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Research Paper

A review of the benefits and risks of including certified compostable packaging in food organics recovery systems

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Federation University Australia acknowledges the Traditional Custodians of the lands and waters where its campuses are located, and we pay our respects to Elders past and present, and extend our respect to all Aboriginal and Torres Strait Islander and First Nations Peoples.

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Glossary of terms, initialisation, abbreviations and acronyms

ABA	Australasian Bioplastics Association
ABA Certified compostable	Refers to products that are certified under the ABA scheme for products that can be marketed as ‘Compostable’ requiring certification to independent Australian standards for compostability (AS4736 and AS 5810) as well as declarations of additives to products.
AORA	Australian Organics Recyclers Association
APCO	Australian Packaging Covenant Organisation
AS4736 /AS5810	Australian standards for commercial and home composability
Certified Commercially Compostable	Refers to products meeting Australian Standards AS4736
Certified Home Compoistable	Refers to products meeting Australian Standards AS5810
CCBP	Certified Compostable Bioplastic
CCFB packaging	Certified Compostable Fibre Based Packaging
CCP	Certified Compostable Packaging
EPA NSW	Environment Protection Authority, New South Wales
FO/FOGO	Food Organics/Food Organics & Garden Organics (resource recovery streams/materials)
FRRC	Federation University’s Future Regions Research Centre
PFAS	Per- and poly-fluorinated alkyl substances
PFOS	Perfluorooctane sulfonate
POPs	Persistent Organics Pollutants that do not readily breakdown and accumulate in the environment, including organochlorides, polychlorinated biphenols, benzenes, and some other aromatic compounds.

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Summary

Federation University's Future Regions Research Centre (FRRC) has been engaged by the Australasian Bioplastics Association (ABA) to undertake a review of the benefits and risks of certified compostable packaging (CCP) formats and their inclusion in Food Organics (FO) and Food Organics-Garden Organics (FOGO) systems where organics are processed using commercial aerobic composting.

This paper details:
1. A review of research reports commissioned by NSW EPA on the potential risks of compostable plastics and packaging, as well as some other reports provided by The Australasian Bioplastics Association.
2. A wider literature review based on-line keyword search of relevant academic and other research. The scope of this review included:
   - An independent review of the benefits and risk of Certified Compostable Packaging (CCP) in the recovery of organic waste recovery, processing of recovered organics, and use of products as a soil ameliorant in commercial and domestic food production and landscape maintenance. This has included consideration of fibre-based coated and bioplastic products.
   - Assessment of net environmental and social benefits of allowing such products to be recovered through FOGO.
   - Assessment of mitigation and management of any risks associated with CCP formats. This included consideration of community engagement/education, engagement with retailers and packing suppliers, as well as required systems for contamination detection and management by FOGO collection and processing operatives.
   - Identification of opportunities for trialling the inclusion of such products in FOGO services.

This review has found that inclusion of products approved under the ABA compostable verification program in FO/FOGO services processed by commercial composters do not pose a significant and irreversible environmental or human health risk. Approval under the verification system requires certification under Australian Standards AS4736 (Commercially Compostable) or AS5810 (Home Compostable) with additional requirements to ensure products are free of introduced chemical contaminants. Verified plastics are both compostable and biodegradable and will almost entirely degrade during the composting process and any residual remaining in compost products will continue to biodegrade and not contribute to lasting 'microplastic' levels in soil or the environment.

Key observations and finding are:
1. The transition from non-recyclable packaging to 100% recyclable and/or compostable packing by 2025 has been a nationally agreed objective of the National Australian Packaging Agreement supported by federal and state government, retailers and the packaging industry.
2. The review does not find evidence that the inclusion of ABA certified compostable products will result in serious, persistent or irreversible risk to the environment. Over 90% of certified compostable products will degrade during commercial composting processes that process materials for at least 8-12 weeks, and any residual particles remaining in compost will degrade in the environment within 12-18 months. Fibre based and thin ply flexible plastic products will typically degrade in commercial composting in less than 8-12 weeks, and in some instances as little as 30-40 days.
3. Some film and rigid plastic compostable items may be screened from FO/FOGO inputs and finished compost. Depending on the screening methods used, up to 20% of compostable items per weight may be removed.

4. Manual 'pickers' decontaminating received FO/FOGO materials can be trained to identify and leave compostable items in the processed organics stream. Compostable fibre products and distinctly coloured plastics can be identified and left in the processed organics stream.
5. Many composters will reprocess less contaminated medium sized 'mulch' grades of screened organics and even stockpile more contaminated 'oversize' grades of coarse material to ensure more of the organics break down and be recovered by later screening. Where this is done, compostable packaging particles remaining in composts effectively have a longer retention time than the minimum batch processing period. This means that the selection of processor and the contract conditions placed on how organic are to be managed could be dictated by councils and businesses to allow compostable packaging formats to be included in FO/FOGO services, rather than the management of organics effectively being dictated by short-period organics processors that put immature pasteurised organics onto the market after a few weeks of processing. These short period organics processors cannot adequately process certified compostable products and will therefore screen a higher proportion of them from inputs and outputs.
6. There are limited and inconsistent data available regarding the potential eco-toxicological risks and effects of certified compostable products in FO/FOGO composts. There are few studies using compostable plastics that would comply with ABA compostable verification program requirement, and very few for complaint fibre-based products. The limited data available shows variability in results, with some having possible slightly negative impacts on indicator species and others showing neutral or beneficial effects. Such variability occurs with testing of composts, and observed impacts may not be caused by the inclusion of compostable packaging. There is often a 'trade off' between the benefits of compost's contribution of nutrients and 'humic' organic matter to soil health and typically short-lived 'phytotoxic' impacts associated with addition of biologically active organic matter to soil (Barral and Paradelo, 2011).
7. The main chemicals and items of concern that may be introduced to composts by non-certified packaging appear to be:
    - Some heavy metals in inks and colourants in printed and coloured products.
    - PFAS/POPs in recycled-content fibre based.
    - Non-digestible particles that may bio-concentrate in organisms. It is uncertain whether bioplastic polymer particles will be biodigested or passed by organisms, but it is likely they will behaviour in a way similar to 'natural' biomass particles. Polymers meeting Australian Standard for certified compostable products are simple and readily biodegradable or bio-digestible hydrocarbons.
    - Potentially plasticisers and other additives that may have endocrine disrupting effect on organisms that ingest them. ABA certified compostable products must comply with ecotoxicity testing thresholds under Australian Standards AS4636 and AS5810 so this risk is minor for certified products.
8. There is little scientific basis for excluding certified compostable packaging from FO/FOGO on the basis of potential chemical contamination risk. The nature and small quantities of bioplastics in FOGO will have insignificant contribution to chemical- or eco- toxicity of compost products compared to 'background' levels in food and garden organics. Inks on printed items is the most significant risk of heavy metal contamination, but testing of compost products with more than twice the expected concentration of bioplastics in FO/FOGO show that this does not have significant impact on product quality. Inks for the newspaper promoted by some councils and NSW EPA as kitchen caddy liners may be a more significant, albeit minor, risk of chemical contamination.
9. Any remnant traces of certified bioplastic which may survive processing will not persist in the environment. They are inherently biodegradable similar to other organic compounds in compost products.
10. The PFAS/PFOS/POPs contamination of food packaging is a historic and declining risk. A recent Australian study of PFAS/POPs in non-certified food packaging found it is not prevalent as a coating on single use fibre-based products, which in previous studies has been the main source

of materials. The most harmful long-chained PFAS/PFOS products have been largely taken off the market and are not present in food packaging streams. Short-chained products are not common in food packaging in Australia. The most likely pathways would be inclusion of recycled paper fibre products manufactured from contaminated feedstock. This applies to the newspaper liners promoted by some councils and NSW EPA as kitchen caddy liners. ABA certification excludes addition of PFAS to products.

11. The low concentrations in products and small amounts of certified compostable products in FO/FOGO means that ABA certified compostable products are unlikely to contribute to contamination above background levels in food and garden organics. Some further trialling and testing of products may be needed to confirm this, but the case for restricting certified compostable packaging on the basis of potential PFAS contamination appears to be unfounded.
12. There are significant limitations to the methodologies of NSW EPA reports into chemical and toxicity risks associated with compostable packaging, and the results of the reports are not applicable to most ABA certified compostable products. The studies use a limited range of non-compostable and non-certified products, and so not include fibre-based products. Extracts from samples of plastics, including printed and coloured products, were found to have some eco-toxic effects but the methodology did not simulate the likely concentrations of leachate or degradation and adsorption of leached chemicals in composting. Eco-toxicity testing of compost products did not mix compost with the required amount of inert sand and the results showed similar ‘toxic’ effects between composts containing the limited range of so-called ‘compostable’ (non-certified) packaging tested and composts not containing any added packaging. The contributions of compostable packaging to tested chemical contamination was found to be statistically insignificant compared to ubiquitous background levels, and therefore do not support the position statement’s exclusion of compostable packaging from FO/FOGO on the basis of potential chemical contamination.
13. The argument that CCP bioplastics do not add value to compost products is immaterial. Although by mass, they will likely provide similar amounts of nutrient benefit as some food organics and fibre based items will add longer-lasting particulate and humic carbon to soils, the benefits of compostable packaging are in increased food waste recovery and reduced contamination of compost products, which diverts more organics from landfill, adds nutrient to compost products, and results in a higher proportion of compost to be marketable with reduced microplastic contamination of soil.
14. The argument that certified compostable packaging is not consistent with Circular Economy objectives to promote waste reduction, reuse and ‘circular’ recycling does not appear to consider the benefits of compostable packaging in: reducing the incidence of non-recyclable and low valuable plastic packaging that contaminate and reduce the viability of both container recycling and commercial composting; and increasing recovery of food organics and food-contaminated packaging, nor the fact that compost products are returned to soil where they improve productivity and reduce the need for other inputs.
15. Compostable plastics approved under the ABA verification program and meeting Australian Standards for certified compostable packaging have advantages over non-compostable plastic food packaging in terms of consumer preference and convenience and greater recovery of uneaten package food and food-contaminate packaging.
16. Greater use of ABA verified and Australian Standard certified compostable packaging to replace formats with no or poor recycling markets should reduce contamination of FO/FOGO streams and improve the viability of container recycling systems.
17. It is expected that the replacement of non-compostable and low value recyclable food packaging with ABA verified and Australian Standard certified compostable packaging formats will increase the recovery of food and food-contaminated packaging, reduce contamination at composting facilities, and reduce contamination risk in composts applied to soil.
18. Risks associated with certifiable compostable packaging can be managed by:

- Ensuring all similar-looking products used by retailers are replaced with certified compostable products in keeping the APCO policy objective of ensuring all packaging is 100% commercially recyclable or compostable by 2025.
- Placing specifications on the use of inks, dyes, plasticisers and additives to certified compostable products. This is covered by the toxicity testing and product declaration components of ABA certification of compostable packaging.
- Requiring testing of fibre-based products as part of the certification process and maintenance to confirm that have low concentrations of unintended chemicals. This is also covered by ABA certification.
- Ensuring commercial composting facilities receiving FO/FOGO materials have appropriate contamination management systems and processing retention times to ensure most compostable packaging is biodegraded.
- If there is uncertainty, periodic testing of ABA verified and Australian Standard certified products and composts could be undertaken to confirm they do not significantly contribute to contamination. However, this is unlikely to necessary as ABA certification requires chemical and ecotoxicity testing and prohibits the addition of PFAS/PFOS products to certified products.
- Periodic testing of areas where FO/FOGO + CCP composts are used to confirm compostable packaging do not have lasting negative effects compared to FO/FOGO composts without CCP. Once, again, this is unlikely to be needed due to the ABA verification program requirements for product testing and prohibition of PFAS/PFOS.

