THE ASSOCIATION
FOR RENEWABLE ENERGY
& CLEAN TECHNOLOGY

Management of Compostables for Organic Recycling

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Acknowledgements

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Executive Summary

This report, funded by the UKRI Innovate UK Smart Sustainable Packaging Challenge, brings together information on aspects of the management of compostable packaging and non-packaging items that are relevant to food waste fed anaerobic digestion (AD) and composting facilities in the UK. Part of the *Closing the Loop for Compostable Packaging* project, this report collates AeroThermal Group's findings on the efficacy of Thermal Pressure Hydrolysis (TPH) as an AD pre-treatment step, highlights key aspects of Envar's in-vessel composting trial, provides an overview of depackaging technology, and highlights aspects of University College London's research (under a different project) on a system for identification and classification of key types of compostable and non-compostable plastics.

Key findings include:

- **Thermal Pressure Hydrolysis and vibrating screen pre-treatment**: Compostable food service ware, coffee pod bodies and their content, food waste bags and tea bags hydrolysed effectively under the trialled TPH conditions. These item types were also shown to contribute significantly to biomethane production under the trialled test conditions, where the yields exceeded those of food waste by a large margin in some cases. However, the coffee pod lids, two types of compostable film and the compostable fresh produce bags supplied did not sufficiently physically transform under these conditions and were retained on the screen. Nevertheless, together these lids, films and fresh produce bags are estimated to be a relatively small proportion of the total mass of compostables that are typically presented to AD facilities. It can be concluded that > 95 % of compostables that are subjected to thermal pressure hydrolysis will enter the digesters and contribute significantly to total biogas production. These projections are consistent with experiences at full-scale.
- **Composting trial**: Most certified compostable items degraded well within the trialled in-vessel composting process, although shredding techniques could be refined to improve shredding of some compostable item and to aid re-composting of the largely woody oversize materials extracted when compost is screened. Compost quality met BSI PAS 100:2018's quality requirements.
- **Depackaging machinery**: Efficiency in separating food/beverage waste from (non-compostable) packaging, liners/bags and non-packaging items is crucial for contaminant reduction at AD and composting facilities. Although machines in the reports, articles and promotional material REA reviewed do not identify, classify and separate compostable from non-compostable items, the information often includes recovery and purity rates for the targeted waste types.

- **Plastic identification and classification**: An IUK funded study carried out by UCL developed a system for identifying and classifying a range of compostable plastics and non-compostable plastics, and tested samples of pristine plastics and 50 plastics samples taken from the compost screening stage at an in-vessel composting facility. UCL found that plastic samples' darkness, thickness, colour and level of contamination significantly impacted the system's identification accuracy and that their size did not greatly affect this once the factors of darkness, colour and level of contamination were removed. Further research could beneficially support development of advanced machine identification, classification and sorting of different types of plastic at composting and AD facilities, e.g. removing non-compostable plastics for rejection and allowing or enabling compostable plastics to be fed in.

This report concludes by outlining where treatment intervention could support feed-in of compostable plastics and removal of non-compostable plastics from waste streams received at food waste fed composting and AD facilities and recognises the need for further research and development. It also identifies that research on machine-ID and –picking of non-compostable plastics from amongst woody oversize screenings (that arise during compost screening) could, if effective, support more re-composting of woody oversize and any compostable plastic remnants or increased value of this non-compostable-plastics-picked waste stream when some portions of it are sent to Energy from Waste facilities.

Introduction

Efficient and effective management of packaging, liners, bags, and other non-packaging items at food-waste-fed AD and composting facilities in the UK is becoming ever more important for achieving good quality digestate and compost outputs. The types of these items – certified compostable or not - in biowaste streams vary according to biowaste stream type.

This report aims to collate information relevant to aspects of managing compostable and non-compostable packaging and non-packaging items in a biowaste management context. It covers identification and classification of key compostable plastic and non-compostable plastic types, depackaging machinery, aspects of a composting trial on various types of compostable items, and the efficacy of a demonstration-scale thermal pressure hydrolysis and screen set-up that could be used at larger scale for pre-treating compostables at wet-AD facilities.

The report was completed as part of the Innovate UK funded, Compostable Coalition UK's project 10020315 'Closing the loop for compostable packaging'. It covers key findings from some of the trial work carried out under this project alongside other relevant information.

The report is set out in four sections.

1. An overview of trials on pre-treatment of compostables before Anaerobic Digestion (AD). This includes the fate of different materials through Thermal Pressure Hydrolysis and screening and testing what passes through the screen for its Biomethane Potential (BMP). This section includes a checklist for AD system operators when considering adding a TPH and screen set-up as part of pre-treatment at food-waste-fed, wet-AD facilities.
2. The parts of Envar's full scale and mini-composter trials on composting compostables that are relevant to how materials are managed at a composting site.
3. An overview of a WRAP report and two BioCycle articles on depackaging machinery, plus summary information on three machines.
4. A summary of a UCL project that developed a system for identifying and classifying key types of compostable plastics and non-compostable plastics, the potential benefits of using it (linked with suitable waste handling equipment) at organics recycling facilities, and REA's perception of what the key on-site intervention opportunities might be.

Section 1: Trials on treating compostables prior to anaerobic digestion

1. Introduction to thermal pressure hydrolysis and screening prior to anaerobic digestion

This section provides an overview of Innovate UK funded trials carried out by AeroThermal Group Limited in 2023[1, 2]. (This section does not include a trial they carried out in 2024[3].) These trials researched the extent that Thermal Pressure Hydrolysis (TPH, a proprietary form of autoclaving) converted different compostable intermediate materials (e.g. printed and unprinted film, not cut and sealed into final product form) and finished products (summarised as 'items') into liquor or floc that passed through a vibrating screen, or that were not substantially physically transformed and so were retained on the screen.

This report's Section 1:

- describes trials using a pilot-scale TPH machine and vibrating screen (with 12 mm apertures) as a pre-treatment for compostable items prior to digestion in systems that rely on pumpable biowastes;
- presents key results and notable findings from the TPH and screen trials;
- describes bench-scale Biomethane Potential (BMP) testing of TPH- and screen-treated compostable items that passed through the screen and their associated biogas and biomethane yields;
- covers AeroThermal's observations on the results and presents the tested compostable items' / mixture of items' biogas yields in comparison with biogas yields obtained in past research when digesting different non-TPH-treated biowastes and purpose grown crops;
- summarises AeroThermal's trial findings and research recommendations, and
- provides a high-level check list of associated considerations for AD system operators interested in TPH and screen set-ups for pre-treating compostable packaging and non-packaging items.

[1] Wang, Z., and Walsh, A., Final report for biodegradable materials (TPH-AD trial), AeroThermal Group Ltd, March 2023, Report No ATG229.
[2] Wang, Z., and Kimber, T., Report on teabags trial, AeroThermal Group Ltd, October 2023, Report No ATG233.
[3] Wang, Z., and Walsh, A., Trial report on [company name redacted] Materials, AeroThermal Group Ltd, July 2024, Report No ATG241.

2. Pre-treating compostables using Thermal Pressure Hydrolysis and a screen

2.1 Description of set-up and trial runs

A variety of compostable intermediate materials and finished products (referred to simply as 'items' below) were supplied by manufacturers, who described them as [industrially] '"compostable" as per EN 13432'. These are the 'bioplastics', 'bio-plastics' and proprietary ones referred to in AeroThermal's reports, which REA has quoted in places in this document.

Seven TPH- and screen-treatment trial runs were carried out on specific compostable items as well as a trial run on a mixture of compostable coffee pods and compostable food waste bags, a trial run on a mixture of compostable items with a mixed-in 'conventional catalyst used for lignocellulosic materials', and a trial run of a mixture of compostable items and non-compostable 'petroleum plastics' items.

Each trial run's items - and catalyst in the applicable trial run - were weighed then loaded into the TPH machine in their 'as received formats' and tap water was added to reach a ratio of 1 part test items to 2 parts water, on a mass per mass basis. Under full-scale industrial treatment compostables from most food waste source types are categorized as Animal By-Products (ABPs) and are macerated to < 50 mm prior to TPH treatment. While this step is mandatory for ABP regulation compliance (EU Method 1), it is not essential for hydrolysis purposes. During each trial run, the TPH machine's contents were subjected to direct steam pressure of 6 bar (160 ^{o}C) for 40 minutes, or 45 minutes in the case of the trialled compostable tea bags. This exceeded the minimum ABP regulation requirement of 3 bar (133^{o}C) for 20 minutes. The pilot TPH plant and screen system is shown in Pictures 1 and 2.

Picture 1 - AeroThermal Group's pilot TPH system

Picture 2 - Vibrating screen system

TPH-treated output (liquor / floc) from each trial run was ejected onto a vibrating screen with 12 mm apertures. Depending on the nature of the bio-waste / biomass, screen apertures of 10 – 16 mm have been used at industrial and pilot scale, i.e., the 12 mm is unrelated to the conventional 'pasteurization' particle size.

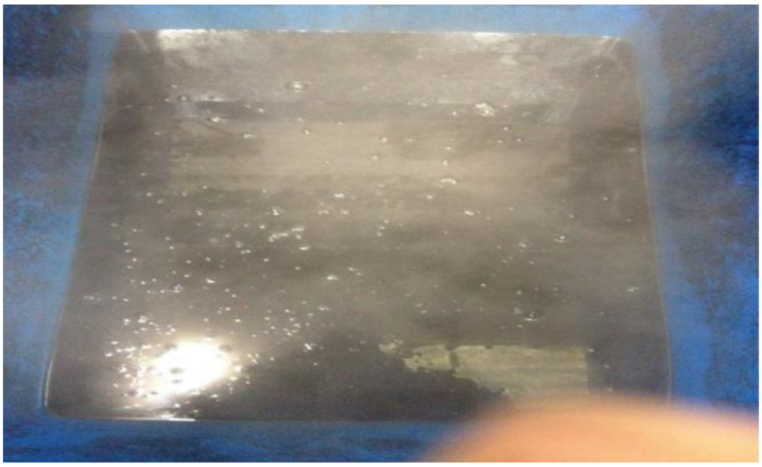
ATG's treatment approach was trialled as an alternative to 'pasteurisation' under Standard Transformation Parameters (STPs) set in the ABPR, this being the most common type of ABPR treatment carried out amongst UK food waste fed AD facilities. These STPs require that before entering the pasteuriser waste particle sizes must not exceed 12 mm, and that the waste is pasteurised at a minimum of 70 ^{o}C for a minimum of 1 hour. The TPH approach sought to address the twin issues of loss of biogenic material through shredding / screening systems that are required to meet the conventional 12 mm standard, allied with digestate contamination issues associated with the shredding of film plastics.

