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PAPER

Characterization of plastic contamination entering food waste management and implications for food system impacts

Jennifer Park[1], **Callie W Babbitt**[1,*], **Nathan C Eddingsaas**[2], **Anna Christina Tyler**[3] and **Thomas A Trabold**[1]

[1] Golisano Institute for Sustainability, Rochester Institute of Technology, Rochester, NY, United States of America
[2] School of Chemistry and Materials Science, Rochester Institute of Technology, Rochester, NY, United States of America
[3] Thomas H. Gosnell School of Life Sciences, Rochester Institute of Technology, Rochester, NY, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: cwbgis@rit.edu

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Abstract

Managing food waste (FW) by composting and anaerobic digestion offers potential sustainability benefits compared to conventional disposal practices. However, these processes can be unintended sources of plastic pollution to the environment, due to the presence of plastic contaminants originating upstream in the food system. During FW processing, plastic contaminants may partially degrade, ultimately leading to microplastic releases by way of agricultural use of compost and other bio-based products. Preventing and managing these releases requires a better understanding of the sources, magnitude, and nature of plastic contaminants traveling through FW management systems. This research collected representative FW samples from common generators, including restaurants, groceries, schools, and households, characterized the abundance, type, and material composition of contaminants present, and interpreted results through the lens of potential economic and ecological risks. Contaminants were observed in 80% of FW samples and were predominantly composite plastics, including multi-layer films, plastic-coated paperboard, and mixed polymer containers. The most common contaminants observed were fruit and vegetable stickers (30% by item count), but their small size and light weight make an insignificant contribution to total contaminant mass (<1%). The majority of contaminants were thin, flexible items, including plastic wraps, bags, gloves, and containers, which present added challenge to FW management due to the potential to impede mechanical equipment and reduce the production and quality of compost products. These results offer insights into potential strategies, including education, policy, and technology development, that can be leveraged across the FW management system to prevent contamination and improve food system sustainability.

1. Introduction

The growing challenge of food waste (FW) presents a major barrier to the sustainability of global food systems. Agriculture and food production consume immense natural resources (Pelletier *et al* 2011, Hoekstra and Mekonnen 2012) and return pollutants and greenhouse gases to the environment (Karl *et al* 2024, Liyana Pathirana and Hadjikakou 2025, Martinez and Ramankutty 2025). Yet over one billion tonnes of food is wasted globally each year (UNEP 2021), leading to the loss of nutritional value (West *et al* 2026) and the carbon, water, and nutrient resources embedded in discarded food (ReFED 2016, Ebner *et al* 2018, Sarangi *et al* 2024). Conventional management of FW by landfill, wastewater treatment, and incineration systems creates social, economic, and environmental impacts (ReFED 2016). Globally, food loss and waste generation and management accounts for an estimated 3.5 Gt CO_2e of greenhouse gas emissions per year and annual economic and social costs exceeding US $1 trillion (FAO 2014).

In response to this growing global challenge, a wide array of policies have been developed to minimize and manage FW (Richa and Ryen 2018, European Commission 2020, Ryen and Babbitt 2022). For

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example, the United Nations sustainable development goals include targets aimed at increasing agricultural productivity, reducing food supply chain losses, and halving retail and consumer sources of FW (United Nations 2015). Meeting these goals will require widespread uptake of new circular economy strategies that re-envision wasted food as a resource (Babbitt *et al* 2022) and valorize waste into higher-value energy, fertilizer, and biochemical products (Nayak and Bhushan 2018, Sarker *et al* 2024), thereby minimizing raw material demand, energy consumption, waste, and pollution (Sarangi *et al* 2024, Chary *et al* 2025). Valorization processes such as anaerobic digestion (AD) and composting not only divert FW from landfills, but also produce nutrient-rich digestate and compost, which can displace conventional, resource-intense fertilizer or soil amendments in food production (Xu *et al* 2018, Chew *et al* 2021).

Despite the importance of FW valorization, widespread uptake of these technologies is still relatively limited. Only about 20% of FW in the U.S. (U.S. EPA 2018) and 26% in the E.U. (Zero Waste Europe 2024) is collected and diverted into resource recovery pathways. The economic costs of valorization, relative to incumbent disposal pathways, represent a major barrier to broader adoption (Roy *et al* 2023). Further, any potential revenue from FW valorization is contingent on the ability to consistently produce high quality, marketable products from heterogeneous FW materials (Cerda *et al* 2018, Xu *et al* 2018). One growing area of concern in this regard is the presence of plastic contaminants in FW feedstocks. The plastic containers, bags, utensils, and labels that are used to package and serve food are frequently discarded along with food materials into the waste management process (U.S. EPA 2021), where they persist during FW treatment (Groß *et al* 2024), and ultimately enter the environment when the resultant products, such as compost, are used in agricultural applications.

These plastic 'hitchhikers' in FW streams might include macro- as well as microplastics, those less than 5 mm in size (Yu *et al* 2021, Fan *et al* 2022, Mioduska *et al* 2023), that arise from partial breakdown within the valorization process or that were already contained in the food itself (Sewwandi *et al* 2023). Recent studies have documented the presence of macro- and microplastics in digestate and compost (Schwinghammer *et al* 2020, Mioduska *et al* 2023, Porterfield *et al* 2023a, Whitney *et al* 2025), suggesting that perceived economic and environmental benefits of FW valorization may be diminished by unintended plastic releases into natural and agricultural systems. An analysis of composting operations across the U.S. found that 21% of composter operating costs go towards removing and managing contamination (Barry *et al* 2024). Almost 40% of large commercial composters in California will not accept FW due to concerns of contamination (U.S. EPA 2021).

Reducing the risks of contamination in FW streams will require concerted effort to identify and remove plastics at the points when food products are separated into waste streams and travel through valorization processes. Such interventions require an understanding of the composition and sources of plastic contaminants, but such information is not yet fully documented in the literature. A limited number of contamination characterization studies have been carried out by municipalities (e.g. Aspray and Tompkins 2019, Cascadia 2023, NYC Department of Sanitation 2023, Foster *et al* 2024) and reported in the academic literature (Thakali *et al* 2022). To contribute to this growing body of knowledge, this study aims to identify and quantify the plastic contaminants that occur in common FW streams and to explore potential downstream economic and environmental risks to the food system that may arise as a result. These findings are intended to inform and prioritize potential policy, education, and technology development interventions, which may in turn help catalyze broader adoption of FW valorization pathways.