This review concludes that compostable packaging items certified to Australian Standards AS4736 and AS5810 and meeting additional ABA certification requirements pose little risk in commercial composting systems and will likely increases the quantities of food organics recovered through FO/FOGO services. Provided there is effective community engagement and education about which products can be composted through FO/FOGO services, and effective contamination and process management at organics processing facilities, their use will reduce contamination risks from FO/FOGO derived compost products. Concerns about chemical contamination, microplastic and potential eco-toxicity from packaging items in composts are not relevant to products meeting ABA verification program and Australian Standards certification.

1 Introduction

Compostable food packaging formats have, until recently, been promoted as an alternative to conventional plastics and plastic-coated products that have no or limited recycling value and are a contaminant of both container recycling ('yellow lid') and food organic and garden organic (FOGO, or 'green lid') resource recovery systems. Such compostable packaging formats include films, fibre-based trays and containers including fibre-based products treated or coated with bioplastics as a water or great protection layer, and rigid bio-plastic containers and 'serviceware' (e.g. cutlery). Many food supply chains have, or are, transitioning from non-compostable and non-commercially recyclable plastic packaging to compostable products.

However, concerns have been raised that compostable packaging items can contaminate compost products from commercial composting facilities, and in 2022 NSW EPA issued a policy directive effectively banning compostable packaging items other than certified compostable bioplastic liners or newspaper 'kitchen caddy' liners promoted by many local governments to increase household participation and diversion rates in food organics recovery systems. This has resulted in market uncertainty regarding the preferable forms of food packaging and will likely nationally delay or halt the transition from non-compostable and non-commercially recyclable food packaging formats, and may result in retailers failing to meet Australia's National Packaging Targets for 2025 of: 100% reusable, recyclable or compostable packaging; 70% of plastic packaging being recycled or composted; and the phase out of problematic and unnecessary single-use plastics packaging. NSW EPA state a willingness to reconsider the 'ban' subject to further evidence.

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   - Identification of opportunities for trialling the inclusion of such products in FOGO services.

1.1 Context

APCO and industry commitments to compostable packaging

The Australian Packaging Covenant Organisation (APCO) and major retailers have committed to the following targets by the end of 2025:

- All retail packaging to be 100% reusable, recyclable or compostable.
- 70% of plastic packaging being recycled or composted.
- 50% of average recycled content included in packaging (revised from 30% in 2020).
- The phase out of problematic and unnecessary single-use plastics packaging.

(APCO, 2023)

The bioplastics industry, through the ABA, has worked to develop a certification scheme based on the Australian Standards for Compostable Plastics. The standards were developed within the Standards Australia structure by independent working groups comprised of federal government department chair, consumer environmental organisations, testing bodies, retailers and the plastics industry. The ABA has also worked with producers and users of certified compostable packing, including major retail supply chains, to obtain regulatory approval for such products to replace plastic items that are not currently commercially recyclable and acceptable in kerbside recycling systems. A range of Certified Compostable coated fibre-based, film and rigid packaging and serviceware products are certified to the standards and have been proven to physically and chemically degrade under commercial composting conditions.

Under the ABA certification scheme, items must:

- Meet the requirements of Composability Standards AS4736 (Commercially compostable) or AS5810 (Home compostable).
- Have applicants confirm that no organic fluorinated chemicals, such as perfluorinated and polyfluorinated substances have been added to the material or product.

CCP formats complying with AS4736 must meet the following requirements:

- Minimum of 90% biodegradation of plastic materials within a maximum of 180 days in compost.
- Minimum of 90% of plastic materials should disintegrate into less than 2mm pieces in compost within 12 weeks (84 days).
- No toxic effect of the resulting compost on plants and earthworms using standardised eco-toxicity testing.
- Hazardous substances such as heavy metals should not be present above the maximum allowed levels.
- Plastic materials should contain at least 50% by weight of volatile /rapidly bio-degradable organic solids.
- The ABA verification program also requires that supplies guarantee that no PFAS products have been added to products. It is not practicable to have a 'zero' detectable PFAS or persistent organic pollutants(POPs) limit because such products are ubiquitous in the environment and may be present in plant grown starch (this is unlikely to occur at detectable levels) and fibre (including recycled fibre) inputs into compostable product manufacture. Such PFAS/POPs products are also ubiquitous in food and garden organics inputs recovered by FO/FOGO services and these materials are the main source of PFAS/POPs detected in FO/FOGO composts that do not contain other organic inputs (e.g. biosolids, paper fibre sludge, or other industrial organics or waste waters that can carry high loads of PFAS/POPs).

AS5810 compliant products must be able to degrade under home composting conditions and will also biodegrade in the environment, and will rapidly biodegrade under commercial composting conditions.

It is important to note there is a range of non-certified packaging items on the market that are marketed as 'degradable', 'compostable', or with other environmental claims or physical appearance that may result those using FO/FOGO services to believe the items can be composted.

NSW Position statement restricting compostable packaging

In 2022 NSW EPA issued a position statement restricting what can and cannot be placed in FO and FOGO services (EPA NSW, 2022), and other jurisdiction may follow with similar restrictions. The statement seems to be focused on household and public event FO/FOGO systems and has effectively banned all forms of compostable packaging without distinguishing between certified compostable and other non-certified 'degradable' or 'biodegradable' products. The stated reasons for restricting these items in FO/FOFO services are:

- They do not always break down in time during commercial composting and so are treated as contamination.
- They may contain PFAS and other potential chemical contaminants that may damage land and food production systems where composts are used. The reports on which these assumptions are reviewed by this paper.
- The restriction of compostable packaging is seen by NSW EPA as being consistent with commitments under the National per- and polyfluoroalkyl substances (PFAS) Position Statement to prevent further dissipation of PFAS into the environment. This does not consider whether compostable items contain PFAS additives.
- They do not add significant nutrient or benefit to end-products.
- Sales of single use packaging items are, or will be, restricted or 'banned' in NSW and this applies to compostable items, so there is no need for exemptions to allow compostable packaging from events to go to FO and FOGO services. This seemingly focuses on 'takeaway' food packaging and does not consider containers with prepared meals or other forms of retail food packaging that are not banned and commonly in use to protected food items and provide convenience to consumers.

These reasons for effectively banning compostable packaging from kerbside FO/FOGO services are examined in Section 4.2 of this report.

The NSW position statement allows compostable liners certified to AS4736 for commercial composting and paper fibre (e.g. newsprint) lining of FO/FOGO containers because they are seen as increasing the participation and recovery rates of FO/FOGO recovery services. Interestingly, the statement allows liners certified for commercial composting but specifies that home compostable liners or items should not be disposed to FO/FOGO services. This fails to recognise that home compostable certified liners are more readily degradable under commercial composting conditions than most commercially compostable certified items.

Another reason for restriction of the inclusion of compostable packaging in FOGO is uncertainty regarding environmental risks associated with the use of composts containing degraded and undegraded compostable packaging items, with suggestions that these may impacted negatively on soil health and other ecosystems. The basis for these decisions appears to be two research papers undertaken for NSW EPA by CSIRO into the potential risks from degradable and non-degradable plastics and from composts containing these. These documents are a key focus of this paper and are reviewed in Section 3.

Precautionary principle and risk

The decision to effectively ban the management of compostable packaging from FO/FOGO services appears to be based on uncertainty about risk and application of the 'Precautionary Principle'.

In Australian law and policy, the precautionary principle expressed as:

Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

In the application of the precautionary principle, public and private decisions should be guided by:

- careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment
- an assessment of the risk-weighted consequences of various options.

(Preston, 2017)

State and federal courts have previously ruled that:

- the precautionary principle, where triggered, does not necessarily prohibit an activity until full scientific certainty is achieved
- the type and level of precautionary measures that will be appropriate will depend on both the degree of seriousness or irreversibility of the threat, and the degree of uncertainty
- measures to comply with the precautionary principle should not go beyond what is appropriate and necessary proportional to the levels of risk and uncertainty.

(ibid)

The implications of this interpretation of the precautionary principle with regard the restriction and management of compostable packaging are considered in the discussion in Sections 3 and 4 of this report.

2 Methodology

This review was conducted during November 2023 and January 2024. Reviewed documents were obtained through:

1. The provision of some key studies for review provided by the Australasian Bioplastics Association and the references cited by these papers.
2. The publicly available research papers previously commissioned by EPA NSW looking at potential risks from compostable and other plastics in the environment and in commercial composting.
3. An on-line key word search using Web of Science and Google Scholar research platforms using variations of the research terms and Boolean expressions containing key words: compostable packaging, bioplastics, plastics, micro-plastics, toxicity, eco-toxicity, soil health, polyfluorinated, chemical contaminants. The criteria for selecting a paper for review favoured: recent (since 2020) meta-analyses and reviews and papers relevant to certified compostable packaging formats. References of relevant papers were also reviewed and selected where relevant. References from the FRRC paper's author's personal library were also considered in the review.