2.2 Key results from TPH then screen treatment

This sub-section covers key findings after various runs on 'as supplied', unshredded / uncut samples of manufacturers' intermediate materials / final products after addition of water prior to thermal hydrolysis. These trials were commissioned after successful trials of mixed compostables and the observations at a full-scale TPH plant with regard to the efficient hydrolysis of compostables and the exceptional biomethane yields from the mixed compostables. Those compostable items in each trial run are described below and treatment in each run was TPH then vibrating screen treatment as described in sub-section 2.1. Results are collated and presented in Table 1 in sub-section 3.1.

Trial run A, coffee pods

This trial tested 3.7 kg of coffee pods with 7.4 kg of added tap water. TPH and screening treatment resulted in 24.2 kg of 'output' including steam condensate as shown in picture 3. The coffee pod bodies (poly-lactic acid; PLA) and coffee inside them were 'totally hydrolysed / liquidised' but their film top covers 'were still very much in shape', picture 4.



Picture 3 - TPH processed coffee pods.

Picture 4 - Recovered top cover films from TPH processed coffee pods.

Analysed characteristics of the post-trial liquor: 15.5 % m/m DM, of which 87.7 % m/m VS. Based on trial results, the trial operator calculated the volatile solids recovery rate of coffee pods is 'about' 856 kg VS/t fresh mass processed, i.e. a 85.6 % VS recovery rate for onward-pass to the digester. In contrast, most if not all of the coffee pods would be discarded by conventional de-packaging equipment.

Trial run B, film sheets

This trial tested 5 kg of unprinted film sheets with 10 kg of added tap water manufactured from a proprietary bio-plastic. THP and screening treatment produced a total of 28.7 kg of 'output' as shown in picture 5.

Picture 5 - TPH processed film used in trial run B.

This film became 'heavier through the absorbtion of water' but it remained thermally stable at the temperatures applied (160°C). Picture 5 shows numerous multi-folded sheets darker in colour than before trial treatment. AeroThermal summarised that this bio-plastic film type was 'not hydrolysed under conditions applied' and 'it can be expected that this material will be rejected from conventional de-packaging and TPH biogas plants unless it is pre-shredded'. Consequently, this film was excluded from trial runs F and H but was included in the catalysed comingled bioplastics trail run G to see whether the catalyst would aid its break down.

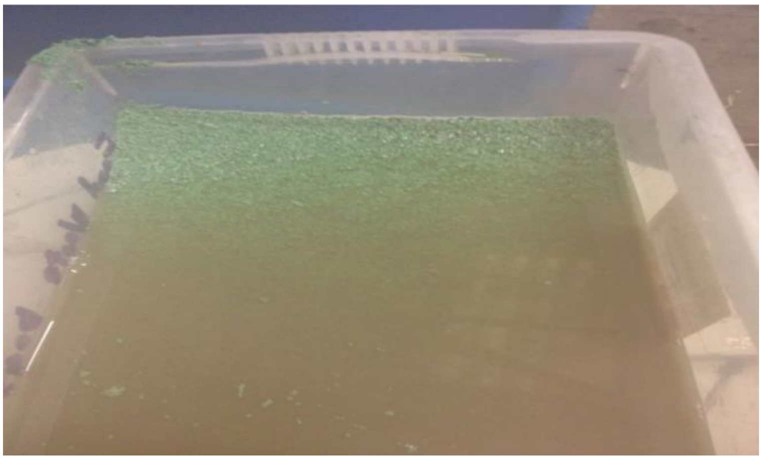
Trial run C, film sheets

This trial tested 1 kg of a further proprietary bioplastic film (single layer printed film sheets, different from those in trial run B) with 2 kg of added tap water. Its TPH and screen treatment resulted in this film becoming 'a large "bio-plastic" ball' as shown in picture 6. AeroThermal went on to comment 'this is typically as seen with hydrocarbon-based plastics and as [a] result this material can again be expected to be rejected from both conventional and TPH pre-treatment systems at biogas plants unless it is pre-shredded to pass a screen after TPH treatment'.

Picture 6 - TPH processed film used in trial run C - 'collapsed into congealed "ball"'.

Trial run D, food waste bags

This trial tested 6 kg of conventional food waste bio-bags with 12 kg of added tap water where it is understood that these bags were composed of cornstarch or similar. Their TPH and screen treatment resulted in 26.5 kg of output, AeroThermal reporting that the food waste bags 'were broken down into small green particles by the steam power but not fully hydrolysed / liquidised'. However, as they passed through the screen's 12 mm holes '100 % of the bags will be available to anaerobic digestion under conventional TPH-AD conditions'. 'In contrast it would be expected that a high proportion of the bags would be discarded from conventional de-packaging equipment unless the material is initially mechanically pulverized.'



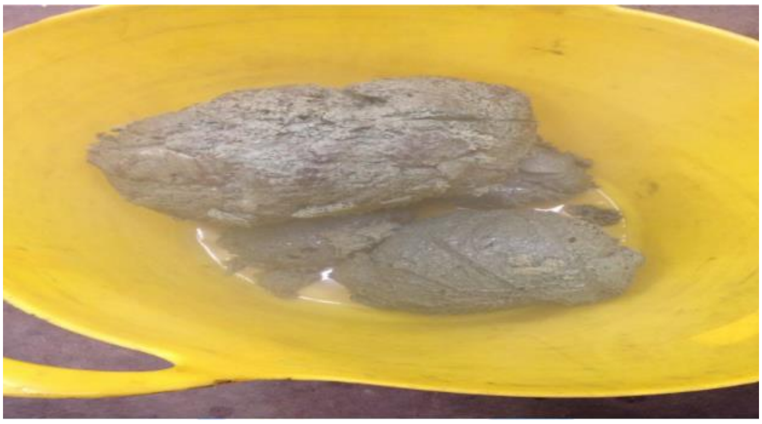
Picture 7 - TPH processed food waste bags.

Analysed characteristics of the 'TPH processed food waste bags' (post-treatment liquor including small pieces of the bag material, as shown in picture 7): 22.2 % m/m dry matter, of which 98.7 % m/m volatile solids.

Based on trial results, AeroThermal calculated the volatile solids recovery rate of these food waste bags was 'about' 976 kg VS/t fresh mass processed, i.e. a 96.8 % VS recovery rate.

Trial run E, fresh produce bags

This trial tested 11 kg of fresh produce bags[4], again manufactured from a proprietary bioplastic, with 22 kg of added tap water. After TPH treatment these bags had become 'bio-plastic balls' (see picture 8) similar to what was seen after TPH treatment of petroleum plastics such as LDPE (see trial run H info). AeroThermal stated the fresh produce bags 'could not be thermally hydrolysed' (under the conditions trialled) and consequently they were excluded from trial runs F and H but included in the catalysed comingled bioplastics trail run G to see whether the catalyst would aid their break down.



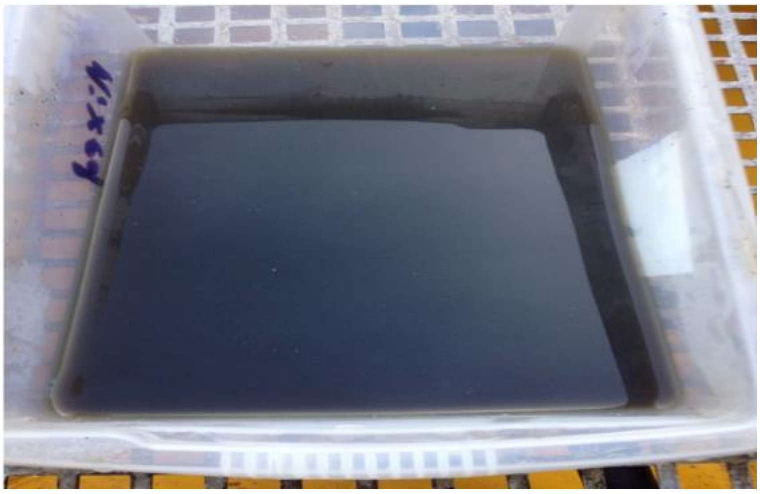
Picture 8 - TPH processed fresh produce bags.

Considering trial run E's results, AeroThermal reported 'it can be expected that the bulk of this material will be rejected from conventional de-packaging and TPH pre-treatments at biogas plants…without pre-pulverization.'

Trial run F, a mixture of coffee pods and food waste bags

This trial tested a mixture of 0.3 kg of coffee pods (PLA) with 1.1 kg of food waste bags (cornstarch) and 2.8 kg of added tap water. TPH and screen treatment of this mixture resulted in 17.4 kg of 'output' as shown in Picture 9.

[4] These bags have capacity to hold 1- 2 kg of fresh produce, are designed to protect the shelf life of fresh produce and be last used by consumers as a food waste bag.



Picture 9 - TPH processed comingled coffee pods and food waste bags.

Screening after the TPH treatment stage removed a low amount, 0.3 kg (wet weight), of the coffee pods' top cover film from the liquor fraction of the output (similar to what screening removed in trial run A). The remaining 17.1 kg of liquor contained 8.1 % m/m dry matter, of which 98 % m/m volatile solids.

The volatile solids recovery rate of the mixture of coffee pods and food waste bags was 'about' 965 kg VS/t fresh mass processed, i.e. a 96.5 % VS recovery rate.

