS+PFHxS and PFOA. The DPE–C&R risk assessment noted that, on review of the analytical data obtained in this study, some FOGO samples had high proportions of PFHxA.[16] To account for this, PFHxA was summed with PFOA for the assessment. This approach provided a conservative assessment as PFHxA is thought to be less toxic than PFOA.[17]

For the PBDE assessment, data were separated into two groups, Br1-Br9 (sum of PBDEs with between 1 and 9 bromine atoms) and Br10 (the fully brominated deca-BDE compound). This was done due to differences in toxicity and environmental fate between these groups.

For the groups of PFAS and PBDEs assessed, there were significant differences in concentrations across the facilities sampled. Risks were therefore assessed separately for each facility.[18]

A risk quotient (RQ) approach was used, where a calculated value above one (1) indicates that the estimated daily intake of a contaminant is above a toxicity reference value (i.e. a value considered a safe dose) and may present an unacceptable risk. The pathways assessed and the assumptions used in the calculations were conservative but realistic. The risk assessment only considered home consumption of produce.

A risk assessment was also conducted for the consumption of homegrown fruit and vegetables for PFAS and PBDEs.[19] The risks for FOGO and GO application in homegrown fruit/vegetables were

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[16] NSW Department of Planning and Environment, January 2023, *Risk assessment of PFAS and PBDEs in food organics and garden organics composts (2020–21)*, and NSW Department of Planning and Environment, January 2023, *Addendum to risk assessment of PFAS and PBDEs in food organics and garden organics composts (2020–21)*

[17] Luz et al. 2019, Perfluorohexanoic acid toxicity part 1: Development of a chronic human health toxicity value for use in risk assessment, *Regulatory Toxicology and Pharmacology* 103:41–55

[18] The dataset from the 2019 round was smaller with less variation in concentrations and the results were combined to calculate risks. The 2020–21 data was statistically different and could not be combined, hence risk assessments were calculated individually for each facility. The risk assessment for the 2020–21 results supported the risk assessment findings from the 2019 round. Assessment report: *Risk assessment of PFAS and PBDEs in food organics and garden organics composts (2020–21)*

assessed for scenario 1 only (surface application of compost without incorporation) as the realistic worst-case scenario. This risk assessment used screening criteria from the PFAS National Environmental Management Plan (PFAS NEMP) and the National Environment Protection Measure (NEPM) health investigation levels for residential areas with garden accessible soil. These screening criteria consider exposure via multiple pathways such as ingestion, inhalation and dermal contact with soil and dust as well as ingestion of homegrown fruit/vegetables. They assume 10% of total fruit and vegetable consumption comes from home gardens. The risk assessment noted that there may be some settings where consumption above 10% may occur, e.g. rural/agricultural properties. Consistent with the risk assessment for eggs, milk and meat, the RQs for homegrown fruit/vegetables consumption were calculated for each facility.

The assessment of homegrown fruit/vegetables pathway did not consider the consumption of herbs grown in the home garden. In general, herbs from the home garden are unlikely to be consumed in sufficient quantities to warrant concern.

General findings from the PFAS and PBDEs detected

There were higher concentrations of PFOA, PFHxA, Br1–Br9 and Br10 in FOGO waste samples than in GO waste samples. Although this result was based on a small dataset, it suggests that there may be sources of these chemicals in FOGO that are not present in GO. Further work was conducted to identify potential sources: this is discussed in Section 5.

Data from two facilities (one FOGO and one GO) resulted in RQs less than one (1) for both PFAS and PBDEs, indicating that a final product that poses a low risk to human health can be achieved. The two facilities differed, in that the GO facility does not take kerbside collections but selects its feedstock from residential, parkland or commercial gardening projects, while the FOGO facility is a small regional operation.

Risk assessment results for PFAS

The risk assessment for PFOS + PFHxS indicated that for some exposure pathways/facilities, there may be an unacceptable risk. The highest-risk pathways were for meat and milk consumption where FOGO and GO compost is land-applied without incorporation and the meat and milk is primarily sourced from home/own farm produce. For PFOS + PFHxS egg consumption presented a low and acceptable risk for all scenarios.

Similarly, the risk assessment for PFOS + PFHxS for homegrown fruit/vegetables pathway resulted in RQs of less than one (1), and presented a low and acceptable risk for all scenarios with 10% consumption.[20] If more homegrown produce were consumed, the RQ would increase. For example, if it is assumed that someone consumes 50% of their fruit and vegetables from homegrown produce, which may occur on rural/agricultural properties, the RQ would be five times higher than that calculated for 10% consumption. This increase could result in an unacceptable risk for some FOGO composts and some GO composts.

The assessment of PFOA + PFHxA indicated that the risks were low and acceptable for all scenarios for egg, milk, meat and homegrown fruit/vegetable consumption. However, for one

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[19] NSW Department of Planning and Environment, January 2023, *Addendum to risk assessment of PFAS and PBDEs in food organics and garden organics composts (2020–21)*

[20] The risk assessment in the report 'NSW Department of Planning and Environment, January 2023, *Addendum to risk assessment of PFAS and PBDEs in food organics and garden organics composts (2020–21)*'uses the assumption in the *National Environment Protection (Assessment of Site Contamination) Measure*, and therefore is considered conservative for the scenario of residential areas with garden-accessible soil. This is a standard assumption. In settings where a higher percentage (i.e. >10%) of fruit /vegetables ingested are sourced from the residential backyard where FOGO and GO have been applied, the RQs will increase. There is a potential that such scenarios for the home consumption of produce may occur in rural/agricultural properties.

FOGO facility the calculated RQ was only marginally below the thresholds. Table 7 provides a summary of the risk assessment findings for PFAS chemicals.

Risk assessment results for PBDEs

The assessment for PBDE compounds Br1–Br9 indicated that there may be an unacceptable risk present for some exposure pathways/facilities from FOGO and GO composts. The highest-risk pathways for Br1–Br9 were for meat and milk consumption where FOGO and GO compost is land applied without incorporation and the meat and milk is primarily sourced from home/own farm produce. Egg consumption presented a low and acceptable risk for almost all exposure pathways/facilities, except for one GO facility that had a high concentration of PBDEs. Risk assessment for Br1–Br9 for homegrown fruit/vegetable consumption showed a low and acceptable risk at 10% consumption.