The research has focused on products that are certified as compostable and biodegradable under the ABA certification scheme including:

- Certified compostable bioplastic (CCBP) coatings, films and bin liners.
- Certified compostable Fibre-based (CCFB) packaging formats, including items coated with CCBP

The following sections of this paper detail the literature review methodology and provide discussion of research outcomes. Conclusions and recommendations for further research and appropriate application of the Precautionary Principle to inclusion of items in FO/FOGO services are provided.

3 Review of key documents

FFRC has reviewed the two main NSW EPA commissioned and publicly available reports that appear to be the foundation of these concerns, as well as conducting a broader review of the literature. Several comprehensive assessments of the performance of and contamination risks associated with compostable plastics have been identified and reviewed. The following discussion first focuses on the two reports commissioned by NSW EPA, and then considers a wider review of risks.

An environmental hazard assessment of biodegradable plastic bags - A preliminary aquatic toxicity assessment, CSIRO 2017

This report was commissioned by NSW EPA to undertake a preliminary chemical and ecotoxicological assessment for a range of biodegradable plastics commonly used in commercial bags in Australia. The objectives were:

- *To characterise chemicals released in water extracts of biodegradable plastic bags unexposed and exposed to simulated weathering; and*
- *Assess the aquatic ecotoxicity of these water extracts from the biodegradable plastic bags using a fresh water cladoceran (Ceriodaphnia dubia), microbial species (MARA assay) and a soil nematode (Caenorhabditis elegans)*.

The plastics selected for this project were sourced from commercially available bags and included:

- A compostable plastic containing naturally-sourced starch-based polymers and certified to AS4736-2006. This bag was coloured green and had black printing on it.
- A compostable plastic containing a synthetic aliphatic aromatic co-polyester (~75%) in combination with starch-based polymers (~25%) and certified to AS 4736-2006. This was a white bag without printing on it.
- A 'hybrid' non-certified degradable bag containing high density polyethylene (HDPE) combined with biodegradable plant starch This bag was coloured blue had white printing on it.
- A non-certified oxo-degradable HDPE bag containing an additive to enhance the rate of disintegration and fragmentation (i.e. not genuine 'degradation'). This was a white bag with green printing on it.
- A conventional HDPE plastic bag. This was coloured white without any printing on it.

The testing undertaken on the plastics included:

1. Artificial weathering by being exposed to intense artificial solar radiation whilst being held at a temperature of 30°C for a period of 2.5 weeks, which was seen as replicating plastics to solar exposure for three months. These are referred to as 'exposed' plastics. This means that the testing did not expose plastics to microbial action nor a composting environment. In effect, all it tests is what chemicals can be extracted from the plastics with and without simulated heat and solar 'weathering'/exposure. It is therefore not an assessment of the performance of plastics under commercial composting conditions.
2. Extraction of 'leachate' from exposed and un-exposed plastics by immersing 100g of plastic in 750ml of 'moderately hard' water (i.e presumably water with calcium carbonate and a pH of 7.0-7.5 although this is not defined in the report) at 50°C for 72 hours. The reasons for this weight of plastic, volume of water, and use of hard rather than distilled water is not provided in the report, but obviously would have determined the concentration of chemicals in the leachate. The methodology is useful for comparing the relative amounts of chemicals in leachate, but the basis for assuming this would be the concentration of leachate from plastics in the environment is not provided. The leachate extracts were tested for a range of heavy metals and chemical contaminants and used in ecotoxicity tests. For reasons not explained, the leachates were tested to the Australia and New Zealand Environment and Conservation Council (ANZECC) *Australian and New Zealand guidelines for fresh and marine water quality.* This implies that the leachate concentrations derived from the 100g of plastic in 750ml of water is somehow representative of what is likely to be produced if the plastic was in the environment. This is almost certainly a misrepresentation because a single use plastic shopping bag of the type of tested bag typically weighs 5-10g, so the 750mL of leachate was extracted from the equivalent of 10-20 bags.

Although this may be useful to assess the comparative levels of chemicals in different plastics, this is a level of exposure and leachate concentration far in excess of what is likely to occur if plastics are managed through FO/FOGO or become litter. Despite this, these concentrated leachates were then used for the chemical analysis and toxicological tests that were used to conclude the plastics pose an environmental risk. The assessment also fails to consider that the ABA CCP certification and AS4736 require that certified products, including inks and additives comply with toxicological testing. This means that by definition, the bio-plastic bags tested that had apparent eco-toxic effects was not compliant with AS4736 or ABA CCP verification requirements, and cannot be considered to be representative of ABA certified products. It does, however, highlight the potential for non-certified product with claims of compostability to potentially have ecotoxicity risk if they become litter in the environment, even if the testing did not simulate the behaviour or fate of the plastics under commercial composting conditions.

The methodology did not simulate commercial composting conditions, where biodegradable compounds including compounds resulting from the degradation of inputs will be more rapidly degraded. It is suggested future assessments of potential toxic risks from plastics use more realistic ratios of plastic weights to volumes of water used to produce leachate. It is also suggested that simulated weathering tests that do not include biological degradation of plastics are not appropriate for assessing the risk of compostable plastics, and future studies should expose materials to commercial composting conditions.

3. Acid extraction of some metals from plastics to assess the concentrations of these the different sampled plastics. This is a legitimate way to assess and compare the presence of the tested chemical in products. However, the method used in the study used a small number of extracts from each sampled plastic and included printed and coloured film plastics. Inks and colourings are likely sources of some of the heavy metals.

Because the work was a preliminary investigation, a small number of three replications was undertaken for tests. Although in some instances there was considerable variability, expressed as standard deviation, in results, in most instances this was small. This indicates the testing produced similar result in all three replications.

Some issues to note about the methodology:

- The range of plastics selected only contained two ‘compostable’ plastics - these were both starch based and likely a combined synthetic- and starch-based product, although one was stated as being ‘100% starch based’. This may refer to only the bio-polymer in the product. It is not clear whether either of the ‘compostable’ bags was ABA certified compostable, but the failure of ecotoxicity tests strongly suggests they would not be compliant.
- The other ‘degradable’ plastic bag other formats were almost certainly not compostable to any recognised standards. No fibre-based compostable packaging formats were included in the testing. This means the test results are of questionable relevance to ABA certified compostable film products and have very little relevance to fibre-based formats.
- The processing method did not simulate commercial, or even home, composting conditions, but focused on what soluble and total elements and compounds were present in the products and those that could be leached from plastics exposed and unexposed to simulated weathering. This means that other than identifying some chemicals present in the tested plastics, the results have little relevance to the performance and environmental risks associated with compostable plastics in commercial or home composting conditions.
- The rationale behind the method used to extract leachate from the plastics and use of water quality standards to assess the potential toxicity of chemicals from plastics is unclear. In particular, the weight of plastic and volume of water used to extract the leachate seems likely to

produce more concentrated leachate than might occur from the amounts of plastic typically found in FO/FOGO, and certainly higher than from fibre-based certified compostable formats that have micron-thin coatings of bioplastics. The comparison of the extracts to the ANZEEC water quality guidelines only makes sense if the leachate is representative of the concentrations that would occur from the presence of the plastics in composting or the environment, and this is unlikely. The use of these extracts for toxicology tests on indicator species at various concentrations is useful for assessing the comparative toxicity of extracts, but consideration needs to be given to whether these diluted concentrations are representative of what would occur in composting or in the environment.
- The potential effect of inks on and colouring in printed bags on the presence of chemicals in samples does not seem to be considered. Although this simulated the printed shopping bags tested by the study, it may not be representative of other forms of unprinted and certified compostable packaging.

Key outcomes of the testing were:
- The water leachate from each type of plastic had alkaline pH in all instances other than the '100% starch' -based polymer and printed bag, which has slightly acidic pH of 6.2-6.3 for both unexposed and exposed plastics. The 'moderately hard' water used to extract leachate would presumably have had a pH of 7.0-7.5, so the printed 100% biopolymer film seem to have resulted in some acidification. The other plastics typically recorded higher (more alkaline) pHs following the simulated weathering. None of the pH readings from the water-extracted leachate were outside the range of pH likely to have lasting detrimental impact to aqueous environments or soil. Once again, it is worth noting that the research method used in the report does not simulate the likely concentration of leachate from plastics under composting conditions and does not include biodegradation, so its relevance to the fate and risks of chemical from bioplastics in composted FO/FOGO is limited. The pH of materials during different stage of the composting process can vary from acidic and alkaline, and organic matter in compost can have a pH buffering or neutralising effect, so any minor acidity or alkalinity generated from decomposition of compostable packaging is unlikely to impact on the composting process, products or any leachate from the composting process.
- The water leachate from all exposed and unexposed plastic films generally complied with AS 4736 chemical parameters and there was little difference between leachates from plastics unexposed and exposed to artificial weathering.
- The printed bio-polymer bag also produced leachate with higher cadmium (Cd), Zinc (Zn) and Lead (Pb) than other bags.
- An assessment of the potential bioavailability of metals found Pb, Sn, Cd, Cu and Ni would be low in leachates from the compostable plastic bags. However, Zn, manganese (Mn) and Cobalt (Co) in leachates from bioplastics was observed, suggesting these metals would be potentially bioavailable. This finding is not consistent with other testing of bio-polymer products. For example: Markowicz and Szymanska-Pulikowska (2019) tested the chemical composition and leachates of a range of compostable and oxo-degradable bags, including printed formats, and did not find elevated heavy metals levels in any sample; Astolfi, et al (2021) similarly found low levels of total and migratable heavy metals in bioplastics derived from crops. This suggests the source of the elevated heavy metals may have been the printing ink on the tested bag rather than the bioplastic itself. The presence of such heavy metals is more consistent with oxo-degradable plastics rather than products meeting Australian Standards and ABA verification program requirements.
- Numerous organic compounds were identified in water leachates and solvent extracts of the plastics. The results for the white compostable bag found highly variable levels of phenol (330±314 µg/L), and the average level for this parameter in the concentration of leachate produced by the extraction method exceeded the ANZECC water quality guideline trigger value (320 µg/L). However, as discussed previously, the method used to extract leachate is likely to

produce more concentrated leachates than would be produced by inclusion of compostable packaging in FO/FOGO collections and processing at commercial composting facilities.