2. Methods

The purpose of this study was to characterize the frequency, magnitude, material composition, and other physical properties of plastic contaminants in FW streams that are entering valorization pathways. Study methods included collecting FW samples, sorting and separating samples to identify contaminants and other non-food items present, and then determining the material composition, physical form, and likely source of contaminants (figure 1). Each of these steps is described in more detail below.

2.1. Sampling

Samples were collected from FW generators in an urban region of western New York that was estimated to produce at least 90 000 t FW per year, based on available data and generation factors for residential (MITRE 2023, U.S. Census 2025) and commercial and institutional FW sources (NYSP2I 2025, Armington *et al* 2026). The specific FW sources sampled were associated with generators responsible for most FW by mass in the U.S. (U.S. EPA 2023) and within the region (percentage contribution relative to the above FW estimate for the study area): residential (42%), retail (20%), food service (16%) and educational institutions (6%). FW samples from wholesale, manufacturing, and hospitality sources were not

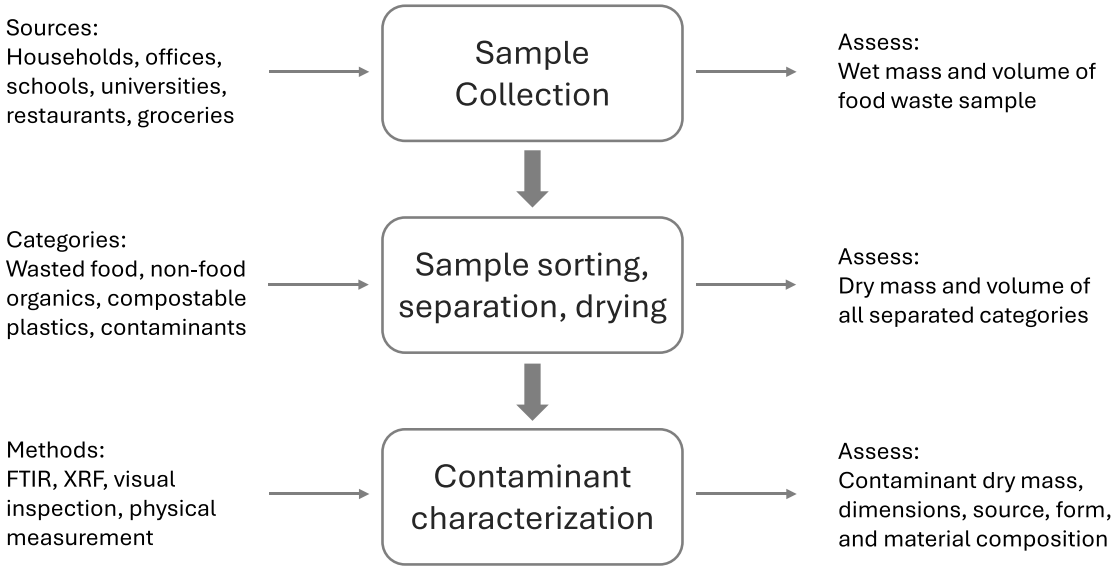


Figure 1. Sampling, sorting, and analysis of food waste and plastic contaminants.

Table 1. Overview of food waste samples collected from commercial, institutional, and residential sources.

Generator	Category	Type	No. of samples	Mass per sample (wet) (kg)	Volume per sample (wet) (m^3)
Grocery	Commercial	Pre-consumer	3	2.6–5.3	0.012–0.017
Grocery (Non-source separated)	Commercial	Pre-consumer	4	4.6–10.9	0.008–0.027
Restaurant	Commercial	Pre-consumer	4	2.9–8.3	0.007–0.013
Office cafeteria	Commercial	Post-consumer	3	1.9–2.3	0.016–0.017
K-12 school cafeteria	Institutional	Pre-consumer	3	3.8–7.3	0.015–0.016
K-12 school cafeteria	Institutional	Post-consumer	3	3.2–6.3	0.012–0.017
University cafeteria	Institutional	Pre-consumer	7	5.3–8.0	0.010–0.021
University cafeteria	Institutional	Post-consumer	4	4.4–5.8	0.007–0.013
Household	Residential	Post-consumer	7	3.1–9.2	0.006–0.018

available or included in the study. All samples were obtained from generators who currently participate in FW landfill diversion programs, primarily composting or AD, to capture a realistic profile of contaminants entering valorization systems. Samples primarily consisted of FW materials that had been source separated at the generator as well as any other materials (e.g. paper towels, some compostable plastics) accepted by the valorization facility receiving the materials. The only exception was a grocery store sending packaged FW to a digester that operates a depackaging system onsite (termed non-source separated or NSS in results).

Samples were collected either at the generator site, once they were separated and awaiting collection, or at the compost facility or collection site, where they were dropped off by an individual or FW hauler. Individuals involved with discarding or sorting FW were not aware of the sampling, to minimize behavioral influence. When possible, samples were obtained of both pre- and post-consumer waste materials. The samples were immediately transported to the researchers' lab and transferred into a standard container with known mass and dimensions. Wet mass was determined with a large balance, tared for the holding container, and wet volume was estimated based on the container's internal dimensions and measured height filled by the FW. Summary sampling information is provided in table 1; all raw data are provided in the online dataset (Park and Babbitt 2026).

2.2. Sorting and separating FW samples

All materials within each sample were sorted by hand into two categories: FW and non-food items (which were further disaggregated as described below). Sorted samples were visually inspected, and the data recorded during this process included type of FW (e.g. banana peel, bread pieces, half-eaten apple), the estimated quantity of each item, and whether the FW appeared to be edible. Initial assessments of the type and quantity of all non-food items were also made according to visual inspection (e.g. paper towel, plastic spoon, glove). The segregated FW was oven-dried at 105 °C for 24 h, and the mass before

and after drying was obtained to estimate the moisture content. Non-food items were gently rinsed, if needed to remove adhered food, and then also dried and weighed. From this point forward, all results were estimated and reported on a dry mass basis.