The assessment of the PBDE compound Br10 indicated that the risks were low and acceptable for all scenarios and all pathways (i.e. eggs, milk, meat and homegrown fruit/vegetables).

Table 7 Summary of PFAS and PBDE risk assessment findings for FOGO and GO compost, for two land-application scenarios

Exposure pathway scenarios[1]		No soil incorporation	Soil incorporation
Egg consumption	-	Risk is low and acceptable with one exception[4]	Risk is low and acceptable with one exception[7]
Meat consumption	Grazing (exposure via soil and pasture)	Risk may be unacceptable for compost from some facilities due to PFAS (PFOS + PFHxS) compounds and from most facilities due to PBDE (Br1–Br9) compounds[5,6]	Risk is low and acceptable with one exception[7]
	Fodder (exposure via pasture only)	Risk may be unacceptable for compost from some facilities due to PFAS (PFOS + PFHxS) and PBDE (Br1–Br9) compounds[5,6]	Risk is low and acceptable with one exception[7]
Milk consumption[2]	Grazing (exposure via soil and pasture)	Risk may be unacceptable for compost from some[5] facilities due to PFAS (PFOS + PFHxS) and PBDE (Br1–Br9) compounds[6]	Risk is low and acceptable with one exception[7]
	Fodder (exposure via pasture only)	Risk may be unacceptable for compost from some facilities due to PFAS (PFOS + PFHxS) compounds and from one facility due to PBDE (Br1–Br9) compounds[4,5]	Risk is low and acceptable with one exception[7]
Fruit and vegetable consumption	Standard assumption: 10% of fruits and vegetables ingested are homegrown[3]	Risk is low and acceptable	n/a[8]

Notes

1. Exposure pathway assumptions are consistent with the preferred assumptions for generic risk assessment in NSW.

2. One FOGO facility was very close to exceeding the acceptable risk threshold for PFOA + PFHxA concentrations for the no soil incorporation scenarios (calculated RQ were 0.99 and 1.00).

3. The use of 10% is consistent with assessment in the *National Environment Protection (Assessment of Site Contamination) Measure*

4. Risk may be unacceptable for compost from one GO facility where elevated PBDE (Br1–Br9) concentrations were found.

5. 'Some facilities' means 50% or less of facilities, while 'most facilities' means more than 50% of facilities.

6. Risk is low and acceptable for compost at all facilities for other PFAS (PFOA + PFHxA) and PBDE (Br10) compounds.

7. Exception: risk may be unacceptable for both (meat and milk consumption) grazing scenarios when compost is incorporated into top 2 cm of soil, as at one GO facility where elevated PBDE (Br1–Br9) concentrations were found.

8. Not assessed; however, risks are considered to be low and acceptable, based on the 'no soil incorporation' scenario.

One GO facility had PBDE (Br1–Br9) chemicals at higher concentrations (more than two orders of magnitude higher) than other findings in FOGO or GO composts. Sources of PBDE include plastics, manufactured timbers, upholstery, electrical equipment, textiles and other household products. Discussions with the facility indicated that engineered wood composites may have been the likely source in these samples. Table 7 summarises the risk assessment findings for PBDE chemicals.

Potential sources of PFAS and PBDE in composts

In NSW the Compost Order 2016 regulates the types of inputs to GO and FOGO compost. It defines compost as any combination of mulch, garden organics, food waste, manure and paunch that has undergone composting. However, information sought at the time of sampling from the composting facility operators indicated that a broader list of materials was being received along with this feedstock, including plastic contaminants, residual paper, cardboard, soil, compostable plastics, disposable cups and cutlery, and treated timber.

To better understand the potential sources of PFAS and PBDEs in FOGO and GO composts, the EPA commissioned a review of international literature. WCA Environment Ltd (WCA) prepared a report, *Brief literature review of potential sources of PFAS and PBDEs in food organics and garden organics composts.*[21]

In summary, the WCA report noted that probable sources of PFAS in composts were paper-based food contact materials, including baking papers, beverage cups, coffee filters, food paper bags, food paper boxes, food paper wrappers, milk bottles with concentrations being significantly greater in microwave bags and paper tableware. The most probable sources of PBDEs in composts were food of animal origin, house dust and possibly engineered timbers mistaken for wood wastes.

A follow-up survey was conducted with all the facilities that were part of this study to gather information on the observed presence and frequency with which some of the potential sources of PFAS and PBDEs were encountered in the feedstock. See Section 5.

PFAS sources

PFAS is used in paper products to make them oil and water resistant (and therefore suitable for food contact materials).

The WCA report showed that the probable sources of PFAS in FOGO composts are paper-based food contact materials used as food and beverage containers. Considerable quantities of PFAS have been found in older (pre-2010) and (some) recycled paper materials used in food and beverage containers. PFAS chemicals may have been added to paper-based packaging materials unintentionally, the source being residues from recycled fibre and paperboard used in manufacturing new products.

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[21] WCA 2021, *Brief literature review of potential sources of PFAS and PBDEs in food organics and garden organics composts,* final report to NSW EPA August 2021. (Available on the EPA website.)

The report included discussion of international studies where food materials and yard (garden) waste were assessed as potential sources of PFAS. Trees and shrubs tended to have maximum concentrations of PFAS chemicals that were greater than those of food sources (fish, seafood, eggs and vegetables) but lower than those of paper-based food contact materials. Other studies have found that composts with and without paper-based food contact materials in their feedstocks differ in PFAS content by an order of magnitude, especially in their content of short-chain compounds (those with six or fewer carbons perfluorinated).

Non-stick cookware and utensils are an unlikely source of PFAS.[22] The international literature showed that PFAS were only released on the first use of the materials, not repeated use, and it did not matter which cooking oils or methods were used.

A comparison between the maximum concentrations of PFOS, PFHxS, PFOA and PFHxA from the NSW EPA FOGO samples with similar organic materials internationally showed the values found in NSW to be two orders of magnitude lower.