- Very high concentrations (1650-4700 mg/L) of dissolved organic carbon (DOC) and low dissolved oxygen (DO) concentrations (13-86%) were also measured in the leachates from the compostable plastics, including the HDPE hybrid plastic which contains starch polymers. This is to be expected because of the presence of biodegradable polymers, but it is irrelevant in the context of a bioplastic being commercially composted because the process will rapidly digest and degrade such DOC.
- Acute toxicity testing of leachates extracted from the plastics using bio-indicator species found some toxicity for the freshwater cladoceran, *Ceriodaphnia dubia (C. dubia)* for the leachates from the green and white compostable plastic bags, while no toxicity was observed in the water leachates from all other plastics. Bioassay testing using nematode and selected bacterial and fungal populations found no observed toxicity for water leachates from all the plastics. However the bioassay tests found some reduced growth when exposed to the white and green 'compostable' plastic leachates. This was attributed to higher dissolved oxygen (DO) levels and potentially elevated heavy metals, or potentially an untested organic chemical parameter. However, as discussed previously:
  - ABA and AS4736 compliant products must pass similar eco-toxicity testing, so by definition, any product failing such a test is not representative of ABA certified products.
  - The method of extracting leachate almost certainly produces a stronger leachate than would occur from the levels of bioplastics present in a FO/FOGO system – even in a scenario where a high proportion of compostable packaging was present in the diverted organics stream (e.g. food diverted from a public event where packaging can be a significant weight of the total recovered organics stream; on average, the proportion of compostable packaging) in household and most commercial FO/FOGO is much lower. Food-rich streams from public events are generally blended with shredded GO.
  - The elevated DO levels detected are not relevant in the context of a commercial composting facility as this would rapidly be biodegraded.
  - The testing does not include fibre-based compostable items.

It is worth noting that the CSIRO study was intended as a preliminary study, using small sample sizes and producing recommendations for further research to further test largely inconclusive findings. None of the findings provide a strong basis for concluding that certified compostable film plastics pose significant, long-lasting or irreversible environmental risk in commercial composting in either the composting process or in compost products. The work is specific to film plastics being used as single use shopping bags at the time, and the testing is more relevant to the fate of such bags should they become litter in the environment that it is to the risks of products in commercial composting. The study is largely irrelevant to fibre-based compostable packaging and bioplastic products using thinner ply film and coatings.

In summary, the CSIRO 2017 assessment of plastic films does not support the case that ABA certified compostable bioplastics managed through commercial composting pose significant, lasting or irreversible environmental risk during composting or in the use of end products. The report does not produce a strong basis for application of the Precautionary Principle to restrict inclusion of certified compostable plastics from FO/FOGO systems.

Compostable plastics in green waste: a lowdown on their breakdown, CSIRO 2021

NSW EPA commissioned CSIRO to undertake a review and testing of the performance and risks of some 'compostable' plastic products when included in green waste composting. This study:

- Surveyed NSW local governments encouraging their communities to use compostable liners in FO/FOGO collections to estimate the typical contribution on liners to composted FO/FOGO input materials. This determined the rate of compostable plastics in FO/FOGO from these councils to be 0.06-0.23 % by weight of total inputs.

- Undertook a review of previous studies of the decomposition of compostable plastic products in simulated commercial composting.
- Added compostable rigid and film plastic items – cutlery, a bowl and various liners – to FO/FOGO compost at a rate of 0.5% by weight of total organic inputs, and tested compost attributes for a range of chemicals and eco-toxicity to indicator species. This rate of compostable plastics in compost is more than twice the rate found to be currently present in FO/FOGO. The tested plastics were:
    - Biobag (PBAT/TPS) bag and BioPak (PLA) cutlery
    - Compost-A-Pak (PBAT/TPS) bag that was commonly distributed by LGAs in NSW
    - BioPak (PLA) bowl to represent a semi-crystalline form of PLA.

It is worth noting that no fibre-based compostable packaging formats were included in the assessment.

Chemical testing was undertaken of key nutrients and heavy metals the plastic products was undertaken. This found all products were compliant with AS4736, and in most instances had levels well below the standard's thresholds for heavy metals of greatest concern. CSIRO used these results with the results from a survey of local government regarding the estimated amounts of plastics in FO/FOGO to estimate the potential contribution of compostable plastics to heavy metals in finished compost and found this would be negligible compared to the background levels of such metals in FO/FOGO composts. This was borne out by the chemical testing of composts produced in the trial (see below). PFAS/POPs or other chemical compounds in bioplastics were not tested.

The compost product testing subjected materials to an initial 'hot' (thermophilic) composting and 'curing for a total period of 60-70 days, followed by a 'maturation' period of a further 35 days for the film plastics (105 days total) and a further 120 days (180 days total processing) for the cutlery. This represents a full composting process to produce stabilised 'mature' composts, and likely exceeds the time taken to process and distribute FO/FOGO composts. Periodic testing of the presence of bioplastic fragments found that the compostable rigid plastic had very significantly biodegraded within 9 days of thermophilic composting, and had substantially degraded and fragmented within 34 days. By 117 days there were some visual white plastic particles, but these were otherwise indistinguishable from other organic particles in the compost. The film plastics tested fragmented rapidly within the first weeks of composting and was not distinct from compost within 70 days. The products complied with AS4736

Chemical and toxicological testing was undertaken to determine the presence of indicator compounds and eco-toxicity of compost products.

Physio-chemical testing found that chemical composition and physical contamination of composts with 0.5% by weight added compostable plastic were indistinguishable from 'control' composts without added compostable plastic. Contaminant levels were low in all tested products and products were fully compliant with the Australian Standard for Composts, Soil Conditioners and Mulches, AS 4454-2012.

The plastic film and rigid plastic products met or exceeded biodegradability requirements for AS4736, with over 90% disintegration and decomposition of materials within days. Some of the rigid plastic cutlery was initially slow to degrade because it needed to hydrate, but once this had occurred after around 30 days, it rapidly disintegrated and biodegraded. This suggests that facilities receiving such items need pre-processing materials shredding and wetting practices to promote rapid degradation of such bioplastics. In most Australian jurisdictions FOGO materials are required by regulators to be processed using such methods and under conditions that should promote rapid biodegradation.

The eco-toxicity testing conducted consisted of tests of:

- microbial function (respiration and nitrification)
- soil invertebrate mortality, reproduction and growth
- plant emergence and growth.

The microbial function testing found no significant differences between the control ('no plastics') compost and composts containing plastics

The ecotoxicity assays were based on standardised protocols for testing of soils but the compost was used as received without further mixing with soil. This meant that the testing did not comply with testing standards. The CSIRO authors' attribute a high mortality in all treatments (control 'no plastic' treatment and the compostable plastics treatments) to a higher than standard testing maximum water holding capacity in all of the unblended compost treatments.

Visual assessments of plastics remaining in compost were undertaken using naked-eye, microscope and electron-microscope assessments.

Overall, the study and review of previous research found that certified compostable plastics performed well under commercial composting conditions, with over 90% breaking down is less than 120 days and having negligible contribution to potential chemical contaminants in finished composts. The analysis of plastics found the levels of tested trace elements, including heavy metals, were higher in printed plastics, supporting the likelihood that inks, rather than bioplastics, are the source of 'elevated' samples of these elements.

The results for seedling germination and earthworm toxicity of products were inconclusive and were not conducted in accordance with AS4454.

This report is relevant to some compostable plastic film and rigid products, but is not relevant to fibre-based products.

Although the CSIRO 2022 report calls for further research into compostable packaging, there are other studies that clearly demonstrate certified compostable products will biodegrade under commercial composting conditions (Alhanish and Ghalia, 2021; van der Zee and Molenveld, 2020; Unmar and Mohee; 2009, Yu et al 2020). These studies are considered in the following discussion.

4 Review of benefits and risks of compostable packaging in FO/FOGO systems

The following discussion considers the benefits and risks of CCP and other packaging formats. It considers:

- The potential benefits of CCP formats in increasing participation and diversion rates in FO and FOGO services.
- The rates at which products biodegrade in commercial composting.
- The presence and fate of biodegradable plastic and fibres during composting.
- The presence and fate of any potentially harmful chemical or physical items in CCP that may pose risk to human or environmental health, and the magnitude of such risk.
- The potential impacts and risks of CCP in landfill.

The review also considers the concerns outlined in the NSW EPA position statement restricting inclusion of compostable packaging in FO/FOGO services.

Once again, it is important to consider the difference between ABA certified compostable products and other non-certified, 'degradable' and fibre-based products. A range of non-certified products are marketed as 'degradable', 'bio-degradable' or even 'compostable', or may be similar in appearance to certified products, but might not meet the criteria for certification, and not be fully compostable/ biodegradable and may contain potential chemical contaminants. Such products have been included in many studies of the performance and risks of 'compostable' packaging. The review of literature has made a distinction between papers that consider non-certified 'degradable' and other packaging formats with those that have considered products that are compostable to AS4736, AS5810 or comparable international standards. Such mislabelling of products as 'compostable' and 'degradable', and the inclusion of such products in previous assessments of the performance of 'compostable' plastics are significant constraints to the wider adoption of genuinely and certified compostable products. It is suggested ABA work with regulators and retailers to remove misleading marketing and labelling of products and work to raise consumer and supply chain awareness and understanding of the need to avoid such products.

It is also important to note that many studies of the performance and risk of 'degradable' plastics have not exposed the products to commercial composting conditions and have been more focused on the likely performance of products as litter or as horticultural film plastic mulch products. Commercial composting conditions require that input organics are managed through the mix of inputs, moisture and aeration to produce 'hot' (thermophilic) conditions, with high levels of thermophilic bacterial activity and bio-chemical and physical conditions that favour more rapid degradation of biodegradable compounds, including by-product compounds produced from the degradation of materials. This means that studies of the performance and potential toxicity of plastics under non-thermophilic conditions may be less relevant for assessing the performance and risks of compostable packaging under commercial composting conditions. This review has made a distinction between studies that have exposed products to commercial composting conditions and those that have not.

A useful framework for assessing the desirability of compostable packaging is provided by the National Compostable Packaging Strategy (APCO 2021) which was developed by the Australian Packaging Covenant Organisation (APCO) in cooperation with ABA and AORA. The strategy advocates that compostable packaging should be managed according to the following principles:

- Compostable packaging should only be used when it generates the highest potential environmental value.
- Elimination, reduction, reuse and material recycling options should be considered first.