2.3. Characterizing non-food items

A more detailed characterization of all non-food items was used to determine item mass, count, dimensions, flexibility (flexible, semi-rigid, rigid), and thickness as well as general descriptors of what the contaminant item was or where in the upstream food system it may have originated. These physical characteristics are relevant to the potential impact of contaminants in downstream FW valorization pathways and to identifying potential intervention points. A total of 1,455 non-food items were observed in total, many of which were similar in ways that suggested natural groupings into broader categories for the purpose of labeling and visualizing results. For example, plastic spoons, forks, and knives had similar dimensions, material type, and rigidity, and thus were grouped into a broader category termed 'plastic utensil.' To ensure consistency in how researchers assigned these categories, a contaminant typology matrix was used to organize and document common attributes by item type (Park and Babbitt 2026).

All non-food items were individually characterized to determine material composition. Polymers were identified using Fourier transform infrared spectroscopy (FTIR, Shimadzu) and near-infrared spectroscopy (NIR, Matoha PlasTell). Metals were assessed using x-ray fluorescence (XRF, SciAps X-500). In many cases, materials were deemed to be composites, due to the presence of multiple polymers, metallic inner layers (e.g. multi-layer snack bag) or plastic-coated papers (e.g. polymer coated food service containers or packaging). Determining precise material composition for these composites was beyond the scope of this study, but as much identifying information as possible was recorded in the dataset. Based on the results of material identification, non-food items were further disaggregated into one of three categories: (1) non-food organics accepted by the waste management facility, such as paper towels, napkins, or coffee filters; (2) compostable plastics; and (3) contaminants, which included all other materials that were not accepted by the downstream facility. These determinations were based on educational materials and instructions provided by the FW management facilities to the generator regarding materials they accept. For example, facilities involved in this study accept plastics labeled as BPI certified commercially compostable or made of specific materials (e.g. polylactic acid (PLA) biodegradable bags). But because these materials are not universally accepted in every FW valorization system, they are presented as a separate category in results.

All raw data associated with FW samples and non-food item characterization were captured in Microsoft Excel spreadsheets and later saved as machine-readable comma-separated value files. Data analysis and creation of visuals were carried out in Rstudio (RStudio Team 2020) using packages tidyverse (Wickham *et al* 2019), RColorBrewer (Neuwirth 2022), ggplot2 (Wickham *et al* 2020), scales (Wickham *et al* 2025), colorspace (Stauffer *et al* 2009), dplyr (Wickham *et al* 2023), and patchwork (Pedersen 2025). All data and code are provided online in an open-access data repository (Park and Babbitt 2026).

3. Results and discussion

Results described herein characterize the mass, composition, and make-up of plastic contaminants obtained from pre-consumer ($n = 21$) and post-consumer ($n = 17$) FW samples collected from commercial, institutional, and residential generators. These results are then discussed in the context of literature that has established linkages between plastic contaminants and downstream management of FW and use of FW-derived products in agricultural systems.

3.1. Presence of non-food items in FW streams

All collected FW samples contained some level of non-food items (figure 2), although in many cases these items were organic materials or compostable plastics that could ostensibly be processed along with FW in composting or anaerobic digesters. Non-food organics were typically uncoated paper products such as paper towels, cardboard, and unbleached paper bags. Compostable plastics included products bearing labels indicating that they were BPI (Biodegradable Product Institute) certified or that were determined from material characterization to be comprised of biodegradable plastics, namely PLA. The highest rate of non-food materials was observed in the post-consumer waste collected from an office cafeteria, where samples contained between 40% and 50% compostable plastics and between 20% and