<u>Trial run G, catalysed comingled 'bioplastics'</u>

This trial tested a mixture of **coffee pods** (0.3 kg)**, the same films as in trial runs B** (1.0 kg) **and C** (0.4 kg)**, food waste bags** (1.1 kg) and **fresh produce bags** (2 kg), with addition of a **catalyst** and 9.6 kg tap water. TPH and screen treatment of this mixture resulted in 21.2 kg of hydrolysed liquor (see Picture 10) and 9.2 kg of unhydrolyzed material, the latter being screened out after TPH treatment (see Picture 11). AeroThermal reported that inclusion of its catalyst 'still couldn't hydrolyse the bio-materials within [the same films used in trial runs C and E] as seen in [their] individual trials'. 'The catalyst used is typically successful with lignocellulosic material such as straw, grasses, cardboard and bagasse etc, but is evidently ineffective with these proprietary bio-plastics under the standard conditions tested.'

Picture 10 - Hydrolysed liquor separated from catalysed TPH processed comingled bioplastics.

Picture 11 - Unhydrolysed materials separated from catalysed TPH processed co-mingled bioplastics.

Analysed characteristics of the post-trial liquor: 8.0 % m/m dry matter, of which 86.3 % m/m volatile solids.

The trial operator calculated that 'catalysed TPH processing of comingled bioplastics [and contents of the coffee pods] achieved a volatile solids recovery rate of 'about' 305 kg VS/t fresh mass processed, i.e. a 30.5 % VS recovery rate.

<u>Trial run H, 'comingled bioplastic with petroleum plastics'</u>

This trial tested a **mixture of coffee pods** (0.3 kg), **food waste bags** (1.1 kg), **petroleum plastics** (0.2 kg, non-compostable) and 3.2 kg of added tap water (see picture 12 for petroleum plastics before their addition to the mixture). The post-autoclave output was screened, the screen retaining 0.3 kg (wet weight) of petroleum plastics and coffee pod lids (see Picture 13) that were then dried at ambient temperature for 48 hours, and at reweighing weighed 0.26 kg ('air-dry' weight). The expected composition of this reject was approx. 0.2 kg of the original petroleum plastics and 0.06 kg of the coffee pod lids. Overall, the 1.6 kg of samples yielded, after treatment, 1.34 kg of DM for digestion, this being 'expected to consist of 100 % of the coffee pod body, the coffee and all of the compostable food waste bag material'.

Picture 12 - Petroleum plastics prior to TPH treatment.

Picture 13 - Recovered petroleum plastics.

Trial run I, food service ware

This trial tested a mixture of **burger boxes** (5.0 kg), **paper cups** (4.9 kg), **dome lids** (1.9 kg), **hot cup lids** (1.9 kg), **napkins** (0.6 kg), **cartons** (0.6 kg), **wooden spoons** shredded to 'no specific particle size' using a home blender (see picture 14) (0.1 kg), and added tap water (30 kg).

Picture 14 - Shredded wooden spoons.

Overall, TPH treatment of the 15 kg of samples and the 30 kg of added tap water yielded a total of 67.8 kg of output, where again the increase in mass is due to condensed steam (Picture 15). 'All of the materials were thermally hydrolysed to become a mash-like floc material' containing 21.6 % DM, of which 92.6 % was VS. The VS recovery rate was 'about 904 kg VS per 1,000 kg of fresh weight processed, i.e. a 90.4% VS recovery rate of a hydrolysed pumpable substrate that can be digested'. The trial operator also reported 'This mechanical hydrolysis performance was similar to previous trials of [the supplier company's] material and confirms the high hydrolytic efficiency of the system when presented with PLA and bagasse / cardboard type materials'.

Picture 15 - TPH processed comingled food service ware.

Trial run J, tea bags.

This trial tested 25 kg of teabags (received unused, in dry form) with 10 kg of added tap water. 'The teabags were significantly hydrolysed during the TPH process and were turned into a homogenised mash-like material' (Picture 16), of which there was 70 kg.

Picture 16 - TPH processed tea bags.

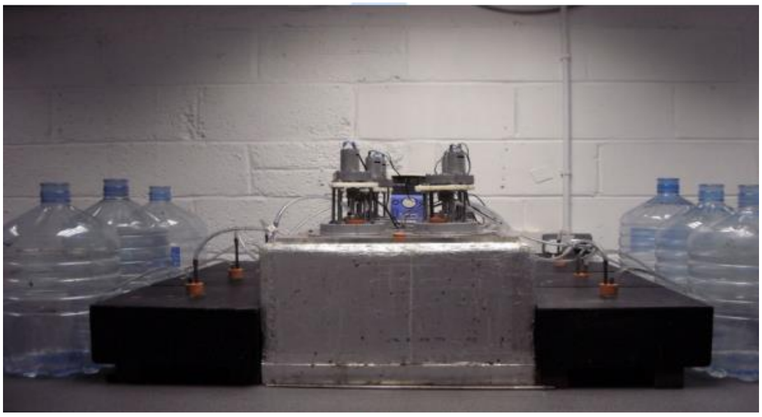
Analysed characteristics of the tea bags as received (in their original form): 94.7 % m/m DM, of which 87.0 % m/m VS and 13.0 % ash.

Analysed characteristics of the post-trial tea bags (incl. tea): pH 4.45, 33.6 % m/m DM, of which 89.3 % m/m VS.

3. Biomethane Potential Tests

3.1 Set-up and management of the BMP tests

Cylindrical constantly stirred tank reactors (CSTRs) were used for the standard biomethane potential (BMP) tests, each with a working volume of 2.0 litres, and were used for separately measuring production of biogas (its methane and carbon dioxide composition) over 30 days (see picture 17). They tested samples of trial-run output that passed through the screen (outputs from trial runs A, D, F, G, I and J) and compostable tea bags that were not TPH- and screen-treated. These samples respectively contained 10 g of VS.



Picture 17 - AeroThermal Group's BMP test rig.

Inoculum (that passed through a 1 mm screen) from a sewage treatment AD process was added to samples of outputs from TPH and screen treatment runs ('substrates' in next sentence), and to a sample of untreated compostable tea bags ('substrates' in next sentence). Sufficient inoculum was used to achieve a ratio of inoculums' volatile solids to substrates' volatile solids of 4.7:1. This inoculum had 4.2% DM content, of which 61.9% was VS. Further details of BMP est. set up are in Table 1.

Table 1 - BMP Test Set up

Type of test	**Output from TPH+screen treatment trial run**						**Tea bags** (original form)
	Trial run A	**Trial run D**	**Trial run F**	**Trial run G**	**Trial run I**	**Trial run J**	
Substrate mass, g	74	26	126	145	50	34	12
Inoculum mass, g	1800	1800	1800	1800	1800	1800	1800
Water mass, g	126	134	74	55	150	166	188
Substrate VS, g	10	10	10	10	10	10	10
Inoculum VS, g	47	47	47	47	47	47	47

After feeding was completed, each CSTR was put into a water bath controlled at 37 ^oC. Biogas was collected via a gas outlet tube connected to a 10-litre gas collector by a method of water displacement. Biogas composition (CH_4 and CO_2) was determined using a Varian CP-3800 gas chromatograph.

Room temperature and atmospheric pressure were also recorded to correct the gas volumes produced by each CSTR to the volume at standard temperature and pressure (STP: zero ^oC and one atmospheric pressure). Volumes of biogas generated by the substrate samples were calculated by subtracting the gas volume generated by the control CSTR from that produced by the substrate CSTRs, from which specific biogas yields and specific methane production of the substrates could be obtained.

3.2 Biogas and biomethane potential test results

Table 2 reports cumulative total biogas (m^3 biogas/t VS) and, as part of that, cumulative total biomethane (m^3 CH_4/t VS) produced by 30 days after test set-up.

The following charts may be available from AeroThermal upon request:

- cumulative total biogas yield from outputs from each of the TPH and screening trial runs;
- cumulative total biomethane yield over 30 days, from outputs from each of the TPH and screening trial runs;
- cumulative total biogas yield from compostable tea bags in their original form (unused and not TPH- and screen-treated); and
- cumulative total biomethane yield from compostable in their in their original form.

Table 2 - Results of 30-day Biomethane Potential test.

Type of test	**Outputs from TPH and screen treatment trial run**						**Tea bags** (original form)
	Trial run A	**Trial run D**	**Trial run F**	**Trial run G**	**Trial run I**	**Trial run J**	
Specific biogas yield, m^3/t VS added	681	178	484	463	599	315	263
Specific biomethane yield, m^3 CH_4/t VS added	394	103	280	268	347	183	151
% methane in biogas	0.579	0.579	0.579	0.579	0.579	0.581	0.574
VS extraction rate, kg VS/t FW* processed	856	967	965	305	904	880	NA
Methane production, m^3 CH_4/t FW*	337	100	271	82	314	145	120
Biogas production, m^3 biogas/t FW*	582	173	468	142	542	250	208

* FW means fresh weight. NA means not available.

Note: In AeroThermal's reports but excluded from table 2 are figures for litres of 'total biogas produced' at STP, litres of 'biogas produced by substrate' at STP, litres of 'methane produced by substrate at STP and grammes of VS of substrate added.

4. Observations

4.1 Intermediate materials / final products that hydrolysed and were BMP tested

The coffee pods (trial run A) had a generally high rate of hydrolysis where the PLA capsule itself dissolved along with the coffee as expected. However, the film lids were 'thermally stable and could not be interfaced with digestion under the conditions tested'; REA interprets this as the lids not passing through the screen and thus would not be available for digestion. 'The BMP test resulted in a relatively high BMP value of 394 m^3 CH^4/t VS (681 m^3 biogas/t VS). It is likely that the coffee powder contained in the pod is likely to have contributed significantly to biogas production.'

The food service ware (trial run I) - composed of bagasse, paper / cardboard and PLA - were generally well hydrolysed. The 'woody fraction' (cutlery) was the exception, but it was not readily distinguishable after autoclave and screen treatment due to its low inclusion rate in the mix during trial set-up. The BMP value for these comingled materials was 347 m^3 CH_4/t VS (599 m^3 biogas/t VS).

Similarly, the food waste bags (trial run D) were observed to have hydrolysed well during TPH treatment. Some of the bag material had physically broken down to 'small particles' but were 'not entirely hydrolysed'. All of the compostable bag material was recovered for digestion, yielding 103 m^3 CH_4/t VS (178 m^3 biogas/t VS). The compostable bags' BMP was lower than the food service ware's BMP.