- A holistic systems approach is required to ensure compostable packaging is only favoured in scenarios where it is practical to collect and process through organics recycling facilities, with minimal cross contamination of other waste streams.
- To ensure high quality recycled products, it is necessary to avoid cross-contamination between organics recovery systems and plastics recovery systems.
- The use and recovery of compostable packaging must minimise impacts on the environment at every stage.
- Adding packaging to the feedstock for organics recycling should not reduce the quality and value or limit the application of composted end products. The strategy acknowledges that the risks associated with use of compostable packaging need to be evaluated and managed.

(APCO,2021)

The following discussion considers benefits and risks/concerns related to compostable packaging in FO/FOGO systems.

4.1 Benefits of compostable packaging

The following discussion identifies benefits of allowing compostable packaging to be managed via FO/FOFO systems under headings.

Biodegradability

There is increasing concern regarding plastics and micro-plastics in the environment, and some concern that 'degradable' plastics result in persistent microplastics with short term or longer-term impact on soil and other ecosystems. A distinction can be made between compostable bioplastics and which will biodegrade in compost and the environment, and plastics that disintegrate and partially biodegrade, resulting in micro-plastics that can take years or decades to fully degrade. Non-degradable plastics such as commonly used PET, PP, HPDE and LDPE will also typically disintegrate when exposed to the environment (particularly sunlight), but will result in microplastics that can persist in the environment for centuries (Jagadeesh and Sundaram, 2021; Ricciardi et al, 2021).

AS4736 certified compostable products will rapidly degrade under the high biological activity, high temperature, and bio-chemical conditions in commercial composting and AS5 certified products will decompose under less extreme home composting conditions. The standards are based on the quantities of plastic particles that do not pass through 2mm screens and to have biodegraded within time periods. A feature of this standard is that up to 10% of plastics can remain in particles of >2mm in size after composting. In reality, most non-rigid plastic and fibre-based products containing bioplastics far exceed this standard, and disintegrate and biodegrade more completely within shorter time periods (Alhanish and Ghalia, 2021; van der Zee and Molenveld, 2020). Bulkier rigid products, such as cutlery and serviceware such as the composting forks tested in the CSIRO 2021 study (see Section 3), can persist for longer. Compostable bio-plastics low ply films and coatings on fibre-based packaging will typically achieve greater than 90% biodegradability within weeks of processing and remaining residues do not typically persist for more than 12-18 months in the environment (Burgstaller, et al, 2018). A study Zumstein et al (2018) using 13C-labelled isotopes to track degradation of bioplastic agricultural mulches unequivocally demonstrated complete (100%) biodegradation and utilisation of carbon in poly butylene adipate-co-terephthalate (PBAT) bioplastic, with any remaining carbon from the plastics being taken up and used by soil bacteria and fungi. Sun et al (2022) found similar complete degradation of a wider range of bioplastic agricultural mulches and improvement in soil biological activity, nutrient turn over/plant availability, and soil structure on soils containing bioplastic. Agricultural mulches would result in much higher concentration of bioplastics in soil than residual bioplastics in compost products, so it can be expected such residual bioplastics will from composts will not persist in the soil.

The rates of disintegration and biodegradation of compostable plastics are determined by the conditions they are exposed to, their overall composition and the thickness/bulkiness of products. The permeability of products to water can also impact of rates of decomposition.

Under commercial composting conditions many compostable packaging types can decompose more rapidly than AS4736 threshold periods. Indicative figures for rates of biodegradation are provided by Burgstaller, et al. (2018):

- Biodegradable under conditions of commercial composting (58 ± 2 °C, max. 6 month):
  - TPS, PHA, PCL: 4-6 weeks
  - PLA, PBAT, PBST: 6-9 weeks
  - PBS: 21 weeks
- Biodegradable in soil /home compostable (20-28 °C, max. 2 years):
  - TPS, PHA, PBSe, PBSeT, PBAT, PCL: 7-12 month
  - PLA: no degradation after 1 year
- Biodegradable in fresh water (20-25 °C, max. 56 days) (NB: this test is less relevant to compostable products, and is more to do with the degradation or disintegration of plastic litter in aquatic waterways)
  - TPS, PCL, PHA: <56 days
  - PBS, PBSA: ca. 3 month
  - PLA, PBAT: >1.5 years
- Biodegradable in seawater (30 °C, max. 6 month) (similarly, this test is less relevant to compostable plastics and relates to plastic litter in marine environments)
  - PHA, PCL, TPS, PBSe: <6 month
  - PLA, PBAT: >1.5 years

(adapted from Department of Agriculture, Water and Environment,2022)

An advantage of ABA certified products is that over 90% by weight will fully biodegrade during commercial composting, and any particles surviving the composting process will not persist for extended periods in the environment. Similarly, ABA certified products that inadvertently become litter will typically not persist in the environment as long as other plastic items. This means the products do not pose a significant or irreversible when composted by FO/FOGO commercial composting facilities.

There are some concerns that compostable packaging formats will not decompose rapidly enough within the production times of some commercial composting facilities This is discussed further in Section 4.2. It a legitimate concern that may need to be addressed by:

- Amendments to standards to allow recognition of more rapidly degrading products.
- Ensuring composting facilities receiving FO/FOGO material that contains compostable packaging have appropriate processing periods and product screening systems to ensure products comply with As4454 and are acceptable to receiving markets. It should be noted that many facilities processing FO/FOGO receive materials containing compostable ’kitchen caddy’ liners, and therefore have processing periods and product screening methods that can manage most compostable packaging formats.

Reduction of food waste

Food packaging serves to protect food and extend the ‘shelf life’ of products within supply chains and at consumers’ residences. The environment benefits of food waste reduction are significant, from reduced ‘up-stream’ impacts of food production (e.g. energy , fertiliser, chemical and water use; greenhouse gas emissions; pressure on land and water ecosystems; etc) and avoided emissions from landfill or, to a much lesser extent, composting. Elimination of all food packaging is therefore not desirable, so the choice then is between compostable, recyclable, reusable or non-compostable and non-recyclable formats. The latter two (non-compostable and non-recyclable) are being phased out under APCO and retailer commitments and there are regulative and practical restrictions on the reuse of many food protection packaging items, so the choice is between compostable or recyclable. Although recycling is often seen as more desirable under the waste minimisation hierarchy, the absence of 'circular' recycling (i.e. where materials are recycled back into products that substitute for simile first use items) options for many food protection and food-contaminated packaging items means that composting can be a more viable recovery option than recycling. Bioplastic products that can be both recycled through existing kerbside systems or composted via FO/FOGO services allow recycling of clean items and composting when they are food-contaminated.

Consumer convenience and trends

There is a consumer preference trend toward pre-made meals and pre-processed food. Ready-made meals that can be microwave or oven heated in the container they are package din are increasingly popular (Statista Market Insights, 2023). Although these products can reduce food waste generation by households from food preparation organic scraps, they increase packaging waste and food-contaminated packaging. Although some of these packaging formats can be recycled, many cannot or have low commercial value to recyclers, particularly when they are food contaminated. Film plastics are not recyclable through most existing kerbside services. Such items are inevitably found in FO/FOGO streams where unfinished meals and food contaminated packaging is disposed as 'food waste'.

In situations where packaged food does spoil, many consumers are reluctant to unpack 'off' food and dispose of the food with packaging. If compostable packing is widely used and accepted by FO/FOGO systems, such items can be recovered instead of landfill. Packaged food is a small but not insignificant contaminant in FO/FOGO services, contributing over 2% by weight (Rawtech, 2018).

Acceptance of compostable packaging in FO/FOGO services would allow more food from unfinished meals and spoilt packaged items to recovered.

Recyclability (in some instances)

Some compostable fibre-based products and potentially plastics can be recovered via kerbside composting systems. This means some fibre-based compostable packaging items have the advantage of being compatible with both recycling and composting systems, whereas the plastic items they substitute for are a contaminant of FO/FOGO systems and usually of low value to recyclers, especially when they are food contaminated.

Increased diversion of food to FO/FOGO services

As discussed previously, some consumers are reluctant to remove spoiled and unfinished food from packaging. When this and other food-contaminated packaging is included in recycling systems they are typically treated as contamination and not recycled. Similarly, food in non-compostable packaging is a significant contaminant of most FO/FOGO services. Increasing the proportion of food packaged in certified compostable formats and promoting recovery of these through FO/FOGO services will increase food organics recovery and reduce contamination both the container recycling and FO/FOGO services.

There is a lack of consistent data and research into they extent to which compostable food packaging might increase rates of food waste recovery. Audits of garbage, recycling and organics materials typically classify packaged food as 'contamination' and rarely quantify this as a discrete stream of materials. A 2013 audit of Victoria's household garbage found around 2% of total garbage and 4% of all food in garbage was food (excluding beverages) still in packaging (Sustainability Victoria, 2014). At this time, few councils offered FOGO services. More recently, a 2019 audit of kerbside waste from 10 Southern Sydney councils found around 7% by weight of household garbage was containerised food, unrecyclable/food-contaminated paper contributed 11% by weight, and that the contributions of containerised food and food-contaminated packaging had increased compared to previous waste audits (APC, 2019). A 2022 audit of ACT's household garbage found packaged/containerised food made up 12.5% by weight of household garbage and this represented more than 30% of food in the garbage stream. The ACT audit also found significant amounts of potentially compostable food-contaminated paper and single use cups in garbage (APC, 2023). These results strongly suggest that very significant increases in food organics diversion and overall resource recovery could be achieved by wider adoption of certified compostable packaging and promotion of recovery of this through FO/FOGO services.

The environmental benefits of food diversion to FO/FOGO are highly significant. The main benefit is reduced emissions of greenhouse gases from landfill and reduced risk from landfill leachate pollution. In landfill, food waste has potential to generate methane with a global warming potential over 100 years of over 2.1 tonnes carbon dioxide equivalents per tonne of food, and even greater warming impacts over a shorter period. Although most landfills receiving food organics in Australia have landfill gas recovery and oxidisation systems, few landfill recovery gas until landfill cells are completed, and most methane emissions from landfilled food occur within a few years of waste deposition. This means most of the methane generated by food in landfill is released to the atmosphere. Food in landfill also creates bio-chemical conditions that speed decomposition of other 'dry' high carbon organics such as paper and timber, meaning more methane is released from these materials. The bio-chemical conditions promoted by food in landfill also generate leachates containing soluble nitrates, heavy metals and organic compounds that can contaminated groundwater and surface water.