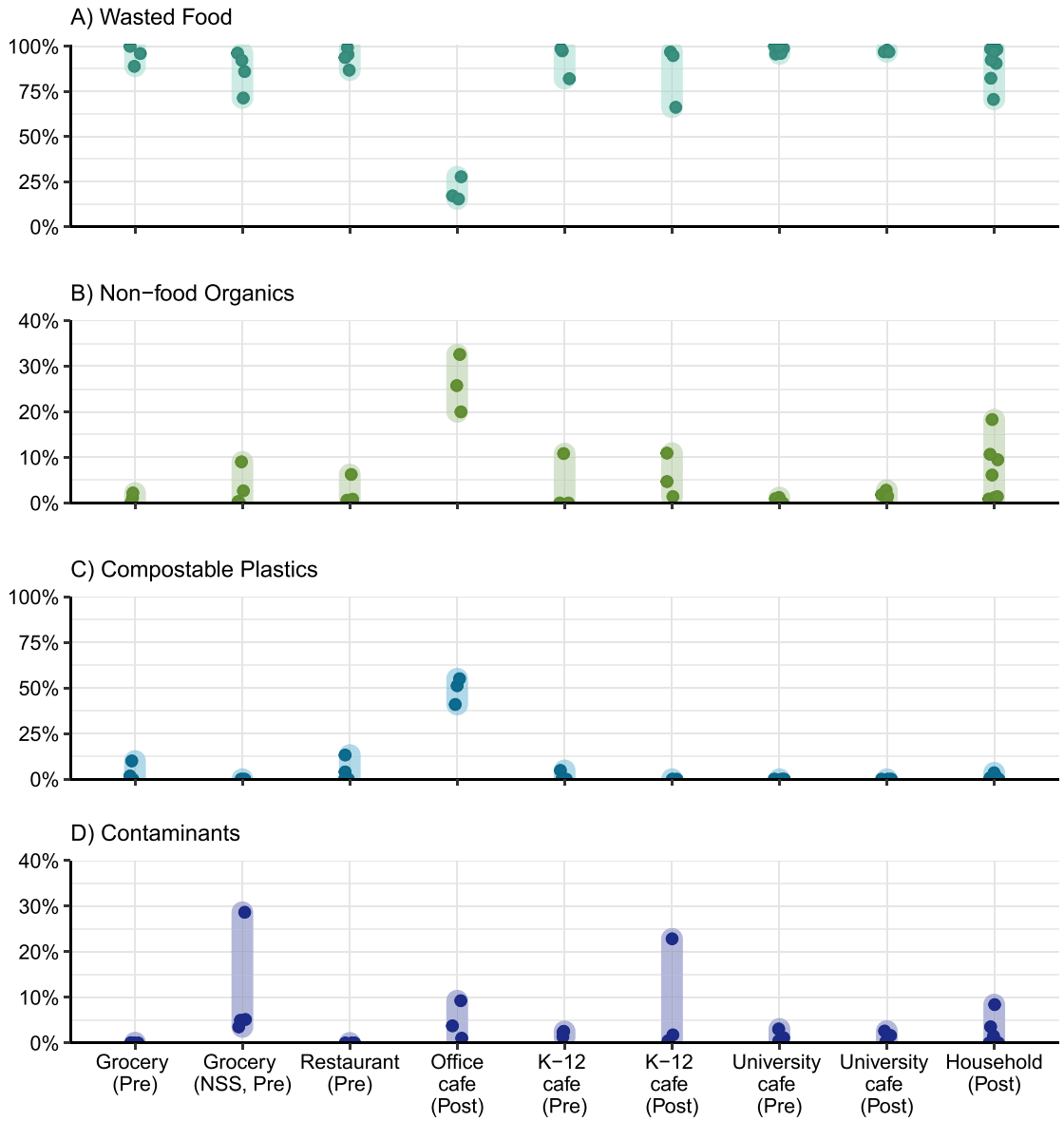


Figure 2. Relative mass contributions to FW samples from (A) wasted food, (B) non-food organics, (C) labeled compostable plastics, and (D) contaminants. Results are reported on a dry mass basis and loosely ordered by generator type (commercial, institutional, residential). Individual dots correspond to a single sample, and shaded segments illustrate the range between maximum and minimum values across samples. Note that plots (A) and (C) are on a 100% scale; (B) and (D) are on a 40% scale to make individual points more visible. Cafe: cafeteria; NSS: non-source separated materials (all others are source separated); Pre: pre-consumer; Post: post-consumer.

30% non-food organics (all results reported on dry mass basis). At this location, most of the non-food items originated from the paper products and compostable plastic cups and utensils that were provided to employees who ate at this location and that were accepted by their FW management partner. Conversely, compostable plastics were observed at much lower mass rates in FW samples collected from households (0%–4%), schools (0%–5%) and university cafeterias (0%). While these materials were present, often in the form of compostable 'biobags' provided by the FW hauler to the generator to collect and contain FW for transport, their light weight made minimal contribution to the total sample by mass.

Plastic contaminants were observed in all but eight of the samples. In general, observed contamination (figure 2) was comparable but typically lower than the mostly closely related study (Thakali *et al* 2022), which counted any non-food item as contamination. The highest occurrence and mass of contaminants (between 3% and 30%) was observed in samples obtained at the grocery store that was allowed to send packaged materials to an AD facility with depackaging equipment. Thus, these materials

are present as the result of realistic practices, rather than non-compliance to source separation guidelines under which other generators operated. Even if not technically contaminants in this context, these materials still present a risk to downstream FW management, as depackaging processes do not remove all plastics and may actually lead to increased microplastic production (U.S. EPA 2021, Porterfield *et al* 2023b).

Aside from this grocery store, higher mass rates of contamination were typically associated with post-consumer FW sources, as seen for the K-12 school cafeterias (0.4%–23%), office cafeteria (1%–9%), and households (0%–8%). In these locations, separation of FW from other dining waste is typically the responsibility of individual consumers, rather than employees who presumably receive training about source separation. However, in the case of the university cafeterias sampled for this study, separation was often handled by employees, when diners returned their dishes, which may have contributed to the relatively low contamination rates (0.3%–2%). FW samples from households were obtained from residential participants taking part in a voluntary municipal composting program that involved bringing their FW to a community drop-off point. Some evidence suggests that participants who make time and financial investments to participate in composting are more likely to follow program guidelines and ensure a clean FW stream (Oehman and Babbitt 2026). Household samples also frequently included contaminants closely commingled with FW, as in the case of tea bags, which a consumer might perceive to be compostable based on the organic material present, not realizing the presence of contaminants such as the metal staple, plastic label, and plastic mesh bag.

3.2. Characterization of plastic contaminants

A detailed dataset was generated on the material, form, type, and characteristics of the plastics and other physical contaminants ($n = 404$ items) observed across FW samples; these data are available online (Park and Babbitt 2026). Results presented here summarize key trends observed.

One of the main findings was that the distribution of contaminant material was highly variable across some generators, particularly post-consumer samples obtained from school and office cafeterias, but relatively consistent across others, particularly households and pre-consumer samples from food preparation in cafeterias and restaurants (figure 3). In many cases, composite plastic materials represented the highest mass contribution and most frequently observed contaminant type. These composites typically included plastic coated paper serve ware, produce stickers that contained a paper label, polymer adhesive, and plastic coating, and multi-layer polymer films (often seen in single-serve snack bags). Multi-layer films typically contained a metal foil sandwiched between outer and inner layers made up of varying combinations of polypropylene (PP), low density polyethylene (PE), polyethylene terephthalate (PET), and ethylene acrylate (EA).

In food service establishments, polyvinyl chloride (PVC) cling wrap and gloves worn by workers were commonly observed in the FW stream. When present, gloves represented between 10% and 100% of the sample's contaminant mass. PE contaminants typically included plastic produce bags, resealable bags, and thin films used during food preparation and service. PP and PET contaminants were commonly observed in post-consumer FW samples and included plastic utensils, straws, condiment containers, and portioning cups. A small number of 'other' plastics were observed, including rubber fasteners and bands, polyamide packaging, and expanded polystyrene (Styrofoam) cups. The other category shown in figure 3 also includes a limited number of metal items that included aluminum can ($n = 1$), discarded foil ($n = 6$), and staples ($n = 3$).