TPH-treatment 'thoroughly hydrolysed' the tea bags (trial run J) and so such treatment 'could significantly enhance [their] biodegradability in a subsequent AD process', resulting in a yield of 183 m^3 CH_4/t VS. Their BMP yield was more than 20 % higher than the 151 m^3 CH_4/t VS obtained from tea bags that were tested in their original form (after adding water and inoculum). 'In a commercial AD process the used teabags will have been mixed with other waste materials via the collection process, which is of course slightly different from what has been tested for these trials. However, AeroThermal fully anticipate the teabags will be thoroughly hydrolysed and homogenised with other organic materials if a TPH pre-treatment is used. AeroThermal concluded that 'with or without TPH pre-treatment, the teabags will contribute to biogas production in an AD process'.

4.2 Biogas yields from trialled intermediate materials / final products in perspective with selected other anaerobically digestible materials

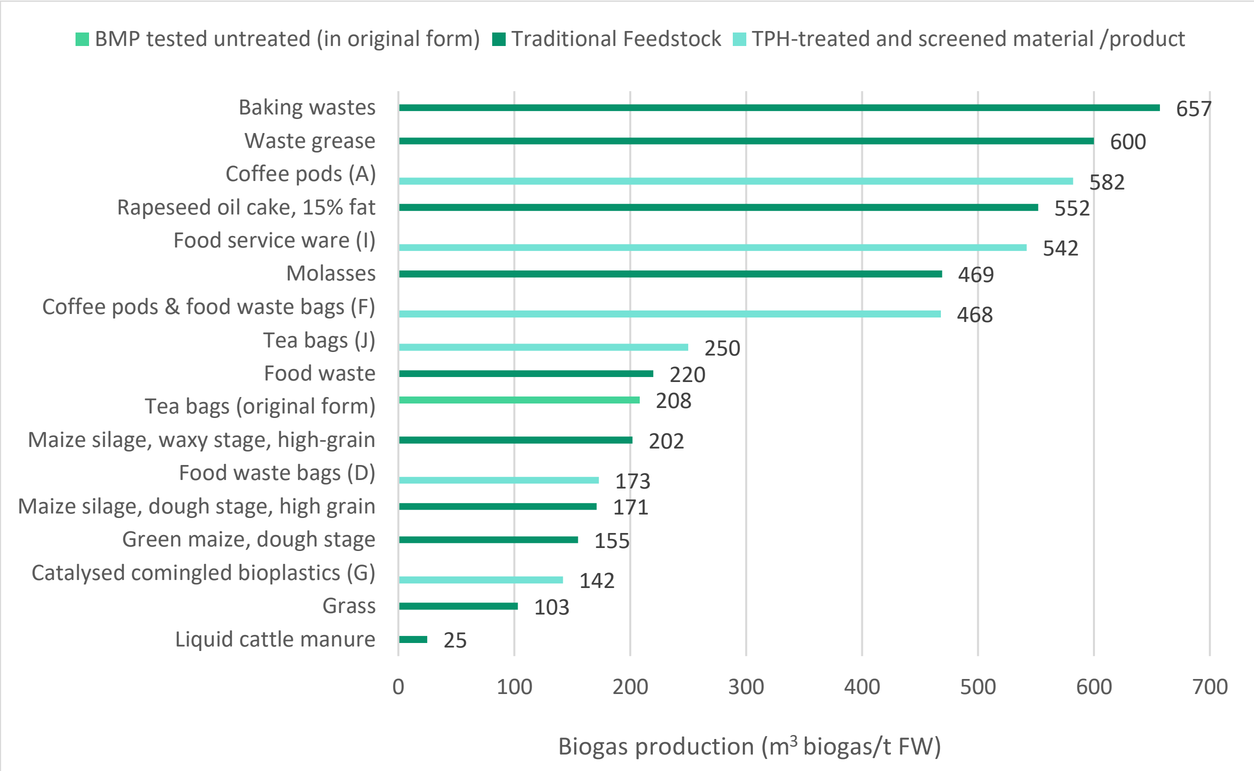
Biogas yield figures from the trial runs are put into perspective in Table 3 and Figure 1, which also includes typical biogas productivity data for a range of biowaste and biomass materials[5].

Table 3 - Biogas produced according to material type and treatment.

Type of material	**TPH-treated and screened material /product**	**Biogas production** (m^3 biogas/t FW)
Baking wastes	No	657
Waste grease	No	600
Coffee pods	Yes (trial run A)	582
Rapeseed oil cake, 15% fat	No	552
Food service ware	Yes (trial run I)	542
Molasses	No	469
Coffee pods & food waste bags	Yes (trial run F)	468
Tea bags	Yes (trial run J)	250
Food waste	No	220
Tea bags (original form)	No	208
Maize silage, waxy stage, high-grain	No	202
Food waste bags	Yes (trial run D)	173
Maize silage, dough stage, high grain	No	171
Green maize, dough stage	No	155
Catalysed comingled bioplastics	Yes (trial run G)	142
Grass	No	103
Liquid cattle manure	No	25

[5] Source of biogas yield figures for materials that were not tested during trial runs by AeroThermal: acknowledged as 'Effenberger, 2006', in Biomass Resource Options: Creating a BIOHEAT Supply for the Canadian Greenhouse Industry, Technical Report, July 2006, Resource Efficient Agricultural Production, Canada. Figure 6, Potential Biogas Yield from various biomass products, p 36. https://www.researchgate.net/publication/310477954_BIOMASS_RESOURCE_OPTIONS_Creating_a_BIOHEAT_Supply_for_the_Canadian_Greenhouse_Industry accessed 22/10/2024)

Figure 1 - Biogas production according to material type and treatment



Considering all trial runs, the PLA coffee pods (trial run A) achieved the highest yield, at 582 m^3 biogas / fresh tonne, similar to biogas yields obtain from anaerobically digesting grease wastes. Such pods 'would be deemed to be a very valuable component within any biogas plant feed, albeit it is evident that such materials would normally be totally excluded from conventional digestion in the absence of the TPH pre-treatment stage and would be landfilled.'

The food waste bags (trial run D) yielded 173 m^3 biogas / fresh tonne yield and compared very similarly with yields obtained by digesting dough-stage, high-grain maize silage (173 m^3 biogas / fresh tonne). Maize silage 'is recognized as the benchmark high performance biomass input digestion'.

The relatively high performance of the mixed sample of coffee pods and food waste bags (trial run F) yielded 468 m^3 biogas / fresh tonne and this was 'driven by the PLA, bagasse and paper / card present'.

The food service ware (bagasse, PLA and paper / cardboard materials) (trial run I) yielded 542 m^3 biogas / fresh tonne, similar to biogas yields obtained from anaerobically digesting rapeseed oil cake and grease wastes in the other cited research. Thus, compostable food service ware of similar composition is of very high biogas value to anaerobic digestion. It is notable that this general mix of compostable packaging represents the most prevalent form of compostable packaging seen in biowastes delivered to food waste digestion plants and as observed at the full-scale TPH demonstration facility, where it was estimated that the hydrolysis of this compostable packaging type added > 20% of the biogas yield from the plant as a whole as it yielded 2.4 times as much biogas as typical food waste (Figure 1). This is notable as compostable packaging is normally rejected from conventional de-packers and its disposal is a cost to the plant.

Achieving a yield of 142 m^3 biogas / fresh tonne, the relatively poor performance of the catalysed sample of catalysed ‘comingled bioplastics’ (trial run G) was ‘not understood, albeit it is nevertheless the case that conventional TPH steam treatment is sufficient to obtain close to the maximum theoretical yield of biogas from these materials’.

The TPH- and screen-treated tea bags (trial run J) achieved a yield of 250 m^3 biogas / fresh tonne, a figure higher than the 220 m^3 biogas / fresh tonne yield reported for AD of food waste in the other cited research but lower than the 468 m^3 biogas / fresh tonne that was obtained after AeroThermal’s TPH and screen treatment of coffee pods and food waste bags (trial run F). The 208 m^3 biogas / fresh tonne yield from tea bags BMP tested in their original form (after adding water and inoculum, without having first been TPH- and screen-treated) was lower than for TPH- and screen-treated tea bags and the other cited research’s biogas yield from food waste, however it was a little higher than the 202 m^3 biogas / fresh tonne yield from waxy stage, high-grain maize silage.

4.3 Bio-materials not subjected to BMP testing

Other TPH- and screen-treated bio-materials / finished product were not BMP tested because their physical state prevented them, or a substantial proportion of them, from passing through the vibrating screen’s 12 mm apertures.

AeroThermal reported: ‘it is understood that the other materials that were not BMP tested due to the conservation of their physical integrity after thermal hydrolysis, are “compostable” as per EN 13432. However, as assessed, the [trial run B film, trial run C film and trial run E fresh produce bags] did not hydrolyse under the typical TPH conditions used and also the use of our conventional catalyst used for lignocellulosic materials had no further appreciable impact. This strongly suggests that such materials will also be rejected from conventional wet-AD de-packaging equipment given that its mechanical properties are very similar to petroleum plastics.’

‘It is therefore assumed that these biomaterials are designed for high temperature use where they even withstand harsh TPH conditions and appear to behave similarly to conventional petroleum-based plastics during TPH treatment.’

Potential solutions AeroThermal suggested are set out as options 1 and 2 below.

Option 1

'The first is to look at pre-shredding as the current standard set-up of the TPH plant is simple bag-opening (coarse shredding) and / or no shredding of bio-wastes and [municipal solid waste] ahead of TPH treatment. However, fine shredding of biowaste is also possible for such wastes ahead of TPH where the anaerobic biodegradability of the product could then be tested as the material could then be presented to digestion. The practical extrapolation of this approach to full-scale deployment and thus projections as to recovery of these materials under field conditions would need to be assessed relative to their abundance in wastes presented for TPH treatment facilities ahead of digestion.'

Option 2

AeroThermal 'could look at alternative catalysts that could modify the chemistry of the steam to facilitate hydrolysis of these thermo-resistant materials. To do that, we would need to understand the chemistry of these biopolymers as regards potential catalysts and steam conditions that could promote the hydrolysis of these materials. In this regard, the standard catalyst used focuses on the delignification of straw and similar biomass where this evidently is not effective on these materials and therefore an alternative is needed.'