A report released by the Australian Packaging Covenant Organisation (APCO) identified the presence of PFAS in a various fibre-based, food contact packaging used in Australia.[23] PFAS is added to food packaging material as a barrier to heat, grease and water. The APCO report further supports the findings of the study on the identified potential sources of PFAS in composts.

The US EPA report *Emerging Issues in Food Waste Management, Persistent Chemical Contaminates* (released in August 2021) also demonstrates the presence of PFAS in food contact packaging and composts produced from food waste.[24]

PBDE sources

The WCA report identified that the potential sources of PBDEs in composts were house dust, food of animal origin, accidentally included engineered timbers, and possibly other unknown sources.

Household dust derived from furniture, textiles and electronic devices is an acknowledged source of PBDEs. It is possible that this is a source of some of the PDBE concentrations measured in compost from FOGO and GO facilities.

PBDEs bioaccumulate in the fatty tissues of animals and are expected to be to present in fatty foods of animal origin. It is anticipated these will be present in food waste inputs into composts. However, food itself is unlikely to be the primary source of the concentrations of PBDEs observed in FOGO and GO composts.

Further information obtained from facilities was that many councils encourage the inclusion of household vacuum dust into FOGO bins. PBDE concentrations were higher in FOGO composts than GO composts when the one GO facility with exceptionally high PBDE concentrations was omitted from the dataset. However, the concentrations of PBDEs in GO indicate an unknown source.

The WCA report noted that the FOGO samples from the NSW dataset contain considerably higher concentrations of PBDEs than the GO samples, approximately 10 times higher (excluding the samples from the one GO facility that had unusually high PBDEs). This indicates that there is a source of PBDEs in the FOGO that is not present in the GO. The initial thought – that this was

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[22] Choi H, Bae IA, Choi JC, Park SJ & Kim MK 2018, Perfluorinated compounds in food simulants after migration from fluorocarbon resin-coated frying pans, baking utensils and non-stick baking papers on the Korean market, *Food Additives and Contaminants: Part B*, https://doi.org/10.1080/19393210.2018.1499677

[23] APCO 2022a (version 2 November 2022), *PFAS in fibre-based packaging*, https://documents.packagingcovenant.org.au/public-documents/PFAS+in+Fibre-Based+Packaging

[24] https://www.epa.gov/system/files/documents/2021-08/emerging-issues-in-food-waste-management-persistent-chemical-contaminants.pdf

likely to be the food waste itself – was reconsidered with the available evidence of very low concentrations of PBDEs detected in the dehydrated food waste. The PBDE concentrations in the NSW FOGO are much higher than those previously reported in food samples from Australia and around the world, i.e. FOGO contains ~40 ug/kg total PBDEs, whereas even the most contaminated foodstuffs such as meat and fish generally contains PBDE concentrations about two orders of magnitude lower, typically ≤0.4 ug/kg. Partial dehydration during composting could result in an increase in concentration in comparison to wet-weight food but this does not explain the levels of PBDEs measured in FOGO-derived compost.

A recent review of studies relating to the US population concluded dietary exposure did not explain the current PDBE body burdens, and exposure to house dust was estimated to account for 82% of the overall estimated intake (from FSANZ 2007).[25] The WCA report surmises that dust from residential properties, and possibly also from dust generated in the FOGO and GO processing facilities, may be contributing the bulk of the measured PBDEs; however, this requires further investigation before it can be accepted as an explanation for the elevated PBDE concentrations determined in FOGO-derived compost.

The WCA report also noted that PBDE concentrations in GO-derived composts are an order of magnitude higher than those observed in food surveys, despite the lack of lipid-rich material (e.g. fatty foods) or potential input of PBDE-containing dust in GO. This suggests that there may be a currently unexplained source of PBDEs or a contribution from the processing facilities that could serve as a source of PBDEs in both GO- and FOGO-derived composts. The compost from the GO facility with the extremely high levels of PBDEs is likely to have been from a source material such as engineered wood composite that may have been accidentally added to the garden organics.

Facility-reported observations

Follow-up surveys were conducted with all the sampled facilities to gather information on the observed presence and frequency with which some of the potential sources of PFAS and PBDEs were encountered in the feedstock (see Section 5). These responses are self-reported observations from staff experiences from the sites sampled and were requested several months after the sampling events took place. It provides a general indication of likely sources in the feedstock and is not a reporting of the contaminants that may have been present in the feedstock of composts that were sampled as part of this study.

With respect to potential PFAS sources, fibre-based food contact materials or other paper products, food packaging, paper towels, cardboard and office paper were reported to be received more frequently by more of the facilities receiving FOGO feedstocks compared to GO feedstocks. Except for office paper, all the other paper-based products were still reported as being frequently present at most of the GO facilities surveyed.

For potential PBDE sources, dust was reported as a frequent input in FOGO but infrequently for GO facilities. As expected, meat was reported as a highly regular input at FOGO facilities and mostly as infrequent or never in GO feedstocks.

Hard and soft plastics were reported as received with every load or weekly at both FOGO and GO facilities.

2.8. Other chemicals not found in any samples

The following chemical groups/chemicals were not detected in FOGO, GO or ORDU wastes:

- organophosphate pesticides (OPPs)

[25] Food Standards Australia New Zealand (FSANZ) 2007, *Polybrominated diphenyl ethers in food in Australia*, https://www.foodstandards.gov.au/science/surveillance/pages/fsanzstudyofbrominat4997.aspx, accessed July 2021

- multi-residue pesticides (a mix of 38 herbicides, insecticides and fungicides)
- glufosinate (a herbicide related to glyphosate)
- polycyclic aromatic hydrocarbons (PAHs)
- bisphenol A (used to make polycarbonate plastics)
- triclosan (used in soaps and some kitchenware).

Organophosphate pesticides are a group of manufactured chemicals that poison insects and mammals. They are used in agriculture, the home, gardens, and veterinary practice.