These results primarily focus on contaminant mass, as a driving factor in downstream magnitude of plastic release from FW management. However, the total number of contaminants present is also relevant, and potentially indicative of opportunities for preventing plastics from entering the food system or improving source separation prior to FW processing. To illustrate this issue, figure 4 compares the disaggregation of materials by mass and by number of items for the pooled samples from generators with distinct contamination patterns: the office cafeteria (post-consumer) and the university cafeteria (pre- and post-consumer). In the case of the university cafeteria, composite materials have a much larger presence by count than by mass, because this material category is primarily made up of small produce or 'price look up' stickers. Across the entire pooled sample of contaminants at all FW generators, produce stickers are less than 1% by mass but make up almost 30% by item count ($n = 116$ stickers). By nature of their size, design, and material composition, produce stickers are difficult and time-consuming to remove at the point of FW separation and do not fully degrade in downstream FW processing (Whitney 2024).

On the other hand, some common contaminants, such as gloves from pre-consumer food processing and PET packaging from post-consumer discards, are observed at relatively low frequencies, but make

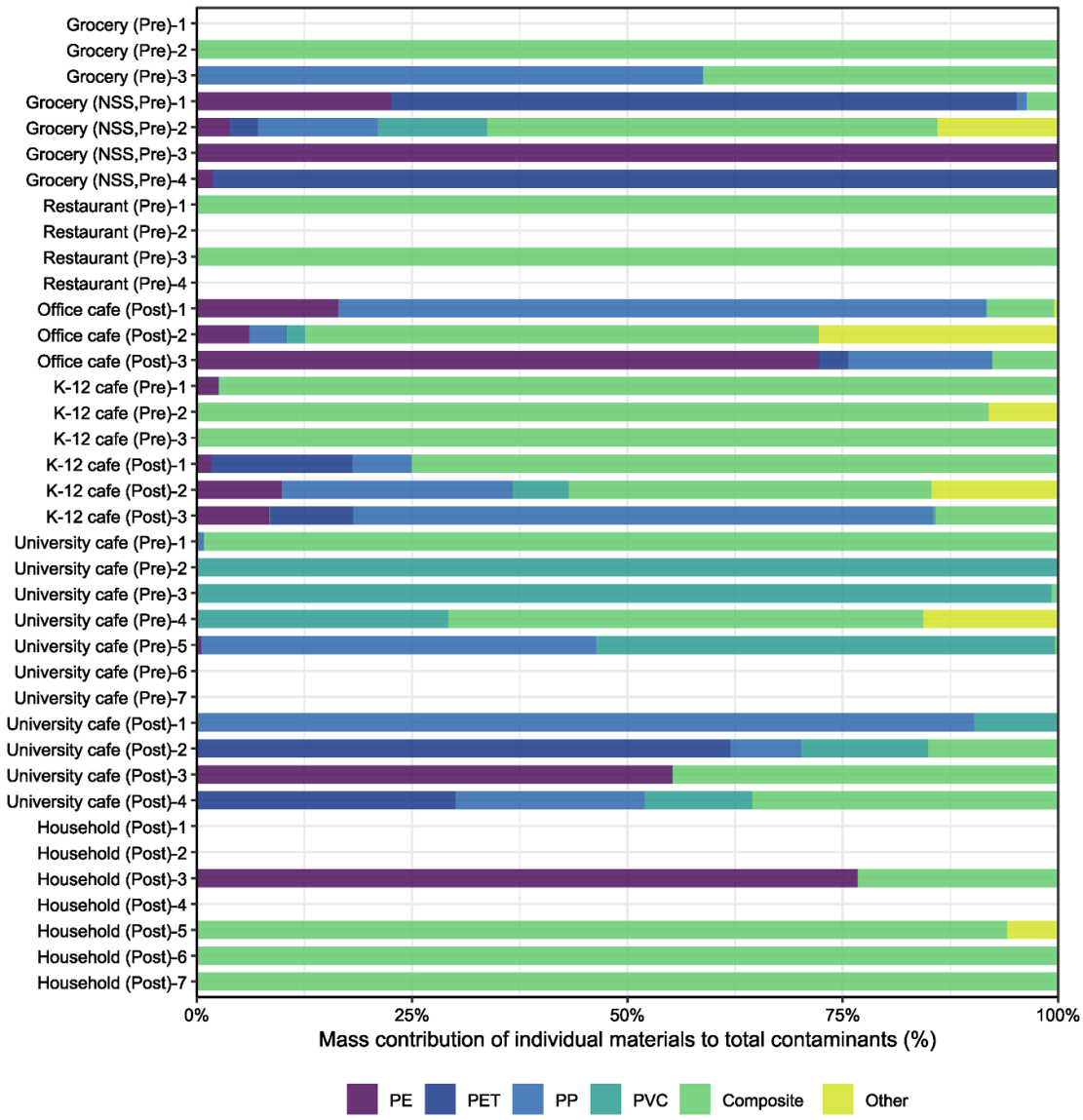


Figure 3. Mass breakdown of contaminants found in each FW sample by generator. Blank lines represent samples with no contaminants identified. PE: polyethylene; PET: polyethylene terephthalate; PP: polypropylene; PVC: polyvinyl chloride; Composites: mixed polymers (multi-layer films) and plastic-coated paper materials; Other: infrequently observed materials, primarily rubber and aluminum. Cafe: cafeteria; NSS: non-source separated; Pre: pre-consumer; Post: post-consumer.

a high contribution by mass to the total contaminant sample (figure 4), by nature of their individual size and mass. For the office cafeteria, mass and frequency were relatively consistent, because commonly observed contaminants here tended to also be larger and higher weight, including plastic-coated paperboard boxes and single-serve plastic packaging. The photographs presented in figure 5 further illustrate the variability in contaminants for these three sources of FW samples.

These images also help convey the challenges in determining a standard contaminant profile by generator type. For example, PVC gloves were observed both in pre-consumer samples, originating from food preparation activities, and post-consumer samples, discarded from employees cleaning the dining area. Contaminant profiles may also be skewed by infrequent occurrence of much larger items. For example, most PP items in the university cafeteria samples were small plastic ties and labels (0.01 g item^{-1}) but a single PP drink lid (12 g item^{-1}) made up about 50% by mass of contaminants in that specific sample. While no statistical analysis is possible due to small sample size by generator, a summary of the pooled data for all samples underscores some of the common distinctions between contaminant material, source, and form (table 2). Detailed data for all generators is provided in the online dataset.