'In any event the option 1 test [fine shredding] is recommended in the first instance as it will at least provide a comparison as to the anaerobic digestibility of these biomaterials compared with its aerobic biodegradability irrespective of the mechanical issues as regards presenting the biomaterials to digestion.'

These options were further investigated in separate trials in 2024 where it was assessed that the thermo-resistant bio-plastics represented a small fraction of the total compostable packaging presented to food waste AD facilities and their loss from the process is estimated to represent < 2 % of the total presentations of all compostables. When combined with the known rejection of wooden utensils it is estimated that the overall losses of compostables and other bio-packaging after TPH treatment is < 5 %. This contrasts with conventional de-packaging where loses of > 50 % are conservatively estimated.

5. Summary of treatment and test findings

Samples of manufactured intermediate materials and finished products were supplied by seven companies and described by them as [industrially] '"compostable" as per EN 13432'. Petroleum plastic, rigid finished product samples were sourced by AeroThermal.

Intermediate materials / finished products whose treated forms were suitable for wet digestion

After water addition and Thermal Pressure Hydrolysis, the intermediate materials / finished products[6] that passed through the vibrating screen's 12 mm apertures were;

- coffee pod 'bodies' and their coffee powder contents (became a brown liquor) (trial run A);
- food waste bags (became numerous, visible, small particles in a liquor) (trial run D);
- coffee pod 'bodies', their coffee powder contents and food waste bags in the mixture of coffee pods and food waste bags (most of the mixture became a liquor with exception of the coffee pods' 'top cover films' (aka lids) (trial run F);
- coffee pod 'bodies', their coffee powder contents and food waste bags from the mixture of samples of all compostable item types supplied (except tea bags) and a catalyst (trial run G, 'catalysed comingled bioplastics');
- coffee pod 'bodies', their coffee powder contents, and the food waste bags[7] in the mixture of items that included petroleum plastic items (trial run H);
- food service ware (became a 'homogenised mash-like floc material') (trial run I), and
- tea bags and their contents (became a 'homogenised mash-like floc material') trial run J).

TPH treatment in accordance with the Animal By-Products Regulation Method 1 followed by fine screening of these materials/finished products enabled the recovery of many of these materials for digestion. The biogas yields, in m^3 biogas/t FW, were comparable with or superior to those that can be obtained from a range of non-TPH-treated waste and non-waste types. Specifically, the coffee pod bodies' and their

[6] Wooden spoons included in the mixed food service ware sample were shredded using a home blender before being mixed in with other food service ware product samples before TPH treatment.
[7] According to AeroThermal's expectation of what comprised the 1.34 kg of DM 'for digestion', this being what passed through the screen (excluding water and moisture content in solids) after TPH treatment. A total of 1.6 kg of samples (all item types, including petroleum plastics) were included in trial run H during set-up.

contents' biogas yield was similar to that from waste grease; the food waste bags' biogas yield was similar to that from high-grain, dough-stage maize silage; the coffee pod bodies, their contents and food waste bags treated together produced a biogas yield similar to that from molasses; the mixed food service ware's biogas yield was similar to that from rapeseed oil cake; and the catalysed comingled bioplastics' biogas yield was similar to that from dough-stage green maize silage; and the tea bags' biogas yield was a little lower than that from food waste. Tea bags BMP-tested in their original form (after adding water and inoculum, without having first been TPH- and screen-treated) produced a biogas yield a little higher than that from waxy stage, high-grain maize silage.

Comparing results for tea bags on a different biogas unit basis, the TPH- and screen-treated tea bags' biogas yield of 183 m^3CH_4/t VS was more than 20% higher than the 151 m^3CH_4/t VS yielded from the 'original sample' tea bags (not TPH- and screen-treated). AeroThermal's summary comment was that 'with or without TPH pre-treatment, the teabags will contribute to biogas production in an AD process but is enhanced by TPH treatment'.

Ranking the TPH- and screen-treated materials/products in descending order from highest to lowest biomethane production in m^3 CH_4/t FW, results showed: coffee pods at 337, food service ware at 314, the mixture of coffee pods and food waste bags at 271, tea bags at 145, food waste bags at 100, and catalysed comingled 'bioplastics' at 82 (all figures). Tea bags that were not TPH- and screen-treated produced 120 m^3 CH_4/t FW.

TPH treatment broke the food waste bags down into small green particles that passed through the vibrating screen's 12 mm apertures. Without TPH treatment, AeroThermal's expectation is that 'a high proportion of the bags would be discarded from conventional de-packaging equipment unless the material is initially mechanically pulverized' (in full-scale treatment this means reduced to small pieces). Mixed biowaste deliveries in the real world would risk petroleum plastics being similarly pulverized and that would then risk the quality of the final digestate. It is worth noting that separate AeroThermal trails have demonstrated that within mixed bio-waste loads that low density polyethylene (LDPE), as is typically used in carrier bags, collapses into high density polyethylene (HDPE) pieces that can be screened off. This additional unique property of the TPH process also protects the final digestate from film plastics that are predominantly LDPE.

Intermediate materials / finished products whose treated forms were entirely or substantially unsuitable for wet digestion, after the trialled treatments

After water addition and Thermal Pressure Hydrolysis, the intermediate materials / finished products that did not hydrolyse and pass through the vibrating screen's 12 mm apertures were;

- coffee pod 'top cover film' (lids) (trial run A);
- a film supplied as film sheets (rather than in finished product sizes & shapes) (trial run B);
- a different film supplied as film sheets (rather than in finished product sizes & shapes) (trial run C);
- fresh produce bags for fresh produce (trial run E);
- film sheets (same as in trial runs B and C) and fresh produce bags (same as in trial run E) from the mixture of samples of all compostable item types supplied (except tea bags) and a catalyst (trial run G, 'catalysed comingled bioplastics'); and
- petroleum plastics and compostable coffee pod lids in the mixture of petroleum plastic items and bioplastic items (trial run H).

In their individual trial runs, the two different films supplied in sheets and the fresh produce bags did not hydrolyse under the typical TPH conditions used, nor did some of the compostable item types in the trial run (G) that included all compostable item types except tea bags and AeroThermal's conventional catalyst used for lignocellulosic materials. 'This strongly suggests that the such materials[8] will also be rejected from conventional wet-AD de-packaging equipment given that its mechanical properties are very similar to petroleum plastics.' While, as above, these high-temperature bio-plastics currently represent a small fraction of total compostables in the waste stream, a treatment option AeroThermal suggested 'in the first instance' was to seek to have these materials separated from the general waste stream where practical, and then fine-shred them prior to TPH treatment and onward-pass to digestion. It is considered that this approach could work in full-scale deployment, subject to their relative abundance in wastes presented for TPH treatment changing over time. An alternative option they proposed was to research alternative catalysts that 'could modify the chemistry of the steam to facilitate hydrolysis' of the relevant items under suitable TPH conditions.

[8] The compostable items that did not hydrolyse under the trialled TPH conditions.

6. Check-list for AD system operators

This section provides a checklist for AD system operators when considering adding a TPH and screen set-up as part of pre-treatment at food-waste-fed, wet-AD facilities with digesters that need to be fed with pumpable biowastes.

Check:

1. estimated or known tonnages of obtainable food waste streams that also include compostable items;
2. estimated or known tonnages of obtainable, used compostable items (e.g. from a food service or other 'closed environment' source where food wastes are collected separately from used compostables);
3. the estimated or known Physical Contaminants (PCs) concentration in the relevant, received waste stream does not exceed any corresponding PCs limit(s) in the site's permit to operate;
4. the estimated or known Non-Compostable Plastics (NCP) concentration in the relevant, received waste stream does not exceed any corresponding NCP limit in the site's permit to operate;
5. each waste stream for TPH- and screen-treatment does not, or is not likely to, include low-melting-point, non-compostable plastics at a greater than negligible concentration, unless the site will machine-identify and remove such plastics to the extent that any remaining are a negligible concentration in waste stream when fed into the TPH machine;
6. whether and how the energy demands associated with running a TPH machine can be met (engineering consultancy services are recommended, and note that for cost and carbon intensity purposes, AeroThermal promotes the use of biomass boilers to raise the steam required for the process);
7. whether changes to the waste reception and pre-treatment hall would work in practice;
8. conditions that would need to be added or changes needed to the site's permit to operate;
9. whether the site would need planning permission for changes associated with receiving new and/or significantly different waste stream(s) and installing an TPH machine and making any other associated changes; and
10. whether there is a business case for installation and operation of a TPH machine and any extra or different pre-treatment equipment required, given the higher biomethane yields, the increase in treatable biowaste types, and lower carbon-intensity of the biomethane produced allied with lower disposal costs as less compostable packaging would be rejected.

Section 2: Summary of in-vessel composting trial and findings

This section provides information on the Innovate UK funded trials carried out by Envar Composting Limited with a particular focus on focus on the fate of the trialled compostable items, compost quality and management of oversize materials at compost screening stage. The Envar Composting Limited report ‘UKRI Project – 10020315, Compostable Coalition – Work Package Four – Compost testing and analysis, degradation trials’ contains further details.

1. Summary of the composting trial

Envar Composting Limited designed and undertook a suite of trials to better understand the degradation profile in the composting process of intermediate materials and finished products independently certified as ‘compostable’. Most of the materials and finished products used in the trials were finished packaging products and intermediate materials (polymer films) used for making packaging products, while at least one product trialled was a format not classed as packaging. The main trial and data collection took place over a period of three months, beginning in late December 2022.

The trial provided data which shows that most of the compostable items supplied for the trial did break down in an industrial composting setting, with a steady degradation profile over time. The degradation profile is affected by how the material is managed and the extent it is spread throughout each composting mass (or batch) in which it has been put. There was a film material that broke down at a slower rate, partly due to having been supplied as baled sheets of film rather than in the sizes and shapes for which it is used as finished products. This bailed film failed to separate properly when processed through the slow-speed shredder. This was not representative of a real-life scenario.