A multi-residue method using liquid chromatography and mass spectrometry (LC-MS) was used to test for a mix of 38 pesticides including herbicides, insecticides and fungicides. A full list of these pesticides is in the study's data (separate document).

Glufosinate was not detected in any sample. It is a herbicide similar to glyphosate which was detected is some samples.

PAHs occur naturally in coal, crude oil and their products. They are also produced when fossil fuels, wood and tobacco are burned.

Bisphenol A (BPA) is used to make polycarbonate plastics and is found in various products including water bottles, lining of metal food cans, bottle tops and waste supply pipes.

Triclosan is an antibacterial and antifungal agent used in some kitchenware such as cutting boards and ice-cream scoops, and in soaps, toothpaste, cosmetics and deodorants.

3. Physical contaminants findings

Both the Compost Order 2016 and AS4454 require testing for the physical contaminants of glass, metal, and rigid and flexible plastics. The analysis is based on the amount of glass, metal and rigid plastics retained on a > 2 mm sieve (the allowable maximum is 0.5% dry weight) and the amount of light, flexible or film plastics retained on a > 5 mm sieve (the allowable maximum is 0.05% dry weight).

All FOGO and GO facilities complied with the glass, metal and rigid plastics > 2 mm limit set in the *Compost Order 2016*, while all but two facilities (one FOGO and one GO facility) complied with the plastics – light, flexible or film > 5 mm test in the *Compost Order 2016*. One ORDU also exceeded the light plastic maximum concentrations. Physical contamination is not permitted in the outputs of ORDU units.

Figure 4 and Figure 5 show photographs of two FOGO compost samples and the anthropogenic physical contaminants identified within them. The compost sample shown in Figure 4 did not exceed either of the two physical contaminant limits set in the *Compost Order 2016* but had a high number of visible plastic pieces within it. The compost sample in Figure 5 exceeded the limit for light, flexible or film plastics but contained less visible plastic than the compost in Figure 4.

These anomalies are possible as this test relies on measuring the gravimetric weight of plastic material retained on a sieve, rather than the number of individual plastic pieces present, which can lead to compliant compost containing more pieces of lightweight plastic film than may be desirable. Other methods to test plastics impurities in waste material are emerging and are discussed at the end of this section.

Reducing plastic in composts remains a key problem for operators and impacts the quality of composts produced.

Figure 4 Photographs of a 2 kg FOGO compost sample and the physical contaminants identified within it

The sample was compliant with all physical contaminant limits set in the *Compost Order 2016*. It reported 0.2% for glass, metal and rigid plastics > 2mm (limit set is 0.5%) and 0.05% for 'plastics – light, flexible or film > 5mm' (limit set is 0.05%). The photos are sourced from the commercial laboratory commissioned by the EPA to conduct physical contaminant testing.

Figure 5 Photographs of a 2 kg FOGO compost sample and the physical contaminants identified within it

This sample was compliant with the glass, metal and rigid plastics limit of 0.5% set in the *Compost Order 2016* (result = 0.1%), but exceeded the 'plastics – light, flexible or film' limit of 0.05% (result = 0.07%). The photos are sourced from the commercial laboratory commissioned by the EPA to conduct physical contaminant testing.

The physical contaminant tests in AS4454 and the Compost Order 2016 both focus on fractions greater than 2 mm for glass, metal and rigid plastics, and greater than 5 mm for plastics – light, flexible or film. Currently there are no established methods to analyse the fraction less than 2 mm and address the knowledge gap on potential microplastic contamination in compost.

Method development is under way in several specialist science institutions nationally and internationally. New methods to measure plastic contamination in waste material could address the challenges of gravimetric determination of lightweight materials (such as estimating the total surface area of plastic in a material).[26] Pyrolysis gas chromatography mass spectrometry (pyrolysis-(GCMS)) is an emerging technique for quantifying the total mass and type of plastic (irrespective of size).[27]

4. Microbiological findings

4.1. Microbial organisms analysed

Microbiological testing for this study included the microbiological tests required under the Compost Order 2016 but was broadened beyond any current regulatory requirements in NSW or

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[26] Kehres B & Thelen-Jüngling M 2006, *Methodenbuch zur Analyse organischer Düngemittel, Bodenverbesserungsmittel und Substrate*, Bundesgütegemeinschaft Kompost e.V., Köln

[27] Okoffo ED, Ribeiro F, O'Brien JW, O'Brien S, Tscharke BJ, Gallen M, Samanipour S, Mueller JF & Thomas KV 2020, Identification and quantification of selected plastics in biosolids by pressurized liquid extraction combined with double-shot pyrolysis gas chromatography–mass spectrometry, *Science of the Total Environment*, 715, 136924

internationally. As food waste is a key input in most of the samples collected, pathogen risks are potentially different to those present in GO alone. The study sought to gather more information to assess whether there were any potential risks relevant to human health.

The study included additional tests for viruses, helminths (parasitic intestinal worms), spore-forming bacteria (*Bacillus cereus* and *Clostridium perfringens*, both known as food-poisoning risks), *Legionella spp*. (known to be a risk with compost) and *Campylobacter spp.* (a known food-poisoning risk).

The viruses analysed in this study (adenovirus, enterovirus and reovirus) represent a range of virus families that are relevant to human health. In addition, adenoviruses are sufficiently persistent and infectious to humans that they can also be used as a 'reference pathogen' for other enteric viruses. Adenoviruses cause a wide variety of illnesses in humans including eye infections, respiratory infections and diarrhoea.[28]

The ova of helminths (e.g. of the genera *Ascaris* and *Taenia*) and bacterial spores (e.g. *Bacillus cereus* and *Clostridium perfringens*) are very resistant to high temperatures and other environmental conditions (e.g. UV radiation and desiccation), and can survive for years once formed.

Grab (discrete) samples were taken for microbiological analyses from the same FOGO, GO and ORDU sites sampled in the study (see Section 1.2). Two replicate grab samples were collected during the 2019 sampling round and three replicates during the 2020–21 round. Grab samples were taken at surface (up to 30 cm below surface) and at depth (approximately 60 cm below surface). Table 8 lists the microorganisms analysed.