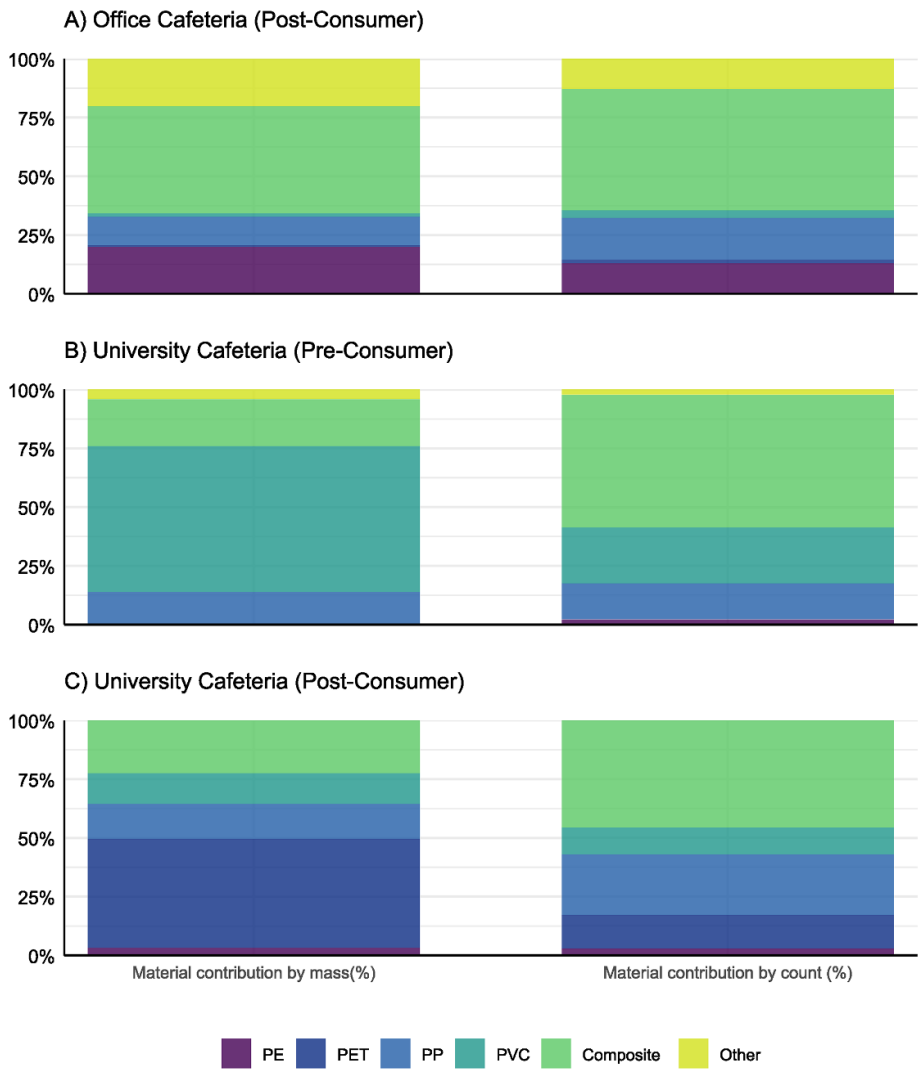


Figure 4. Analysis of contaminant mass and counts for pooled samples from (A) office cafeteria (post-consumer, $n = 62$ items, 148 g of contaminants), (B) university cafeteria (pre-consumer, $n = 46$ items, 87 g of contaminants), and (C) university cafeteria (post-consumer, $n = 35$ items, 97 g of contaminants).

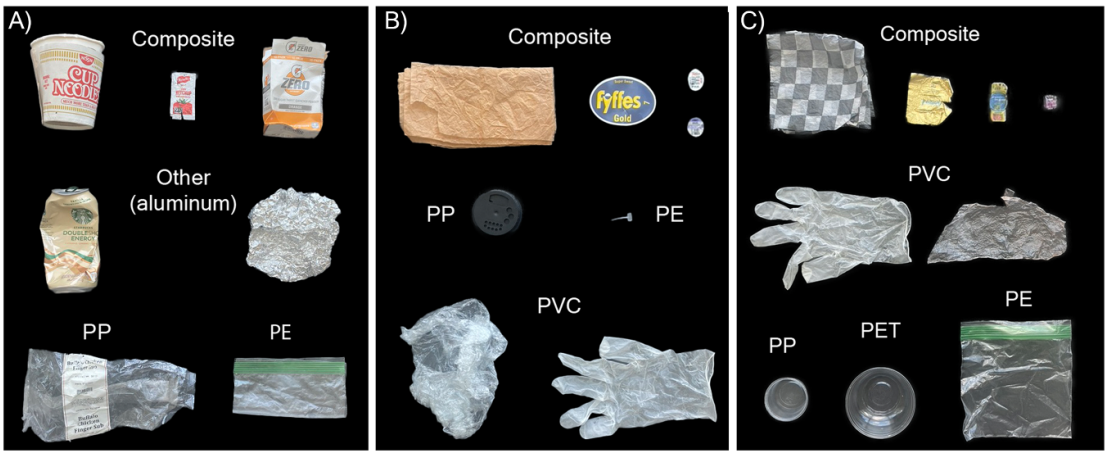


Figure 5. Examples of contaminant sources and materials. Select items are used to illustrate the variability within samples across different types of FW generators: (A) office cafeteria (post-consumer), (B) university cafeteria (pre-consumer), and (C) university cafeteria (post-consumer). Photos taken by the authors.

Table 2. Summary of contaminant category, form, and material relative to the total pooled sample mass (1280 g) and number (n = 404) of items from all food waste samples and generators.