Despite some of the material of the compostable items remaining visible at the final stage of the composting process, it was found that contamination levels of the final compost were acceptable. Compost was screened to 0 - 10 mm and then representatively sampled at 16.7 weeks and sent for independent laboratory tests that covered the minimum quality criteria set out in BSI PAS100:2018. The results showed the compost was compliant with quality requirements set in BSI PAS100:2018 except for glass, which ‘was almost certainly due to contamination from another source outside of the compostable packaging supplied for the trial’. Later, a further sample from the same batch of compost was taken and passed the physical contamination tests. Envar reported that ‘analysis looking at all types of microplastics also showed that compostable material microplastics were not present in sampled, screened compost, indicating a full breakdown'.

2. Front-end pretreatment

Usually, Envar undertake mechanical breaking up of incoming material in the form of shredding the homogenised feedstock through a slow speed, industrial shredder (Doppstadt 3060 Biopower). This shreds materials to a maximum of 400 mm in any one plane. In reality, this results in a smaller particle size due to the grinding nature as the material is pulled through the shredder's rakes, compacting and tearing it. Shredding happens prior to the composting of materials and its purpose is to reduce the size of large items, increase the materials' surface area to volume ratio and to homogenise the different materials to a more consistent mixture. Shredding does not differentiate compostable materials from non-compostable materials.

The mechanical process is also used to separate materials from each other, for example a sack containing cut grass. Ideally the sack would be required to be removed, or at least split open, to enable its contents to be effectively mixed and composted. Shredding can serve this purpose. However, this action; when traditional plastics are used as the container, can cause issues. The plastic is likely to be more difficult to be removed, as it is smaller after being shredded. The small plastic pieces can cause environmental problems which an operator is expected to control. Issues include the requirement to capture the plastic fragments (so they do not blow off-site), its removal from the composting mass and the cost of disposal after the removal.

On-site visual identification and hand picking of non-compostables from delivered waste is a relevant sorting technique but can be time- and cost-constrained. At Envar's site, removing non-compostable plastics and other non-compostable items that are not large or visually obvious when pre-treating waste (before composting) is not practical due to the sheer volume of materials managed at the site. Hand picking of non-compostables and other physical contaminants on surfaces of outdoor windrows is carried out when necessary for quality control purposes, although is not a routine practice. Compost screening and oversize material 'clean-up' tends to be more effective at removing most physical contaminants that reach those stages (see Section 3).

During the trial, the compostable materials to be tested were separately delivered to the composting site prior to being mixed with the food and garden waste before shredding occurred. Some of the baled compostable materials were also separately shredded prior to mixing with food and garden waste and further shredding. The compostable products that arrived already used and contaminated with food waste and residues were shredded and, in many cases, after shredding (prior to composting) stayed in their original format. In addition to the materials mixed with the food and garden waste, samples of the compostable materials for testing were placed into individual net bags and not subjected to shredding prior to being inserted into the composting batch. The compostable items to be tested comprised 7.5% mass/mass of the total feedstocks in the composting batch, which equated to a loading rate of 5% volume/volume.

The 5% v/v loading rate was chosen by Envar using the following rationale: the UK produces 9.5 million tonnes of food waste per annum[9] and 5% of that would be approximately 500K tonnes of compostable plastic (if all compostables supplied were made of compostable plastic materials). This would represent more than 20% of plastic being replaced in the UK by compostable plastics (annual basis). Thus, a 5% v/v load-rate represents a much higher percentage of compostables than what is considered feasible in the near future and therefore stress tests the whole process as being able to cope with the intended normal percentage easily.

3. Compost screening and management of oversize

After composting, Envar screen material using a Doppstadt SM-720-SA rotating drum screen with 10 mm holes and the larger particles are separated from the sub-10 mm compost see picture 18. The screen has brushes that are used to clean the 10 mm drum holes as the barrel of the drum rotates, this ensures the sieving is as efficient as it can be. Without the brushes, the material gradually forms a plug over the hole and the hole does not function to let material pass, eventually eliminating screening efficacy all together.

The ‘oversize’ material that does not pass through the screen’s 10 mm apertures includes larger fragments (such as ‘very coarse woody particles’) that have not completely biodegraded and most of any physical contaminants that reach compost screening stage. Envar return this non-composted oversize material to the start of their process and use it to adjust the carbon to nitrogen ratio of the incoming food and garden waste and to provide structure. Prior to re-introducing this material, Envar undertake quality control checks to determine if it meets their criteria for inputs to the composting process. If needed, there is some ‘action to sufficiently reduce the concentration of physical contaminants’ prior to being re-assessed for quality. This composting facility includes rea 70 m by 40 m plant which segregates plastic and other

[9] https://wrap.org.uk/taking-action/collections-recycling/markets-materials/organics-collection-sorting-reprocessing

contamination in a building dedicated to removing physical contaminants from oversize material.

Envar note that ‘visible remnants of independently certified compostable items in portions of woody oversize for re-composting are not counted as physical contaminants because they are allowed input types although care needs to be taken with how quality control checks differentiate compostable item remnants from non-compostable ones’. The latter are removed as best as practicable if their concentration exceeds the site’s physical contaminant criteria applicable to inputs. Checks on quality of wastes for feeding into composting processes tend to be done visually by site workers.

Any remnants of independently certified compostable items are allowed to be re-circulated and re-exposed to the composting cycle and thus subjected to further biodegradation. Current machine removal of plastics from oversize does mean some compostables (partially degraded) would go to an off-site waste disposal or recovery facility.

Picture 18 - Envar's Doppstadt Compost screener

Section 3. Depackaging machinery

This section explains the importance of depackaging machinery in the context of UK food waste management. Many in-vessel composting (IVC) and anaerobic digestion (AD) facilities process food waste from diverse sources, which often includes non-compostable packaging materials. As quality standards tighten for compost and digestate products, the role of efficient depackaging machinery becomes more critical.

Some depackaging machinery breaks up packaging and/or bags/liners into small fragments that could end up in the resulting compost or digestate if the fragments are not caught by screens. This section discusses the need for better technology to remove physical contaminants (and non-target materials) and improve the potential for identification and positive-selection or feed-in of independently certified compostable items.

Machinery/system information in Part 3 is based on published reports and desktop research and may not be fully comprehensive. Readers are urged to conduct their own research and consult manufacturers directly for performance specifics.

1. Why depackaging is important

Numerous in-vessel composting facilities and food-waste-fed AD facilities in the UK receive food waste from a variety of source types, from local authority kerbside collected food wastes in liners/bags to commercial/industrial food wastes in liners/bags. Some also receive food-retail-back-of-store food/beverage wastes in a variety of packaging.

Usually, during pre-treatment at food-waste-fed wet-AD facilities in the UK, food/beverage wastes received are mechanically separated, as best as practicable, from any packaging or liners/bags they arrive in. In-vessel composting sites in the UK are typically designed for treating local authority food and garden wastes that (mostly) arrive in certified compostable liners/bags. Such waste streams are usually visually checked for physical contaminants (e.g. metal, glass and non-compostable plastics) and provided waste quality is satisfactory, the food, garden and certified compostable liners/bags are shredded, and a composting batch is then formed using front-end loaders or similar mobile machinery. Some sites may have manual picking stations to remove physical contamination prior to composting.

An expected outcome from the current revision of the Compost Quality Protocol and AD Quality Protocol is that End of Waste rules will set substantially tighter limits on plastics equal to or larger than 2 mm (in any dimension) in composts and digestates. Therefore, the efficacy of depackaging machinery is ever more important, as too are upstream waste supply chain measures that exclude or minimise non-compostable packaging and non-packaging items and downstream process control steps that remove such items or fragments from composts and digestates as best as practicable.

Anecdotal and some interview feedback is that a number of food waste fed AD operators and in-vessel composting operators use pre-treatment machinery that shreds or tears packaging and non-packaging items into many small pieces.

Picture 19 is of removed liners/bags and packaging after their machine separation from local authority food wastes (that arrived mainly in compostable bags/liners) and commercial source food-wastes (that arrived, as described by the operator, in polyethylene bags/liners and packaging such as cartons and cardboard) at an AD facility in the UK. Machinery shreds the wastes to a maximum of 12 mm particle size, as per standard pre-treatment requirements in the EU Animal By-Products Regulation. A screen is then used to separate the sub-12 mm waste particles (mainly a 'food waste soup' that is fed into the digester) from waste particles retained on the screen (mainly pieces of bags/liners and packaging but also including adhered food/beverage residues and loose, small pieces of food waste). Picture 20 shows the typical appearance of the removed waste after it has been washed on-site.

Picture 19 - Removed bag/liner and packaging pieces before washing

Picture 20 - Removed bags/liners and packaging pieces after washing, before being pressed and sent to landfill

In future, if more food-waste-fed facilities use machinery that splits these items or in some other way removes them near-intact from food/beverage waste then it would be easier to remove any items/part items because most of them would have larger dimensions. This would prevent them getting through to the biological phases of treatment at composting / AD facilities.

Removed packaging and non-packaging items that are nearer to being intact should also be easier to identify (by material type) and this could enable positive selection of at least some compostable packaging / non-packaging items. Accurate identification of material type is influenced not only by item/fragment size but also its lightness/darkness and how much biowaste is stuck to its surfaces (see Section 4).

2. Depackaging machinery guides

2.1 The Waste & Resources Action Program (WRAP)

In 2009, WRAP carried out a web-based literature review and published a report[10] identifying potential suppliers of food waste depackaging equipment capable of separating solid and liquid organic wastes from packaging. They then collected data from identified suppliers to create data sheets with manufacturer contact details,

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[10] B. Balkenhoff, 'Review of Food Waste Depackaging Equipment.' WRAP, April 2009: http://www.organics-recycling.org.uk/uploads/article1762/Wrap%20Report%20on%20Food%20Waste%20Depackaging.pdf.

design application, operating principals, technical specifications, capital investment costs, operating and maintenance costs, required service intervals, delivery time, reference facilities and installations, and any guarantees provided by the supplier. These data sheets are no longer available, but the report may be useful for companies that treat packaged and/or bagged food wastes and for researchers interested in producing data sheets on depackaging (or other) equipment.

2.2 BioCycle

Founded in 1960, BioCycle is a recognized magazine dedicated to the advancement of organics recycling worldwide. BioCycle has extensively covered the development and deployment of food waste depackaging systems, identifying best practices for evaluating new depackaging equipment, highlighting new technology on the market, and addressing key barriers to broader implementation.