Table 8 Bacteria, helminths and viruses analysed in FOGO and GO composts and dehydrated food wastes

Group	Microorganism	Unit of measurement
Bacteria	*Salmonella* spp.[1]	Present or absent /25g
	Thermotolerant coliforms [1]	MPN/g
	Escherichia coli [1]	MPN/g
	Clostridium perfringens	CFU/g
	Bacillus cereus	CFU/g
	Campylobacter spp.	CFU/g
	Legionella not *L.pneumophila*	CFU/mL
	Legionella pneumophila SG1	CFU/mL
	Legionella pneumophila SG2-15	CFU/mL
	Total Legionella count	CFU/mL
Helminths	*Taenia* sp. ova (eggs)	/40 g [4]
	Ascaris sp. ova (eggs)	/40 g [4]
Viruses	Enteroviruses [2]	/40 g [4]
	Adenoviruses [2]	/40 g [4]
	Reoviruses [2]	/40 g [4]
	Noroviruses [3]	/10 g

[28] NSW Department of Planning and Environment, January 2023, *Quantitative microbial risk assessment of adenovirus and* Ascaris *in FOGO and GO composts*, page 4. (Available on the EPA website.)

Notes

1. Required to be tested under the NSW *Compost Order 2016*.
2. Viable counts
3. Noroviruses were analysed by PCR tests and were not detected in FOGO samples in the 2019 round. Samples collected in 2020–21 were not tested for norovirus.
4. Units for samples tested in 2019 were /20 g, and for samples tested in 2020–21, /40 g.

4.2. Microbiological findings

Microorganisms that were detected and not detected in the sampling rounds of both 2019 and 2020–21 are listed in Table 9.

Table 9 Microorganisms detected and not detected in FOGO and GO composts and dehydrated food wastes from sampling events in 2019 and 2020–21

Detected	Not detected
Thermotolerant coliforms[1]	*Salmonella spp.*[1]
Escherichia coli[1]	*Campylobacter* spp.
Clostridium perfringens	*Legionella* spp.
Bacillus cereus	Reoviruses
Taenia spp. ova (eggs)	Noroviruses[2]
Ascaris spp. ova (eggs)	
Enteroviruses	
Adenoviruses	

Notes

1. Required to be tested under the NSW *Compost Order 2016*.
2. Only tested during 2019 sampling round

The Compost Order 2016 requires three microorganisms – *Salmonella* spp., *Escherichia coli* (*E. coli*) and thermotolerant (faecal) coliforms – to be tested for in final composts ready for supply. It sets maximum upper limits of non-detected (*Salmonella* spp.), 100 MPN/g (*E. coli*) and 1000 MPN/g (thermotolerant (faecal) coliforms).

Of the 10 FOGO facilities sampled for the study in the June 2019 round, six were tested for compliance against the microbiological parameters set out in the *Compost Order 2016* and all 18 composting facilities were tested during the 2020–21 round. The combined results from all the facilities tested showed that none of the facilities had a positive detection for *Salmonella* spp. and none exceeded the upper limits for *E. coli*. However, three of the facilities sampled during 2019 exceeded thermotolerant (faecal) coliform limits and all were compliant in the 2020–21 round.[29] Detection of thermotolerant coliforms, above the 1000 MPN/g limit as set in the *Compost Order 2016* serves as an indicator of the likely presence of other bacterial pathogens that may have survived the pasteurisation process.

The pathogen testing requirements for the outputs from ORDUs differ from those specified by the *Compost Order 2016*. The resource recovery orders for ORDUs require that *Salmonella* spp., *E. coli*, *Clostridium perfringens* and *Bacillus cereus* are all absent at the limit of reporting if the outputs are to be directly applied to land. Two of the three units tested were compliant, with one unit exceeding the limit for *Bacillus cereus*.

[29] The method used by the commissioned laboratory for the detection of thermotolerant coliforms in 2019 was an in-house modification of AS5013.15 (2006) for *Escherichia coli*.

While most composting facilities over the two sampling rounds complied with the microbiological limits set in the *Compost Order 2016*, other pathogens from the suite tested were detected in both sampling rounds in FOGO composts, and were also detected in GO and ORDU samples that were added for the second round of the study.

The general findings from the microbiological analyses were as follows.

Bacteria

Bacterial pathogens and bacterial indicators, including *Clostridium perfringens*, *Bacillus cereus*, thermotolerant coliforms and *E. coli,* were detected in compost (FOGO and GO) and – infrequently – in dehydrated food-waste organics. The bacteria *Salmonella* spp*., Campylobacter* spp. and *Legionella* spp. were not detected in any sample.

Helminths

Helminth ova (intestinal worms), of the genera *Taenia* and *Ascaris*, were frequently detected in both composts (FOGO and GO) and dehydrated food wastes. Helminth ova are stable structures that persist in the environment.

Viruses

Viruses, including enteroviruses and adenoviruses, were detected in compost (FOGO and GO) but not in dehydrated food-waste organics. Reoviruses were not detected in any sample collected for this study in 2020–21. Noroviruses were not detected in FOGO samples from the 2019 round and analysis for this virus was not done for samples collected in 2020–21.

Most of the microorganisms detected were the more resistant groups of spore-forming bacteria (*Bacillus cereus* and *Clostridium perfringens*), adenovirus, enterovirus, and helminth ova of the genera *Taenia* and *Ascaris*. **Table 10** gives numbers of facilities that had positive detections for these organisms.

Table 10 Number of facilities that had positive detections of microorganisms less commonly analysed in recovered organic wastes

Microorganisms		FOGO[2] (n=6–10)	FOGO[3] (n=13)	GO[3] (n=5)	ORDU[3] (n=3)
Bacteria	*Bacillus cereus*[1]	1	7	3	1
	Clostridium perfringens[1]	1	2	2	0
Helminths	*Taenia* spp. ova (eggs)	10	11	5	2
	Ascaris spp. ova (eggs)	4	3	2	0
Viruses	Adenoviruses	4	7	4	0
	Enteroviruses	1	2	2	0

Notes

1. Bacteria that form spores which are extremely adept at surviving in the environment for years.
2. Ten FOGO facilities were sampled and tested in 2019. Bacteria were sampled and tested at six facilities, while helminths and viruses were tested at ten facilities.
3. Thirteen FOGO facilities, five GO facilities and three ORDU units were sampled and tested in 2020–21.