	Mass		Count	
Contaminant category	g	%	n	%
Coated paper	548	43%	82	20%
Plastic container	255	20%	31	7.7%
Plastic packaging	122	9.5%	34	8.4%
Composite packaging	119	9.3%	36	8.9%
Plastic film	78	6.1%	29	7.2%
Glove	72	5.6%	15	3.7%
Metal packaging	34	2.7%	10	2.5%
Other	27	2.1%	43	11%
Plastic utensil	21	1.6%	8	2.0%
Produce sticker	4.7	0.37%	116	29%
Contaminant Form				
Thin, flexible	828	65%	338	84%
Thin, semi-rigid	339	27%	55	14%
Thick, semi-rigid	92	7.2%	3	0.7%
Thin, rigid	21	1.6%	8	2.0%
Contaminant Material				
Composite	689	54%	241	60%
PET	214	17%	25	6.2%
PE	132	10%	30	7.4%
PP	95	7.4%	58	14%
PVC	86	6.8%	28	6.9%
Other	64	5.0%	22	5.4%

4. Implications for downstream impacts and contaminant management

Results show that plastic contamination is common and widespread in FW collected across different types of generators, even when source separation processes exist. In some cases, the observed contaminants are small, poorly visible, and adhered to or combined with food being discarded. In many cases, however, the contaminants were relatively large, distinct, and highly visible items that could be feasibly identified and removed from the FW stream. Many of the generators from which samples were obtained have stated sustainability and FW recycling commitments, some are required by regulation to divert FW from landfills, and most have been participating in source separation programs for several years. Thus, these findings suggest that without further interventions, plastic contaminants will continue to appear in the FW stream and may limit the full potential of valorization pathways for diverting waste from landfill and producing high-quality agricultural products.

A summary of potential impacts arising from plastic contamination in FW management systems is shown in table 3, mapped to the commonly occurring contaminants documented in this study. Presence of contaminants may negatively impact the operational efficiency and performance of common FW valorization technology. Potential impacts may be linked to the physical form of the contaminant and its interaction with FW conveyance and processing equipment, the chemical composition of contaminant material and its impact on the biological processes involved with composting and AD, or the potential for materials to carry over into FW valorization byproducts and reduce quality or create ecological risks.

4.1. Technical and economic impacts

Plastic contaminants can influence economic costs and profitability of valorization systems. A FW hauler who supported this study noted that when they receive materials that are determined on visual inspection to have high contamination rate (a judgement by the worker), the entire bin or bag of material is discarded, thus wasting the labor and transport costs of collecting materials that will not be processed and adding waste management costs from tipping fees levied on materials that must then be landfilled. Contaminants that are relatively large can be removed manually (by hand) or through automated mechanical processes, including depackaging, screening, shredding, grinding, or other forms of physical separation (Weithmann *et al* 2018, U.S. EPA 2021, Yang *et al* 2022), but such steps add costs, time,

Table 3. Potential economic and environmental impacts of plastic contamination in food waste management.

Downstream impacts	Relevant FW contaminants	References
Damage to equipment and operational down time due to flexible materials that wrap around stirrers, clog pumps, and impede operation	Cling wrap, thin films, gloves, resealable bags	Frear *et al* 2012, Kakadellis *et al* 2021, Gilbert and Ricci-Jurgensen 2023
Damage to equipment from hard, rigid, or abrasive materials	Aluminum cans, plastic utensils	Dalke *et al* 2021, Gilbert and Ricci-Jurgensen 2023
Inability to degrade composite materials during FW processing; lack of alternate management pathways due to poor recyclability	Multi-layer films and composites (e.g. snack bags, milk cartons)	Brinton *et al* 2018, Soares *et al* 2022, Hobson *et al* 2025
Formation of microplastics, reduced product quality and value, potential downstream ecological impacts	PET packaging, containers, and utensils	Friege and Eger 2021, Porterfield *et al* 2023a, Whitney *et al* 2025
Inhibition of methane production during anaerobic digestion due to presence of fossil-derived polymers, reduced economic profits.	Cling wrap, gloves, plastic bags, plastic cups and containers	Lim *et al* 2018, Wei *et al* 2019, Wang *et al* 2022, Tang *et al* 2022, Zhang *et al* 2022, Wang *et al* 2023, Yang *et al* 2025, Xiao *et al* 2026
Widespread occurrence and persistence of small, coated stickers that are difficult to separate and remain in FW valorization products.	Produce stickers	U.S. EPA 2021, Groß *et al* 2024, Whitney 2024

and labor, may require investment in costly capital equipment (Gilbert and Ricci-Jurgensen 2023), and can ultimately erode profitability. For example, an analysis of 10 composting operations across the U.S. found that firms spend up to $45 per ton of processed FW to manage contamination, representing an average of 21% of their total operating costs (Barry *et al* 2024).

Broader public and policy concerns over contamination and potential health risks may also limit the potential market for and revenues from compost and other bio-products sold for agricultural applications (Weithmann *et al* 2018, Friege and Eger 2021). While the persistence of identified contaminants through the composting process is poorly understood (Zhang *et al* 2025), the range of values observed here in the FW feedstock (figure 2) is greater than most existing policy limits for finished compost. In New York State, compost products may not contain more than 2% (dry mass basis) of physical contaminants (NYS 2022). In the EU, regulations dictate no more than 0.5% contamination by non-degradable materials (glass, metal, plastic), with a limit of 0.3% for any individual type of material (European Union 2019). The threshold for plastics is set to be reduced to 0.25% in 2026 (European Compost Network 2021). While there are currently no regulations on microplastics, compost has been identified as a source, potentially accounting for up to 5% of all microplastics emissions in Germany (Bertling *et al* 2018). Thus, any future regulations on microplastics could similarly inhibit compost sales and use, without interventions to minimize and manage plastic contamination.

4.2. Downstream environmental impacts

While this study does not examine the fate of plastic contaminants after FW valorization, past work suggests that these materials will persist and be retained in compost and digestate products that are used in agricultural and environmental applications (Groß *et al* 2024, Whitney 2024). Composting may cause larger plastic contaminants to break down into microplastics (Zhang *et al* 2025), and even films marketed as compostable may persist through industrial composting, entering the soil where they break down into microplastics (Accinelli *et al* 2020). The downstream use of compost is therefore expected to be a source for microplastic releases (Vithanage *et al* 2021, Porterfield *et al* 2023a), which can lead to wide-ranging impacts on agricultural systems (Shimly *et al* 2025). Microplastics from organic amendments can accumulate in soils with repeated application to fields (Colombini *et al* 2022), where they may be taken up by crops, reduce plant productivity, facilitate uptake of heavy metals, and negatively impact soil microbial and arthropod communities (Bello *et al* 2025, Srećkov *et al* 2025). Microplastics in agricultural soils may preferentially erode with run off (Rehm *et al* 2021, Naderi Beni *et al* 2023), entering downstream waterbodies and leading to a suite of negative impacts (Rashid *et al* 2025).