Reduced contamination of inputs and outputs

Where compostable packaging formats are visually identifiable, personnel engaged in input decontamination at composting facilities can be trained to leave these in the organic stream. This is already the practice for bioplastic FO caddy liners and many paper fibre items. Because most certified compostable films and fibre-based products will rapidly disintegrate and biodegrade under commercial composting conditions, most of these items will not be present and need to be screened out in final product cleaning. The issue of microplastics and chemical compounds that may survive the commercial composting process is considered in the following discussion in Section 4.2.

A viable alternative to more problematic packaging

Non-container food packaging items serve an important role in protecting and extending the life of food, as well as meeting consumer demand for convenient and ready-made meals. However, they are often problematic for both materials recycling and organics recovery facility operators. Reducing food-contaminated and often lower value packaging from MRFs, and reducing non-compostable packaging at organics recycling facilities will improve their viability. Compostable packaging items are not without management issues (see Section 4.2) below, but they have been seen and promoted by both APCO and the Australian Organics Recycling Association as a preferable alternative to non-compostable and often non-recyclable packaging items. The NSW EPA policy directive excluding certified compostable packaging from FO/FOGO will likely delay or halt the transition to compostable packaging formats, and maintain the current situation where many food packaging items are effectively a contaminant at both MRF and FO/FOGO composting facilities.

It is suggested consideration needs to be given to the likely fate of many of the non-compostable packaging formats that could be substituted with compostable packaging. Markets for low value plastics are currently and historically poor, with few instances of 'circular' recycling and the need for development of new 'down-cycling' (i.e. moving to lower and 'linear' resource use) uses such as plastic composite 'lumber' and road surfacing which disperse microplastics into the environment.

4.2 Risks and concerns regarding compostable packaging

The following discussion considered potential risks posed by compostable packaging. This discussion also considers risks posed by non-compostable packaging. It is worth noting that numerous studies have been conducted into the degradability and biodegradability of compostable bioplastics. Historically, many of these studies have included review of plastics that would not meet the specifications and standards of ABA certification and have included products containing polymers that are not readily biodegraded, such as oxo-degradable, photo-degradable and plastic blends containing plastic polymers resistant to biodegradation and resulting in fragmentation and persistent microplastics. This means that non-academic on-line searches of the risks of degradable plastics will generate many links to articles about the risks and impacts of degradable plastics, but do not apply to ABA certified compostable products. It is also worth noting that some ABA certified compostable products may persist in soil in the same way that other biodegradable but less soluble and labile organics, such as larger particles of 'woody' organics containing lignins, cellulous, hemi-cellulose, chitins and other compounds resistant to decomposition persists in soil. Such compounds can have means residence times of several years, and even greater if they are occluded/protected by the formation of soil aggregates. The question therefore must be not whether some small fragments persist in soil and the environment, but whether these compounds and particles cause any more harm than, or have similar benefits to, 'natural' woody particles in soil. The following discussion considers this question for each of the identified risks and uncertainties about the fate and impact of ABA certified compostable plastics

Physical and chemical contamination risks

One of the key reasons for NSW EPAs restriction of compostable packaging formats from FO/FOGO services is concern that physical and chemical contamination of products pose risks to soil and environmental health. The basis for these concerns appears to be the CSIRO studies reviewed in Section 3.

The contamination risks include:

- **Visual contamination impacting on appearance and market value.** Visual contamination by plastics and other physical contamination reduces the market value of composts. There is concern that compostable materials will not break down sufficiently in some commercial composting processes and contribute to visual contamination. However, the rapid biodegradability of many compostable products, as well as input and product screening systems in place to manage non-compostable contamination suggest this is a manageable risk and that compostable plastics significantly reduce the risk of visual contamination in products (van der Zee and Molenveld, 2020;). The greatest risk is at facilities that have poor pre-process screening and shred inadequately screened input, have short (less than 6-9 week) processing periods, and have inadequate product-screening processes. Most composting facilities in Australia use a combination of manual/visual and mechanical pre-screening of inputs, and manual operators can be instructed to leave identified compostable items in composting stream (as they currently do for FO plastic liners and most paper products). Most Australian facilities screen a fine and 'cleaner' compost fraction and also 're-work' screened fractions with moderate visible contamination and high organic content. Reworked material containing compostable package will, over two or three 'runs' through the process, be exposed to the 6-9 weeks they need to decompose. Non-compostable packaging remains the main source of visual contamination and systems to remove this will also remover compostable packaging (van der Zee and Molenveld, 2020).
- **Micro-plastic contamination of products impacting on receiving soils and the environment.** There is increasing concern about the effects of microplastics on soil micro-fauna such as earthworms, with evidence that they can have negative impacts (Fan et al, 2022; Markowicz and Szymanska-Pulikowska, 2019). Persistent, non-degradable microplastics have the potential to

accumulate in soils or runoff to surface water ecosystems (Markowicz and Szymanska-Pulikowska, 2019). Studies into the impacts of compostable plastics on soil microbiology are inconsistent, with some suggesting some short-term negative impacts and others suggesting no negative impacts and even benefits /growth stimulation (Fan et al, 2022; Liwarska-Bizukojc,2021). There is some suggestion that ingestion of microplastics negatively impacts earthworms and presumable other fauna, and that it accumulates, or 'bio-concentrates' in food chains and particularly aquatic and marine ecosystems and food chains (Markowicz and Szymanska-Pulikowska, 2019). However, compostable bioplastics 'microplastics' small enough to be ingested are likely to be digested or passed in the same way that other 'woody' organic materials are, and although some research has found negative impact on some species, others have recorded neutral or positive impacts. Separating the benefits of adding compost to the soil from any negative impacts of micro-plastics may be difficult, and it may be even more difficult to attribute this to the compostable particles rather than the non-compostable plastics that are increasing ubiquitous in our environment. The potential contribution of bio-plastic packaging in composts to the total amounts of micro-plastics in the environment is very minor. The main sources of microplastics in the environment are rubberised plastics from vehicle tyres, synthetic microfibres from clothing and other textiles, plastic paints and coatings, and the weathering of plastics (An et al, 2020; Sustainable Investment Institute, 2021). Also, the biodegradability of most forms of compostable plastic suggests these are unlikely to persist in the environment for more than 7-12 months (Sun et al, 2022; Taib et al 2023; Unma and Mohee, 2008; Zumstein et al 2018) and cannot be considered to be a significant, long-lasting or irreversible environmental impact. Further work may be needed to investigate any negative effects of more persistent 'micro-plastics'/organic particles from ABA certified bioplastics in compost, but it is unlikely to have significant or lasting impact.

- **Chemical contamination of products impaction on receiving soils.** This risk will depend on chemicals in and printing on the compostable packaging. The main chemicals of concern are: 'plasticisers' such as phthalates; phenols; and heavy metals in plastics, dyes and inks. The issue of potential PFAS/POPs contamination is discussed separately below. There is little evidence to support the case that ABA certified compostable packing or other products certified to AS4736 or AS5810 pose significant risk of chemical contamination. Numerous assessments of chemical risks from compostable bioplastics and packaging, including the results of the CSIRO 2017 and 2022 studies reviewed earlier, do not suggest significant, lasting or irreversible environmental risk from products in compost that would comply with AS4736.
- **Physical contamination removed by input and product screening**. As discussed, there is risk that compostable packaging items that cannot be distinguished by manual and mechanical screening will be removed from composts and enter the landfilled waste stream. The study by van der Zee and Molenveld, 2020 suggest around 20% removal through pre-screening, 70% decomposition in short period composting, and 10% removal in final product screening. This research does not consider the 'reworking' or lightly contaminated mid-sized screenings. Re-working is a common practice and will result in mediums sized (typically 10-30mm, depending on the screens used) materials, including pieces of plastic, being put through the composting process again, and exposing any undegraded compostable packaging to further degradation. However, larger pieces of compostable packaging may be removed in pre- and final screening and typically landfilled. Some composters will stockpile contaminated 'oversize' for extended periods to allow further degradation before screening the final products. Where this occurs further degradation of compostable plastics can be expected. The amounts of compostable packaging screened from organics could be reduced by operators being trained to identify and leave compostable packaging in processed materials, and longer retention times for physically contaminated screened organics. It is also important to ensure that the composters receiving organics containing compostable packaging have decontamination systems and processing times suited to the degradation of products.

Potential addition of PFAS/POPs to composts

NSW EPA has also expressed concern that compostable packaging formats contain PFAS chemicals that may contaminate the environment. Previous research has found elevated levels of these chemicals in packaging products and composts containing such packaging (O'Connor et al 2002; Treier et al 2011; Deluca et al, 2021, Sivaram et al, 2022, Goosen et al 2023). However, other recent research of trends suggests that this may be a declining and historic issue because of the phasing out of more bio accumulative and known potential mutagenic and carcinogenic longer-chain PFAS/PFOS products in food packaging and other exposure pathways (Toms et al 2019, APCO 2021). On-going phasing out of PFAS compounds with known or suspected health risks should further reduce this risk.

The ABA certification systems for compostable packaging requires those seeking certification to legally declare that no PFAS have been added to products. Although some studies have found 'unintended inclusion' of PFAS in some paper fibre packaging that is present due to recycled fibre containing PFAS treated packaging (O'Connor et al, 2020), a recent study of Australian packaging formats found very low incidence of PFAS in products (APCO, 2021) and an international assessment of PFAS in 'takeaway' fibre-based plastics found most products have low or no detectable levels of these chemicals (Straková et al, 2023). The likely low concentrations of PFAS/PFOS compounds in paper fibre compostable packaging and low amounts of compostable packaging in FO/FOGO collection suggest that the possible 'worst case' contribution of this source to PFAS/PFOS in finished composts will be low compared to ubiquitous levels of PFAS/PFOS in food and garden organics and this is borne out by studies of chemical contamination levels in composts with and without compostable packaging (NSW EPA 2022; NSW EPA, 2019). It is worth noting that newsprint, which is accepted and promoted as a compostable kitchen caddy liner for household FO recovery, typically has high recycled content and potential for 'unintended inclusion' of PFAS (Fernandes et al, 2023).

The composting process can degrade longer-chain PFAS/PFOS products know to pose greater health risks into shorter chained compounds that have fewer known health risks (Sivaram et al 2022; Zhang et al, 2022). However, the shorter chain compounds are still detectable in laboratory testing for PFAS are more readily taken up by plants so this may increase food chain exposure to these chemicals (Zang et al, 2022).