4.3. Quantitative microbial risk assessments

Quantitative microbial risk assessment (QMRA) modelling was developed by DPE–C&R to enable consideration of the pathogens analysed in the compost samples for potential risk to human health. This is novel science and is based on internationally accepted QMRA methodology developed as an assessment framework for the water industry. The QMRA was developed for adenoviruses and ova from the helminth *Ascaris.*[30] While the helminth *Taenia* was more frequently detected than *Ascaris* in FOGO and GO composts and ORDU outputs, currently there is insufficient scientific literature to enable the development of a QMRA.

QMRAs use data derived from epidemiology to determine the dose-response relationship for each microbial pathogen. Importantly, there is a probability of infection at any dose, as each single organism has the potential to initiate infection. The 'single hit' theory is adopted within current QMRA methodology, replacing a historical assumption that an 'infectious dose' is required for infection to occur.

The probability of infection is combined with the probability of becoming ill as a result of infection. For each pathogen, there is a range of illness outcomes varying in severity and duration. These illness outcomes are characterised within QMRA, and compared with a health-based target. The disability adjusted life year (DALY) is used as the health-based metric to weigh illness outcomes in QMRAs. The DALY is a measure of population health: it incorporates the different severities and durations associated with various illnesses for that fraction of the population made ill due to infection. A disease burden of 1 DALY per million people per year is an established target known as one micro-DALY or 1μDALY, representing a level of disease burden in the community that does not pose an unacceptable risk to human health. A disease burden greater than 1μDALY indicates a potential unacceptable risk to human health, requiring further consideration and investigation. Further information about the QMRA methodology is provided in the QMRA report.[31]

[30] NSW Department of Planning and Environment, January 2023, *Quantitative microbial risk assessment of adenovirus and* Ascaris *in FOGO and GO composts*. (Available on the EPA website.)

[31] NSW Department of Planning and Environment, January 2023, *Quantitative microbial risk assessment of adenovirus and Ascaris in FOGO and GO composts*. (Available on the EPA website.)

Five exposure scenarios were developed for the microbial risk assessment (Table 11) with pathways for exposure being through the ingestion of pathogens from hands after handling compost and consumption of unwashed food crops that have been in contact with compost.

Three scenarios representing residential use of composts were:

1. surface incorporation by hand trowel in the domestic garden for growing plants, with exposure via ingestion
2. surface incorporation by hand trowel in the domestic garden for growing home garden crops, with exposure from ingestion and consumption of unwashed crops
3. home potting (in pots) using undiluted compost, with exposure from ingestion.

Two scenarios representing agricultural use were:

4. field incorporated compost to 10 cm depth, with exposures to farmworkers by ingestion
5. field incorporated compost to 10 cm depth, with exposures to public consumers by ingestion of unwashed vegetables.

Risks to human health were modelled for both adults and children in all scenarios, except for the exposure to farmworkers in scenario 4: it was assumed that full-time farmworkers are adults.

Unlike the chemical risk assessments undertaken in this study, exposure through consumption of eggs, milk or meat was not considered in the QMRA and only direct exposure scenarios were assessed. These scenarios also do not include specific consideration of the use of preventative measures such as wearing gloves and masks, or washing hands after using composts.

Table 11 summarises the results from the QMRA. For adenovirus there is a probability of exceeding the health-based target through the use of FOGO and GO composts in all scenarios. For *Ascaris* ova the probability of exceeding the health-based target were through the use of FOGO and GO composts in home gardens used to grow garden crops (scenario 2), potting plants (scenario 3). In agricultural settings the probability of exceeding the health-based target for *Ascaris* ova was for farmworkers through the use of FOGO composts (scenario 4).

The QMRA concludes that there is a potential risk of harm to human health from microbial pathogens in the sampled FOGO and GO composts, primarily due to the levels of adenovirus detected, with a minor contribution from *Ascaris* ova.

The exposure scenarios did not specifically consider the use of gloves, masks and hand washing. Practising good hygiene when using composts would be expected to reduce the risks identified. Good hygiene practice is already recommended for the use of bagged compost and should be followed whenever handling composts or dehydrated food wastes.

Table 11 **Pathogen exposure scenarios modelled for human-health risk assessment with results of QMRA – adenoviruses**

Location	Modelled exposure scenario	Human receptor(s) (pathways)	Probability of exceeding health-based target of 1 µDALY for adenoviruses
Home gardens	**Plants** Surface-incorporated[1] (hand tilling)	Resident (hands → ingestion)	High (38–95%)
	Home garden crops Surface-incorporated[1] (hand tilling)	Resident (hands → ingestion *and* unwashed vegetables → ingestion)	High (76–99%)
	Potted plants (compost only)	Resident (hands → ingestion)	High (88–99%)
Agriculture	**Crops** Field-incorporated[2] (10 cm depth)	Farmworkers[3] (hands → ingestion)	High (87–98%)
		Public consumers (unwashed vegetables → ingestion)	Low to high (1–57%)

Table 12 **Pathogen exposure scenarios modelled for human-health risk assessment with results of QMRA – *Ascaris* ova**

Location	Modelled exposure scenario	Human receptor(s) (pathways)	Probability of exceeding health-based target of 1 µDALY for *Ascaris* ova
Home gardens	**Plants** Surface-incorporated[1] (hand tilling)	Resident (hands → ingestion)	Meets health-based target (0%)
	Home garden crops Surface-incorporated[1] (hand tilling)	Resident (hands → ingestion *and* unwashed vegetables → ingestion)	Low (0–0.8%)
	Potted plants (compost only)	Resident (hands → ingestion)	Low (0.1–14%)
Agriculture	**Crops** Field-incorporated[2] (10 cm depth)	Farmworkers[3] (hands → ingestion)	Low (0–4.2%)
		Public consumers (unwashed vegetables → ingestion)	Meets health-based target (0%)

Notes

1. 'Surface incorporated' represents home garden tilling by hand, using garden tools such as hand trowels.
2. 'Field incorporated' represents commercial agricultural practices of incorporation using farm machinery.
3. For commercial agriculture it is reasonable to assume that only adult farmworkers would be exposed (i.e. exposure was not modelled for children).