Evaluating machine/system performance

The efficiency of a depackaging machine, or system, is measured by recovery and purity. Recovery refers to the percentage of the total food waste that is successfully extracted from its packaging. For example, a 99% recovery rate means that 99% of the food waste has been separated from the packaging and is available for further processing. Purity indicates the quality of the recovered food material. High purity means that the recovered food content is almost entirely free from its packaging. For example, if the purity of material after depackaging is 99.5%, it means that only 0.5% of is the recovered material consists of packaging. Systems reviewed in Biocycle's September 2021 article[11] operate within a 90 to 97% recovery and purity range.

The article emphasizes that modern depackagers are also evaluated on their force, handling, and water-use efficiency. Craig Coker writes for BioCycle, "Newer models are designed to separate the packaging with the least amount of applied force needed, through fine adjustments like changing the angle of paddles mounted on a shaft, and to convey that separated packaging out of the machine with the least amount of additional handling."

[11] C. Coker, 'Food Waste Depackaging Systems.' BioCycle, 28 Sept. 21: https://www.biocycle.net/food-depackaging-systems

Technology on the market

July 2019[12] and October 2021[13] articles from BioCycle provide a detailed look at depackaging systems on the U.S. market. Below is a summary of the listed technologies. REA recommends that operators interested in purchasing depackaging equipment read the full articles and conduct their own research.

- Doppstadt DSP-205 BioPress[14] -- counter-rotating dual auger mixing/feeding hopper and screw press with 99.2% recovery and 99.5% purity on average.
- Drycake Twister[15] -- vertical cyclonic separation with a patented debagger and Seditank for microplastic, silt, sand, and grit removal.
- Dupps Mavitec[16] -- horizontal shaft unit with adjustable paddles and custom configuration settings and screens.
- Fitec BioSqueeze 200[17] -- liquifies organics and removes contaminants based on their different densities to produce a high solids bio-pulp.
- Gemidan Ecogi[18] -- water-based pulping process to open packaging and separate contaminants with 99.9% purity of recovered food waste.
- Monsal ADT Re: Sep 2[19] -- 50 mm (≈2”) shredder and vertical mill where water and source separated organics are blended to create a slurry that is pumped through a hydrocyclone to remove grit prior to digestion.
- Remu Screener-Crusher[20] -- numerous adjustable blades on a horizontal shaft attached to a front-end or skid steer loader to cut packaging away from organics.
- Smicon[21] -- swing hammers that remove organics from the packaging and push food waste through a screen.
- THOR Turbo Separator[22] -- low-rpm depackaging system that separates packaging using paddles, without shredding or needing supplemental water, and its energy use varies between 47 and 173 kW depending on the model.

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[12] C. Coker, ‘Food Waste Depackaging Systems.’ BioCycle, 10 July 19: https://www.biocycle.net/food-waste-depackaging-systems
[13] C. Coker, ‘Food Depackaging: The Systems.’ BioCycle, 5 Oct. 21: https://www.biocycle.net/food-depackaging-the-systems
[14] Doppstadt Recycling, *DSP 205 BioPress*: https://youtu.be/xYWG9OKM-SU?si=qX-d4hJkn604h9cf
[15] Drycake Twister, *Twister in Action*: https://youtu.be/orhT795Opsc?si=kG-TNhkkU3yUyVfS
[16] Mavitec Green Energy, *Mavitec Paddle Depackager*: https://youtu.be/J54XXkz1XuY?si=KqtrT9pInqd15Yc8
[17] Fitec Environmental Technologies, *BioSqueeze 200*: https://vimeo.com/600946516
[18] Lars Ravn Nielsen, *Gemidan Ecogi*: https://youtu.be/hUouMYSjI-E?si=yjZ7uFP4UNZhXuQu
[19] SUEZ, Monsal* advanced digestion technology (ADT) Re: Sep* 2: Managing Food Waste: https://d3pcsg2wjq9izr.cloudfront.net/files/1902/download/668840/1902_19_20210624072908832031.pdf
[20] REMU, REMU *Screening Bucket*: https://youtu.be/tOi-ufmgQGc?si=JYJ6PHpaF2xmyIuF
[21] Van Dyk Recycling Solutions, *Simicon Food Waste Depackagers*: https://vdrs.com/smicon-food-waste-depackagers/
[22] Turbo Recycling, Depackaging Grocery Waste II: https://www.youtube.com/watch?v=bRR_ezDNyKM

- Veolia ECRUSOR™[23] -- two shaftless screw augers to force packaged foods against a plate with protruding teeth that puncture packaging, forcing the food and liquids through the screen and into a hopper beneath.

Most of the listed technologies are mechanical separation systems that use physical force to separate food waste from its packaging. However, some systems use water-based processing to separate food waste from packaging.

Machinery that does not reduce packaging and non-packaging items to many small pieces enables minimisation of the number of items, part-items or item fragments that get into biological treatment phases, and which could get through to the ready to use digestate or compost. When depackaging removes close-to-intact or relatively large item pieces/fragments of packaging, bags or liners that contain biowaste, this gives greater potential for higher accuracy in machine identification and sorting of removed items by material type (see section 4). This could be explored further in future research and by organics recyclers and companies they could potentially supply in future.

Amongst the BioCycle listed machines/systems, Scott Equipment's five food waste depackagers the TS-20, TS-30, TS-40, THOR and MEGA-THOR units, BioCycle's July 2019 article includes manufacturer explanation about efficacy of their machines. They vary in capacity from 2 to 40 tons per hour, require footprints of 400 to 1,250 square feet (sq. ft.), and do not require any additional water to liquify the food waste. The horizontally configured machines employ a set of paddles or flails rotating at 400 rpm (relatively low compared with rpms of some of the other machines) to break open packaging. Kevin Pedretti, Business Development Manager for Scott Equipment, explains, "Once the package is empty, it is carried along the top of the processing chamber by the rotating paddles or flails so that the packaging leaves the chamber virtually whole." Durable packaging, like plastic peanut butter jars packed in cardboard boxes, are separated further along the horizontal processing chamber. The reduced residence time limits packaging breakage, helping to prevent packaging fragments from contaminating the separated food waste.

Insights on broader implementation

The September 2021 BioCycle article highlights key drivers and barriers to the increased use of alternative depackaging technologies to shredders in organics recycling.

Zero Waste to Landfill programs, Simpler Recycling, and other food waste diversion and collection initiatives have increased the amount of food waste feedstocks provided to

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[23] Tob Darby, *ECRUSOR™ in Use*: https://vimeo.com/340975511

AD and composting facilities. However, these feedstocks continue to have significant levels of physical contaminants, primarily from packaging materials. Food-waste-fed AD facilities also receive non-compostable plastic kitchen caddy and food bin liners and bags used for the collection of household food wastes; these too are physical contaminants. Combined, this increase in food wastes received and significant levels of physical contaminants arriving with them have driven AD and composting operators to increasingly seek out depackaging systems that can separate food waste from packaging materials, and in the case of AD, machinery/system that can separate food waste from liners and bags.

Stringent health, safety and environmental standards often necessitate costly equipment modifications and upgrades which increases the capital investment necessary for adopting new technologies. Additionally, obtaining the necessary permits and approvals for installing new equipment can be time-consuming and costly, often delaying project timelines and affecting the overall feasibility of implementing depackaging solutions. Regulatory standards often dictate how waste materials must be processed, handled and disposed of or sold, which can restrict the type of technologies able to be employed, limiting depackaging options available to processors.

3. Other depackaging machinery

3.1 Flexidry depackaging machines

The Flexidry Bio-Waste Depackaging System[24] separates organic content from packaging using perforation-compression-screening technology. PRM Waste Systems claims that the system is ‘ideal for the agri-foodstuffs, supermarket (superstores) and restaurant industries that sort and recover their production, unsold and leftover food waste’ because the Flexidry ‘reduces damage to packaging, and therefore, avoids mixing inerts with the organic matter.’ Their website says that the Flexidry ‘processes all types of packaging including cans’ and claims a 99.5% purity standard for recovered organics.

3.2 RUNI machines

The RUNI SK370 Dewatering Screw Compactor[25] separates liquid from containers using high-pressure screw technology. RUNI claims the SK370 reduces waste weight and volume by up to 50%, increasing AD feedstocks and cutting bin lift costs. RUNI states that the screw's high movement allows for more efficient liquid extraction than

[24] PRM Waste Systems, *Flexidry Bio-Waste Depackaging System*: https://www.prmwastesystems.com/machinery/flexidry-bio-waste-depackaging-system/
[25] PRM Waste Systems, *Dewatering Solutions – Runi SK270*: https://www.prmwastesystems.com/machinery/runi-sk370/

traditional methods, and it can process faulty or returned goods, leaving dry, compacted waste suitable for recycling.

3.3 Drycake TWISTER

The Drycake TWISTER[26] is a de-packaging and separation unit that uses a wind force vortex to clean and dry ‘rejects of residual organics’ [appears to mean to clean and dry ‘light rejects’] and remove other packaging. The patent-pending drum redesign increases filtration by 20% and improves recovered organics purity by 30%. Drycake claims the TWISTER can remove various types of packaging such as cans, wrappers, bags, plastic bottles, and jars from any food waste streams, resulting in 99.8% pure organics for AD or composting.

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[26] Drycake, *TWISTER DEPACKAGER*: https://www.twisterseparator.com/

Section 4. Machine identification, classification and sorting of compostables from non-compostables in biowaste recycling

During this Innovate UK funded project, RECOUP and some of this IUK-funded project's other consortium partners have trialled machine identification and sorting of compostable packaging (items that together cover a range of material types) from non-compostable items using equipment used in a Materials Recycling Facility (for dry recyclable wastes). That trial's findings will be reported in a separate document and are not covered in this report.

During this Innovate UK funded project, the REA has contacted a number of waste identification and sorting equipment/system providers, aiming to find some that can;

a) identify used compostable plastics and compostable polymer-coated fibre-based compostable products that have food/beverage residues on them,
b) identify used non-compostable plastics and non-compostable-polymer-coated fibre-based products; <u>and</u>
c) provide sorting solutions that support feeding compostables into the biological treatment stage and that reject non-compostables (especially at the mechanical pre-treatment stage).