There is some uncertainty regarding the risk of adding potentially harmful PFAS compounds via compostable packaging, but in Australia the risk appears to be declining due to the phasing out of harmful products and seems to be limited to some 'wax lined' bags (such as some microwave popcorn products) and the potential for 'unintended inclusion' of chemicals in recycled fibre content products. Where they do occur, the levels of these chemicals in products are low, and the concentration of these products in FO/FOGO is low, meaning the inclusion of products do not significantly contribute to the concentrations of these compounds in composts above ubiquitous background levels found in FO/FOGO products. It is suggested regulators restricting and discouraging the inclusion of compostable packaging in FO/FOGO services due to concerns about adding PFAS to soils and the environment . One concern is that the current detection methods and thresholds for PFAS do not distinguish between known likely carcinogenic and mutagenic long-chain polyfluorides that have largely been phased out but are still present in the environment, and short-chain polyflorides that may not be harmful as they do not bioaccumulate, and even of other fluoride products. The 100 ppm fluoride detection limit is based on the likely toxicity risk of longer chain PFAS, but may be less applicable to short chain compounds.

Incomplete biodegradability and contribution to microplastics in the environment

One concern about CCP in FO/FOGO systems is that products may not fully degrade during the compost process and result in visible physical contamination of end products and the receiving soil and environment. Also, most composting facilities screen inputs and outputs for physical contamination and these systems may remove CCP from the organics stream, with the residual contaminant waste stream being send to landfill.

As stated previously, CCP formats complying with AS4736 must meet the following requirements:

- Minimum of 90% biodegradation of plastic materials within a maximum of 180 days in compost
- Minimum of 90% of plastic materials should disintegrate into less than 2mm pieces in compost within 12 weeks (84 days)
- No toxic effect of the resulting compost on plants and earthworms using standardised eco-toxicity testing
- Hazardous substances such as heavy metals should not be present above the maximum allowed levels.

The CSIRO 2022 report and other testing of CCP products under composting conditions has found that many products far exceed the requirements of the standards, breaking down more rapidly and having levels of potentially toxic chemicals well below the standards' thresholds.

An advantage of ABA verification program compliant compostable products is that they will continue to biodegrade, so any residual fragments in compost product will not persist in the soil or environment.

Many low-ply film products and fibre-based CCP formats, with and without CCBP coatings or films, will disintegrate and degrade more rapidly than the standards' thresholds. EPA NSW's acceptance and promotion of the use of paper fibre food 'kitchen caddy' liners, such as newsprint, seemingly acknowledges this. It is suggested ABA seeks clarification from NSW EPA why compostable fibre-based products were excluded from FO/FOGO services under the 2022 policy direction.

It is worth again noting that items certified for home composting are more rapidly biodegradable than commercially compostable items, so any item certified to AS5810 will degrade more rapidly under commercial composting conditions that items certified to AS4736 The NSW Policy directive that excludes CCP certified to AS5810 from FO/FOGO does not appear to recognise this. It is recommended ABA seeks clarification from NSW EPA why AS5810 certified items have been excluded from FO/FOGO services.

Items have greater risk of surviving the composting process if:

- They are a heavy ply film or solid rigid item.
- The organic processor receiving FO/FOGO materials produces 'young'/immature products that have been through a less than 30–40-day process or through a process with slow decomposition (e.g. if materials are allowed to become too dry or has anaerobic pockets in processed materials). This includes facilities that pasteurise organics using in-vessel or windrow technologies and put products into the market without sufficient maturation of products. Such facilities are not fully complying with AS4454-2012 requirements for the production of matured composts and are not the intended processors for FO/FOGO containing CCP items. It is also likely that the short-term nutrient draw-down and phyto-toxicity risks associated with such immature products will pose a much greater risk than any chemical attributes of matured composts from inputs containing CCP.

Contamination management at composting facilities

Most composting facilities employ a combination of manual labour and mechanical physical screening of input to remove physical contamination. Where these systems are based on manual labour screening (and most facilities use manual labour screening on inputs prior to shredding and composting), the operators can learn to distinguish non-CCP and CCP items, allowing fibre based 'shells and trays to remain in the composted stream. This is already typically done for paper-fibre products, where operators will leave paper in the composted stream. Mechanical screening is typically used to remove plastics and metals from materials prior to shredding and composting, and after composting, and it is possible that some CCBP film items not weighed down by food will be removed and presumably landfilled. However, CCBP that remains in the composted stream will then biodegrade during composting. Often screened 'oversize' from finished composts will be 'reworked' by being added to fresh batches of compost, and any CCBP that has survived the first composting process will degrade when reworked. Any CCP fragments that somehow survive into finished composts will bio-degrade when applied to land and not result in lasting physical contamination. This is a key advantage of CCP formats.

It should be noted that a key advantage of CCP items is that they are biodegradable, so any fragments that survive the composting process and remain in products (and, in particular, products from facilities with short materials processing times) will biodegrade when applied to land. They do not create long-term risks associated with microplastics in soils. However, some concerns have been raised about the potential for immediate and short-term impacts on soil and environmental health due to chemical and physical contamination of products. The potential for chemical and physical contamination of items during the composting process and in end products are now discussed.

Consumer confusion

One concern about allowing CCP formats in FO/FOGO is that it may confuse service users and result in similar-looking items that are not CCP being disposed to and contaminating FO/FOGO. However, as the packaging industry and food retailers move to meet the APCO objective of all packaging being re-useable, recyclable or compostable by 2025, all fibre-based food packing items should be compostable. The concern then would be that some non-certified fibre-based items that are recyclable, and so will meet APCO objectives, may have non-compostable plastic liners or contain chemicals with potential to contaminate compost products.

If CCP formats are permitted in FO/FOGO services, the service users and the operators removing contamination at organics facilities would need to be educated about which items can and cannot be disposed to FO/FOGO service. This is currently the case for compostable liners that are permitted in FO/FOGO. CCP items may need to be labelled with consumer information about their preferred management pathway, and/or given a distinct colour to make them more readily identifiable. This may be impracticable for all CCP items due to technical constraints and supply chain specifications. There should also be effort to replace products with non-degradable liners or chemical treatments with fully compliant CCP formats, as this would improve their recyclability as well as ensuring they could be composted.

Greenhouse gas emissions from biodegradable packing in landfill

A concern raised about increasing the incidence of compostable packaging is that some of this will be disposed to general landfilled waste and degrade in landfill, producing the potent greenhouse gas methane and contributing to pollutants in leachate. The rate and extent of decomposition of compostable packaging in landfill is unknown, but it can be expected that they will degrade and have amounts of degradable organic carbon per unit of mass similar to paper and textiles. These materials have an expected methane emissions potential of 2.0 - 3.3 tonnes of CO2-equivalents per tonne of landfilled material at a landfill without gas recovery systems (Commonwealth of Australia 2022). Assuming average landfill capture of 60-80% of methane from such materials, the expected methane ‘greenhouse footprint’ of landfilled compostable packaging in Australia is in the order of 0.4-1.3 tonnes CO_2-equivalents per tonne of compostable packaging. The amount of compostable packaging likely to be landfilled is expected to be relatively small and a minor contributor to methane emissions from landfill. It is anticipated that compostable packaging will result in greater community and business participation in and diversion of FO to FO/FOGO services and the benefits of keeping this material out of landfill will be greater than emissions from any additional landfilling of compostable packaging. Effort and community engagement will be needed to ensure compostable packaging formats are managed through the FO/FOGO streams.

No additional benefit to compost products

EPA NSW has stated that a reason for excluding compostable packaging from FO/FOGO is that it will not add benefit to compost products.

This does not appear to consider the soil conditioning benefits of providing organic carbon to soil and energy to soil microbes. The microbes that biodegrade bioplastics in compost and soil will generate some organic compounds that contribute to soil function, but the amounts of organic carbon remaining in soil per unit of bioplastic is small. Fibre-based products containing cellulose, hemicellulose, lignin and/or chitin, are likely to result in the creation of beneficial organic compounds that will persist for longer is soil. However, the main benefits of compostable packaging are their contributions to greater food waste recovery and reduced non-recycled packaging rather than any attributes they directly contribute to compost. More realistic criteria of assessment of the benefit or risk of compostable packaging could be whether they result in additional recovery of organics, whether they reduce non-recyclable packaging, and whether they have any significant or irreversible risk in compost and soil.

Phasing out of single use packaging

NSW EPA has stated a reason for restricting and discouraging the inclusion of compostable packing in FO/FOGO services is that most formats of single use non-recyclable packaging from public sales of food (takeaway and public events) are to be phased out. This does not apply to many home consumer packaging items. As discussed previously, pre-packaged meals and food items on protective trays with film plastic wrapping, are expected to continue to be used. Replacing such items with compostable and recyclable alternatives should increase participation in, and diversion of food organics to, FO/FOGO services. The resource recovery benefits are in the additional diversion of food rather than in the compostable packaging.

Lack of ‘circularity’

NSW EPA has stated that a reason for restricting and discouraging compostable packaging from FO/FOGO services is that this is not consistent with ‘Circular Economy’ policy objectives that promote materials recycling into remanufactured items over management pathways that ‘devalue’ materials into lower resource use products. This implies that readily recyclable packaging formats such as metals, glass, paper fibre, and PET and HDPE are superior to compostable plastics and commercially compostable plastics.

A number of observations can be made about this interpretation of ‘circularity’ and the current recovery systems and markets for recyclables:

1. The production and recycling of metals, glass, paper and plastics requires significant inputs of materials, energy and water and generates pollutants including a proportion of recyclates that cannot be recovered through the process. The production of ABA certified compostable plastic and fibre-based products also require materials, energy and water inputs and generate pollutants, but when managed and composted as part of the FO/FOGO stream require few additional inputs for their recovery.