The finding for adenoviruses is surprising, as adenoviruses are human pathogens of faecal origin and so would not be expected to routinely be in the source material accepted by facilities to make either FOGO or GO compost. None of the facilities sampled accepted biosolids. The contracted laboratory undertook additional analyses and established that the source was not from food or garden organics, but was of human origin.[32].

Follow-up investigation into materials-handling processes and operations at the facilities sampled has not revealed obvious sources, and further work is required.

The microbiological data shows that pathogens were detected in FOGO and GO composts and in dehydrated food wastes. It is unclear if the pathogens have survived the pasteurisation process or whether they have been introduced at a later stage of the process, after pasteurisation. Unlike bacteria, viruses and helminth ova cannot multiply outside a host, so the number of viruses or ova would not be expected to increase during the composting process.

[32] NSW Department of Planning and Environment, January 2023, *Quantitative microbial risk assessment of adenovirus and* Ascaris *in FOGO and GO composts*. (Available on the EPA website.)

5. Post-sampling survey

5.1. Discussions with facilities

The EPA met with each facility included in the study to present an overview of the preliminary findings, to ask about contaminants the facilities saw in their feedstock, and to gather more detail of the facilities' operational practices. This information was used to develop a survey that was sent to the facilities soon after the meetings. The survey sought information about: the sources and frequency of potential chemical and microbiological contaminants, potential cross-contamination opportunities at the sites, monitoring and testing for the processes undertaken, and the main destination of the compost generated.

5.2. Sources of contamination reported by facilities

Contaminant types in feedstock

The responses received were observations based on memory, or were impressions of the types of contaminates received, that provide an indication of feedstock composition. They should not be taken as quantitative estimates of contaminant types.

FOGO facilities reported receiving more contaminant types that are potential sources of PFAS (fibre-based food contact materials in particular) and PBDE (fatty meat, vacuum dust, engineered timbers) than GO facilities. **Figure 6** presents the responses for all types of contaminants observed in feedstocks by both FOGO and GO facilities.

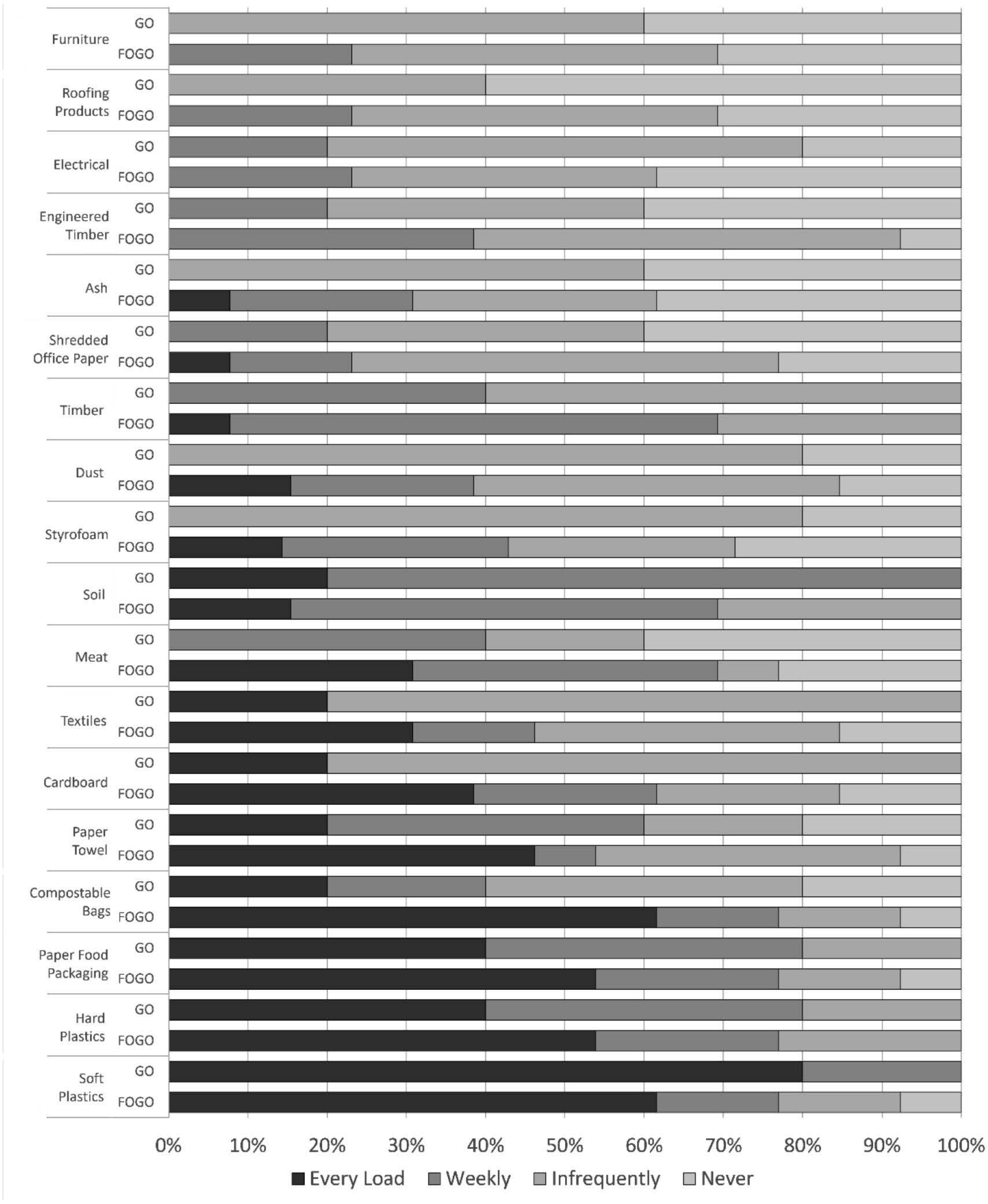
Potential PFAS sources – fibre-based food contact materials or other paper products, food packaging, paper towels, cardboard and office paper – were reported by more of the facilities receiving FOGO feedstocks than by facilities receiving GO feedstocks. However, most of the GO facilities still reported that paper-based products other than office paper were frequently present.