Unfortunately, no providers of these particular equipment / systems specialised for use at AD / composting facilities were found. Consequently, this report section highlights findings from a University College London study on a system for identifying compostable and non-compostable plastics 'contaminated with soil in compost sample obtained from an industrial composting plant'. Although the very small soil/compost particles adhered to the sampled and tested plastics are not the same as food/beverage residue that tends to coat packaging and non-packaging items that arrive with food waste at composting and AD facilities, the key variables that UCL found may have the same influences on the system's accuracy at identifying plastic material type.

1. UCL's hyperspectral imaging study

In UCL's study[27], researchers applied Hyperspectral Imaging (HSI) with various pre-processing techniques in the short-wave infrared (SWIR) region to develop an efficient

[27] Taneepanichskul, M., Hailes, H. C., and Miodownick, M. (23 May 2024). Using hyperspectral imaging to identify and classify large microplastic contamination in industrial composting processes, Frontiers in Sustainability, DOI 10.3389/frsus.2024.1332163. https://www.frontiersin.org/journals/sustainability/articles/10.3389/frsus.2024.1332163/full?utm_source

model for identifying and classifying plastics and large microplastics during industrial composting. Materials used included compostable plastics such as PLA and PBAT, and conventional (non-compostable) plastics including PP, PET, and LDPE.

Chemometric techniques were applied to develop a classification model, and they found that the Partial Least Squares Discriminant Analysis (PLS-DA) model effectively distinguished between virgin PP, PET, PBAT, PLA, and PHA plastics and 'soil-contaminated plastics'[28] measuring larger than 20mm × 20mm, achieving accuracy of 100%. The model also achieved a 90% accuracy rate in 'discriminating between pristine large microplastics[29] and those contaminated with soil'.

Testing plastics from compost screening

When UCL's model was used for testing 50 randomly selected plastic samples obtained at compost screening stage (rotary trommel screen with 10 mm apertures) at an in-vessel composting facility ('IC plant'). This facility was treating 'mixed food waste and garden waste', and this received waste included 'compostable plastic and non-compostable plastic'. UCL found that plastic identification accuracy 'depended on parameters such as darkness, size, colour, thickness and contamination level'. Their model achieved 85 % accuracy for 'plastics and large microplastics detected within compost'.

Factors affecting accuracy

The plastics' darkness level significantly affected the classification model's accuracy. Brightly coloured plastics had a lower misclassification rate compared to dark-coloured plastics. This is because opaque plastics absorb most of the radiation in the SWIR region, making it difficult for spectroscopic analysis to penetrate the material and detect its chemical composition. The absorption of radiation by dark-coloured plastics resulted in a low signal-to-noise ratio, making it challenging to distinguish them from other materials in the sample.

UCL reported that plastic thickness is 'another critical factor that significantly impacts the model' and that 'thinner plastic tends to provide inadequate spectral information'.

=Email_to_authors_&utm_medium=Email&utm_content=T1_11.5e1_author&utm_campaign=Email_publication&field&journalName=Frontiers_in_Sustainability&id=1332163 and summary with link to the published research at https://www.plasticwastehub.org.uk/news/new-hub-paper-on-compostable-packaging-identification-technologies

[28] The paper's conclusion section content about microplastics explains that some of what was studied was '…large microplastics contaminated with soil in compost sample obtained from an industrial composting plant'.

[29] 'Large microplastics are categorized as microplastics spanning dimensions between 1 mm and 5 mm.'

Using plastic samples from the composting facility, the model achieved peak accuracy of 100% when analysing plastic thickness within the range of 2 mm to 4 mm. ‘However, it’s important to note that this conclusion is based on a limited sample size, with only two thick plastic samples available for analysis, one of which was dark in colour. When focusing solely on bright plastic samples, the model exhibited decreased accuracy in detecting thinner plastic due to the loss of spectral information’ (a finding consistent with observations made by other research papers cited in UCL’s research paper). ‘For LDPE and PP, plastic within the range of 2 mm to 4 mm demonstrates the highest accuracy, reaching 100%. However, the model demonstrates significantly lower accuracy in detecting thin PP, achieving only 43%. In the case of thick plastic, PP achieves 100% accuracy, while PBAT attains 0%. This discrepancy can be attributed to the high darkness level of PBAT, which affects the spectral characteristics and compromises detection accuracy.’

Plastic sample colour also profoundly affected the model’s accuracy. Its accuracy ‘decreased moderately to 75% when identifying transparent plastics and dramatically dropped to 33% when identifying black and multicoloured plastics. In contrast, size did not affect accuracy greatly once the other factors of darkness, colour and sample contamination were removed.’

Accuracy of identification

UCL stated that their ‘experiments have shown that [the] PLS-DA model can accurately detect a wide range of conventional (non-compostable) plastics that are typically found to contaminate compost during IC processing including PET, PP, and PE’. They trained their model ‘first on virgin plastics and soil contaminated plastic but then tested the model on plastic collected from an IC plant’. ‘These plastic fragments were of various sizes (The average size is 27.14 cm^2), colours, thickness and brightness. Crucially they were also contaminated with earth and compost that was ingrained into the fabric of the plastic as a result of being of through the composting process. Nevertheless, [UCL’s] model was able to identify them to 80% of accuracy.’

UCL also stated that ‘the success of our approach invites consideration as to how our technique can be employed to help the waste processing sector’. ‘Clearly, we have shown that identifying compostable plastics such as PLA, PBAT, and PHA from a mixed recycling stream is possible, even when there is moderate contamination. It is noteworthy that PET and PLA can be easily distinguished from each other which is a problem for traditional IR detection systems. There is a high commercial value of increasing the purity [of] PET recycling streams [that] might justify the expenditure of investment of a SWIR-HSI system. The PLA that is identified could also be separated and sent to an industrial composter.’

UCL found that plastic samples' darkness, thickness, colour and level of contamination significantly impacted the model's identification accuracy and that their size did not greatly affect this once the factors of darkness, colour and level of contamination were removed.' Specifically, **darker colour, smaller size, thinner and more highly contaminated surfaces were factors that contributed to lower accuracy** in the plastics classification model. This 'reinforces the importance of considering these specific plastic attributes when developing and assessing detection models for optimal performance'.

A limitation of UCL's study was that 'the threshold for image segmentation determined the resolution thus, the smallest plastic sample [they] could detect was 2 mm. Nevertheless, the findings highlight the substantial progress made by [UCL's] model in accurately detecting microplastics and the potential it holds for further research and practical applications in waste processing plants.'

Potential benefits and further research

Writing about potential benefits in future, UCL suggested that 'industrial composting plants could benefit from deploying a SWIR-HSI together with PLS-DA model to help them decrease contamination of the end compost and thus increase its value both commercially and environmentally'. 'Because it can give real time information it could quantify large microplastics content as a function of process variables thus helping operators to optimize their system to minimize them. By identifying the large plastic fragments separated by the trommel [used when screening compost], the PLS-DA model could also identify any compostable plastics [that] are failing to biodegrade and feed this information back to the manufacturers.'

UCL also suggested that 'Anaerobic digestion (AD) plants could also use this method to assess in real time the plastics coming into their systems mixed in with food and agricultural waste'. 'At the moment it is standard practice to remove all plastics whether they are compatible with AD plants or not. Combining SWIR-HSI with PLS-DA model could help AD plants identify and separate compostable plastics and send them to an IC plant. Similarly, this approach could be used to assess the microplastic content of the digestate and to determine the mix of plastics in it.'

REA comments that future research could lead to valuable findings on using a SWIR-HSI with PLS-DA model in conjunction with suitable waste handling machinery at priority-type composting and AD facilities.

Conclusions

Key intervention opportunities for supporting feed-in of compostable plastics and removing non-compostable plastics in waste streams received may be:

1. at food-waste-fed wet-AD facilities – depackaging packaged food/beverage wastes (e.g. food retail back of store wastes) and debagging otherwise-loose food waste (e.g. local authority food wastes) such that the packaging / bags / liners (these items collectively covering a range of material types) are only squashed or split open then compostable plastics are machine-identified and machine-picked from amongst the waste pre-treatment rejects stream (ID and picking stage may need to be after rejects washing stage) and then can be sent to an in-vessel composting facility, dry-AD plus composting facility, or a wet-AD facility with a TPH machine;
2. at food-waste-fed wet-AD facilities with TPH and screening as part of waste pre-treatment – depackaging the same types of waste as in bullet point 1, such that the packaging / bags / liners (these items collectively covering a range of material types) are only squashed or split open then non-compostable plastics are machine-identified and machine-picked from amongst the squashed / split packaging / bags / liners waste stream and rejected, and the remaining material is fed into the TPH machine;
3. at food-waste-fed wet-AD facilities with TPH and screening treatment of food+compostable items waste streams, or used compostable items waste streams, where what passes through the after-TPH screen is fed into the AD process; and
4. at food-waste-included composting facilities – depackaging packaged food wastes such that the packaging (these items collectively covering a range of material types) is only squashed or split open then compostable plastics are machine-identified and machine-picked from amongst the waste pre-treatment rejects stream, and the picked compostable plastics are fed into the composting process.
5. In the food-waste-included composting facility scenario, the REA has assumed that loose food waste from household sources would continue to be received in compostable liners / bags and that any food waste+compostable packaging waste accepted from business sources has low enough physical contaminant rates that these waste streams would be visually inspected, shredded and fed into the biological phase of treatment.

An opportunity to support recirculation of compostable plastic remnants at food-waste-included composting facilities could be research on machine-ID and -picking of non-compostable plastics from the predominantly woody oversize particles (that arise during compost screening), thus supporting more re-composting the woody oversize and any compostable plastic remnants or supporting this picked waste stream’s value when some portions of it are sent to Energy from Waste facilities.

There could also be intervention opportunities associated with digestate screening and management of the screen-removed rejects stream and/or the separated fibre digestate; dialogue with AD facility managers and AD process engineers may aid progress with research and operational practices.

Find Out More and Support the Sector

The report is available on the REA website at https://www.r-e-a.net/resources/management-of-compostables/

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