2. Current recycling systems and markets often do not recover food-contaminated packaging. Promoting continued or greater use of ‘recyclable’ formats over compostable formats will likely result in continued and potentially greater contamination of the container recycling stream and landfilling of packaging waste.
3. Markets for many materials other than metals are periodically and frequently over-supplied. Oversupply is resulting in investment in forms of materials recovery that are arguably not ‘circular’ such as disposal of glass and plastics to road construction and surfacing. Promotion of the use of technically ‘recyclable’ plastics or glass over composting formats will likely result in ‘linear’ management of these materials to lower resource use value uses. It is questionable whether a life cycle analysis would favour linear use of plastic or glass packaging formats over compostable formats.
4. The return of plant-derived bioplastic and bio-fibre products to the soil and agriculture is ‘Circular’.
5. Non-compostable food packaging, and particularly film plastics, rigid plastics and glass, are significant contaminants of FO/FOGO. Replacement of common non-compostable food packaging contaminants with ABA certified compostable products will reduce this problem, resulting in greater recovery of organics (i.e. fewer losses to screened contaminated organics) and less risk of contamination of compost products.
6. Fibre-based compostable packaging can have recycled fibre content and can technically be recycled (although it often has a lower market value and is unrecyclable if it is food-contaminated). It is therefore compatible with Circular Economy objectives.
7. Some bioplastics can be synthesised from food processing wastes or agricultural residues, and this is consistent with Circular Economy materials production systems. They also have potential to be recycled, but not through current municipal kerbside recycling systems.
8. The main Circular Economy benefit of compostable packaging formats is likely to be increased recovery of food organics through greater participation and diversion by households and businesses, and fewer losses of organics to contamination screening. Compostable packaging should be seen as technology for achieving this objective rather than judged entirely on its material composition.

5 Conclusions and recommendations

This review has found that inclusion of products meeting ABA Certified compostable standards in FO/FOGO services processed by commercial composters does not pose a significant and irreversible environmental or human health risk.

Key observations and finding are:

1. The transition from non-recyclable packaging to 100% recyclable and/or compostable packing by 2025 has been a nationally agreed objective of the National Australian Packaging Agreement supported by federal and state government, retailers and the packaging industry.
2. The review does not find evidence that the inclusion of ABA certified compostable products will result in serious, persistent or irreversible risk to the environment. Over 90% of certified compostable products will degrade during commercial composting processes that process materials for at least 8-12 weeks, and any residual particles remaining in compost will degrade in the environment within 12-18 months. Fibre based and thin ply flexible plastic products will typically degrade in commercial composting in less than 8-12 weeks, and in some instances as little as 30-40 days.
3. Some film and rigid plastic compostable items may be screened from FO/FOGO inputs and finished compost. Depending on the screening methods used, up to 20% of compostable items per weight may be removed.
4. Manual 'pickers' decontaminating received FO/FOGO materials can be trained to identify and leave compostable items in the processed organics stream. Compostable fibre products and distinctly coloured plastics can be identified and left in the processed organics stream.
5. Many composters will reprocess less contaminated medium sized 'mulch' grades of screened organics and even stockpile more contaminated 'oversize' grades of coarse material to ensure more of the organics break down and be recovered by later screening. Where this is done, compostable packaging particles remaining in composts effectively have a longer retention time than the minimum batch processing period. This means that the selection of processor and the contract conditions placed on how organic are to be managed could be dictated by councils and businesses to allow compostable packaging formats to be included in FO/FOGO services, rather than the management of organics effectively being dictated by short-period organics processors that put immature pasteurised organics onto the market after a few weeks of processing. These short period organics processors cannot adequately process certified compostable products and will therefore screen a higher proportion of them from inputs and outputs.
6. There are limited and inconsistent data available regarding the potential eco-toxicological risks and effects of certified compostable products in FO/FOGO composts. There are few studies using compostable plastics that would comply with Australian Standards and ABA verfication program requirements, and very few for compliant fibre-based products. The limited data available shows variability in results, with some having possible slightly negative impacts on indicator species and others showing neutral or beneficial effects. Such variability occurs with testing of composts, and observed impacts may not be caused by the inclusion of compostable packaging. There is often a 'trade off' between the benefits of compost's contribution of nutrients and 'humic' organic matter to soil health and typically short-lived 'phytotoxic' impacts associated with addition of biologically active organic matter to soil (Barral and Paradelo, 2011).
7. The main chemicals and items of concern that may be introduced to composts by non-certified packaging appear to be:
    - Some heavy metals in inks and colourants in printed and coloured products.
    - PFAS/POPs in recycled-content fibre based.
    - Non-digestible particles that may bio-concentrate in organisms. It is uncertain whether bioplastic polymer particles will be biodigested or passed by organisms, but it is likely they will behaviour in a way similar to 'natural' biomass particles. Polymers in ABA and Australian Standard certified compostable products are simple and readily biodegradable or bio-digestible hydrocarbons.

- Potentially plasticisers and other additives that may have endocrine disrupting effect on organisms that ingest them. ABA certified compostable products must comply with ecotoxicity testing thresholds under Australian Standards AS4636 and AS5810 so this risk is minor for certified products.

8. There is little scientific basis for excluding certified compostable packaging from FO/FOGO on the basis of potential chemical contamination risk. The nature and small quantities of bioplastics in FOGO will have insignificant contribution to chemical- or eco-toxicity of compost products compared to 'background' levels in food and garden organics. Inks on printed items is the most significant risk of heavy metal contamination, but testing of compost products with more than twice the expected concentration of bioplastics in FO/FOGO show that this does not have significant impact on product quality. Inks for the newspaper promoted by some councils and NSW EPA as kitchen caddy liners may be a more significant, albeit minor, risk of chemical contamination.
9. Any remnant traces of certified bioplastic which may survive processing will not persist in the environment. They are inherently biodegradable similar to other organic compounds in compost products.
10. The PFAS/PFOS/POPs contamination of food packaging is a historic and declining risk. A recent Australian study of PFAS/POPs in non-certified food packaging found it is not prevalent as a coating on single use fibre-based products, which in previous studies has been the main source of materials. The most harmful long-chained PFAS/PFOS products have been largely taken off the market and are not present in food packaging streams. Short-chained products are not common in food packaging in Australia. The most likely pathways would be inclusion of recycled paper fibre products manufactured from contaminated feedstock. This applies to the newspaper liners promoted by some councils and NSW EPA as kitchen caddy liners. ABA certification excludes addition of PFAS to products.
11. The low concentrations in products and small amounts of certified compostable products in FO/FOGO means that ABA certified compostable products are unlikely to contribute to contamination above background levels in food and garden organics. Some further trialling and testing of products may be needed to confirm this, but the case for restricting certified compostable packaging on the basis of potential PFAS contamination appears to be unfounded.
12. There are significant limitations to the methodologies of NSW EPA reports into chemical and toxicity risks associated with compostable packaging, and the results of the reports are not applicable to most ABA certified compostable products. The studies use a limited range of non-compostable and non-certified products, and do not include fibre-based products. Extracts from samples of plastics, including printed and coloured products, were found to have some eco-toxic effects but the methodology did not simulate the likely concentrations of leachate or degradation and adsorption of leached chemicals in composting. Eco-toxicity testing of compost products did not mix compost with the required amount of inert sand and the results showed similar 'toxic' effects between composts containing the limited range of so-called 'compostable' (non-certified) packaging tested and composts not containing any added packaging. The contributions of compostable packaging to tested chemical contamination was found to be statistically insignificant compared to ubiquitous background levels, and therefore do not support the position statement's exclusion of compostable packaging from FO/FOGO on the basis of potential chemical contamination.
13. The argument that CCP bioplastics do not add value to compost products is immaterial. Although by mass, they will likely provide similar amounts of nutrient benefit as some food organics and fibre based items will add longer-lasting particulate and humic carbon to soils, the benefits of compostable packaging are in increased food waste recovery and reduced contamination of compost products, which diverts more organics from landfill, adds nutrient to compost products, and results in a higher proportion of compost to be marketable with reduced microplastic contamination of soil.
14. The argument that certified compostable packaging is not consistent with Circular Economy objectives to promote waste reduction, reuse and 'circular' recycling does not appear to

consider the benefits of compostable packaging in: reducing the incidence of non-recyclable and low valuable plastic packaging that contaminate and reduce the viability of both container recycling and commercial composting; and increasing recovery of food organics and food-contaminated packaging, nor the fact that compost products are returned to soil where they improve productivity and reduce the need for other inputs.

15. ABA verification program approved and Australian Standard Certified compostable packaging has advantages over non-compostable plastic food packaging in terms of consumer preference and convenience and greater recovery of uneaten package food and food-contaminate packaging.
16. Greater use of ABA and Australian Standard certified compostable packaging to replace formats with no or poor recycling markets should reduce contamination of FO/FOGO streams and improve the viability of container recycling systems.
17. It is expected that the replacement of non-compostable and low value recyclable food packaging with ABA verification program approved and Australian Standard certified compostable packaging formats will increase the recovery of food and food-contaminated packaging, reduce contamination at composting facilities, and reduce contamination risk in composts applied to soil.
18. Risks associated with certifiable compostable packaging can be managed by:
    - Ensuring all similar-looking products used by retailers are replaced with certified compostable products in keeping the APCO policy objective of ensuring all packaging is 100% commercially recyclable or compostable by 2025.
    - Placing specifications on the use of inks, dyes, plasticisers and additives to certified compostable products. This is covered by the toxicity testing and product declaration components of ABA certification of compostable packaging.
    - Requiring testing of fibre-based products as part of the certification process and maintenance to confirm that have low concentrations of unintended chemicals. This is also covered by ABA certification.
    - Ensuring commercial composting facilities receiving FO/FOGO materials have appropriate contamination management systems and processing retention times to ensure most compostable packaging is biodegraded.
    - If there is uncertainty, periodic testing of ABA verified and Australian Standard certified products and composts could be undertaken to confirm they do not significantly contribute to contamination. However, this is unlikely to be necessary as ABA certification requires chemical and ecotoxicity testing and prohibits the addition of PFAS/PFOS products to certified products.
    - Periodic testing of areas where FO/FOGO + CCP composts are used to confirm compostable packaging do not have lasting negative effects compared to FO/FOGO composts without CCP. Once, again, this is unlikely to be required due to the ABA verification and Australian Standard certification requirements for product testing and prohibition of PFAS/PFOS.

This review concludes that compostable packaging items certified to Australian Standards AS4736 and AS5810 and meeting additional ABA certification requirements pose little risk in commercial composting systems and will likely increases the quantities of food organics recovered through FO/FOGO services. Provided there is effective community engagement and education about which products can be composted through FO/FOGO services, and effective contamination and process management at organics processing facilities, their use will reduce contamination risks from FO/FOGO derived compost products. Concerns about chemical contamination, microplastic and potential eco-toxicity from packaging items in composts are not relevant to products meeting ABA and Australian Standards certification.

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