Among potential PBDE sources, dust was reported as a frequent input for FOGO but an infrequent one for GO. As expected, meat was reported as a very frequent input for FOGO but a mostly infrequent or non-existent one for GO.

Hard and soft plastics were reported as received with every load or weekly at both FOGO and GO facilities.

Further investigation showed that in an effort to minimise waste entering landfill and increase the recovery of organically derived materials, many councils that supplied the FOGO in this study, as well as some facilities themselves, encouraged putting a wide range of wastes into FOGO bins. These wastes included kitchen paper wastes, pizza boxes and other cardboards, compostable food packaging, pet waste, vacuum dust, dryer lint and human/pet hair. Many organically derived products have chemicals that may become contaminants in compost. The inclusion of these additional products has likely led to the contamination of FOGO composts with chemicals such as PFAS and PDES, and some of the microorganisms detected in this study.

Figure 6 Responses from FOGO and GO composting facilities on observed waste types and frequencies of appearance in incoming feedstocks



Potential pathogen sources

The survey included questions on possible sources of pathogens that may be accidentally introduced to the operational site. These included proximity to operations that may use biosolids, position of toilets at the site, observations of nappies or pet waste in feedstock, sources of water used to irrigate composts, and whether on-site machinery or delivery trucks may be used for other purposes and so introduce pathogens to the site. The information from discussions with facilities and the responses to the survey was inconclusive and further work is needed to explore this issue.

5.3. Time and temperature data

Very few of the facilities sampled kept records of the time and temperature conditions of their processes, meaning the processes could not be analysed and compared with the pathogen data found at each facility. As part of the measures to support sustainable composting, the EPA has started reviewing pasteurisation practices, to ensure pasteurisation is achieved consistently in NSW.

5.4. Land-use application

The facilities were asked who their main customers were for their compost. The most-reported consumers for both FOGO and GO facilities were landscape suppliers, followed by councils and then farmers. Mine rehabilitation and roadside maintenance or construction were the least-nominated end uses.

This data supports findings in the *NSW Organics Market Analysis 2020*, commissioned by the EPA.[33] The study showed that most compost (68%) was being used in the urban amenity market. The agriculture sector is the second-largest market, with growth accelerating. The mandated separation of FOGO will lead to an increase in the supply of recovered organics for land application, with demand for land application in agriculture and other markets expected to increase in line with supply.

[33] NSW EPA 2020, *NSW Organics Market Analysis 2020*. (Available on the EPA website.)

6. Conclusions and recommendations

Conclusions

This study explored the composition of compost derived from food and garden organics beyond what is normally required, to ensure that future regulatory settings support the establishment of a sustainable recovered organics industry in NSW. It has provided insights and learnings that are novel in both Australia and internationally.

The study found that both FOGO and GO composts contain a number of chemical contaminants that are not currently regulated in NSW or most other Australian jurisdictions. These include PFAS and PBDE chemicals, which are probably due to 'organically derived' materials being innocently placed in FOGO and GO kerbside bins. The potential sources of PFAS are fibre-based food contact materials, such as baking papers, paper bags and wrappers for food, beverage cups, coffee filters, and paper tableware such as serviettes. The most likely sources of PBDEs are house dust derived from furniture, textiles and electric devices, and engineered timber mistaken for wood waste.

Microbiological findings included the frequent detection of viruses and helminth eggs in FOGO and GO composts and, less frequently, spore-forming bacteria. It is unclear whether the detected pathogens have survived the pasteurisation process or whether they are introduced at a later stage of composting. Helminths and spore-forming bacteria were also detected in ORDU outputs.

Recommendations

The EPA will use tools and approaches from its regulatory strategy to address the study's findings. Some steps have already been taken. Recommendations to support sustainable composting in NSW target every point along the compost chain, from collection and preparation of materials for processing to treatment and verification of the final compost's quality.

To improve controls on inputs and initial processing to reduce the likely sources of physical and chemical contaminants

1. Place only food and garden wastes in FOGO bins, the sole exception being fibre or compostable-plastic kitchen caddy liners. The aim is that feedstocks for composting are as contaminant-free as possible from the point of collection, from both domestic and commercial sources. The EPA took action on this step by releasing its position statement on the matter in July 2022.
2. Focus on removing physical contaminants from feedstocks before composting begins. Many facilities shred feedstocks and try to remove contaminants at the end of the process. Potential physical contaminants, and the chemicals associated with them, are more difficult to remove once they are mixed throughout a compost.

To improve process monitoring and record keeping, to manage pathogens

3. Monitor processing practices better and improve record keeping. This will help show why pathogens have been detected in composts and how to remove or reduce them.
4. Verify pasteurisation procedures. This will help show if pathogens are inactivated during pasteurisation and if they are accidentally being added at a later stage of the composting process.
5. Encourage good hygiene practices when handling composts. This will minimise health risks from pathogens.

To consider amendments that may be appropriate for current monitoring requirements for final composts

6. In due course, review and update where necessary statutory instruments and guidelines such as the *Compost Order 2016* and Composting Guidelines.
7. In future, possibly monitor final composts for pathogens and key chemicals found in the study.

The EPA's final regulatory approach will take into account the study's findings and also align with the recommendations of the Resource Recovery Framework and works initiated at the national level, such as the National Chemicals Regulatory Framework (e.g. PFAS NEMP 3.0). Furthermore, the EPA will share its learning and seek national consistency on best practices in the area of recovered organics.

The EPA is committed to maintaining a learning mindset, and to listening and actively engaging with people to understand the issues affecting them. We will continue to consult with the industry, councils, businesses and the community to ensure that the recovery of valuable food resources is sustainable.