While literature has established that FW valorization byproducts can transport plastics into agricultural systems (Whitney *et al* 2025), it is difficult to forecast downstream microplastic load that would be directly attributable to plastic contaminants observed in this study. Some primary microplastics may be introduced with food items (Sewwandi *et al* 2023, Thompson *et al* 2024), already be present on site (Lwanga *et al* 2023), or be generated from agricultural plastics that are used in the same locations (Malarkey and Babbitt 2025). In addition, fully characterizing downstream impacts of contaminants is challenging because microplastics are considered a suite of contaminants (Rochman *et al* 2019), with impacts that vary across different polymer types (Chomiak *et al* 2024).

4.3. Opportunities to minimize and manage plastic contaminants

To prevent these economic and environmental impacts and improve the overall sustainability and feasibility of FW valorization, it is critical that interventions be developed to minimize plastics contaminants entering FW streams. Results presented here underscore the importance of efforts to improve the education, awareness, and training of consumers and workers involved in source separating FW to reduce contamination from the start. Past research and applied studies suggest that such interventions should include consistent and regular training of workers (Hall *et al* 2023), the use of clear signage and FW collection bin labels that show accepted materials (Buckland *et al* 2025), and provision of information about the composting process and importance of a clean FW stream (Matthews *et al* 2025, Oehman and Babbitt 2026). However, these interventions are typically not effective as one-time endeavors, and instead require continuous outreach and education to reinforce the message (Shah and Lipson 2025a, 2025b), routine feedback on common contaminants and intermittent contamination events, and systemic change to empower staff involved in work processes linked to contamination (Hall *et al* 2023). Evidence from successful FW intervention projects shows the importance of engaging frontline workers in developing solutions and providing clear, consistent training that connects worker efforts with company values and incentives (Harper *et al* 2024).

Economic and policy interventions are also required to prevent or reduce plastic contaminants entering FW valorization systems and downstream products. Economic incentives or costs tied to contamination, similar to pay-as-you-throw models, may be required to ensure necessary quality in FW streams (Friege and Hentschel 2026). For example, composting firms and municipal programs may levy surcharges or fines on heavily contaminated loads of FW feedstocks (Coker 2017, BioCycle 2025) to encourage separation by the generator and help offset costs of managing contamination. In parallel, policy can play a key role by establishing quality requirements and contamination limits for the use of compost and other organic amendments (Cesaro *et al* 2015, Friege and Eger 2021). For example, the E.U. sets forth mass-based limits on the relative amount of plastic allowable in finished compost (European Union 2019), and some states in the U.S. are developing similar standards (Wallace 2026).

Even with aggressive economic action and policy limits, some degree of the plastic contamination observed here is likely unavoidable, particularly small, lightweight materials like produce stickers, which are hard to identify and separate from food materials. At present, there is growing interest in eliminating produce stickers by directly labeling fruit and vegetables with lasers (Khadka *et al* 2024) or water-soluble inks (Kim *et al* 2024) or by requiring produce stickers to be fully degradable in home composting systems (Saldaña-Pierard *et al* 2025). Some countries are banning plastic packaging and food labels and/or mandating use of compostable materials (Audran 2021, Parkinson 2021, NZ Ministry for the Environment 2024). In the U.S., a few states are considering regulatory mandates for compostable produce stickers, but have not yet enacted requirements due to concerns over cost, availability, and food safety (Greene Economics 2025, Washington State 2025). Similar policy efforts may also help mitigate concerns about the 'compostable' plastics that were commonly observed in this study, which may not actually be fully degradable in FW valorization systems. Italy has demonstrated success with an extended producer responsibility system that requires collection of FW in containers and bags that meet rigorous compostable certification standards and then closely monitors compost quality and material degradation (CIC 2021, Centemero *et al* 2024).

However, there are still broader uncertainties about the feasibility, effectiveness, and sustainability of universally mandating the use of bio-based and compostable materials in food systems. Not all bioplastics are fully compatible with existing FW processing technology (Kakadellis *et al* 2022), and thus greater coordination between food system stakeholders is required to standardize or certify materials that are biodegradable in composting or AD systems (Kakadellis *et al* 2021). Further, any evaluation of biodegradable or compostable plastic options must consider the benefits of contamination reduction relative to the broader life cycle sustainability impacts of their production, adoption, and end-of-life management (Hobbs *et al* 2021, Piao and Yao 2026).

An alternative perspective is that complete elimination of contaminants in FW streams may simply be infeasible, given the complex array of materials, plastic products, and interactions with food products and the food system workforce. There is a need to pursue parallel development of FW management technologies that are better suited for handling contaminated FW and that may be able to create new products and value streams (Armington *et al* 2018). For example, pyrolysis is a well-established process that involves heating organic feedstocks to high temperature, typically 500 °C–800 °C, in the absence of oxygen to create multiple co-products including bio-oil, hydrogen-rich syngas and carbonaceous biochar. Several studies have shown that co-pyrolysis of biomass with small amounts of plastic (<10% by mass) does not negatively affect the conversion process and may in fact enhance important physical properties of biochar and bio-oil (Cisse *et al* 2022, Hilber *et al* 2024, Deng *et al* 2025). Further research is needed to fully understand the properties of outputs generated by co-pyrolysis of FW with the various plastic wastes outlined in this study, especially when the primary objective is to produce biochar as an agricultural soil amendment.

5. Limitations and future research needs

The results reported herein reflect extensive data collection but are specific to FW samples collected from generators operating in an urban region in Western New York State. While the specific categories of generators included represent those responsible for the most FW on both a national and local scale, the individual amounts and contaminant profiles at each location may not be indicative of national or global trends. The most comparable benchmarks are municipal waste audits and contamination studies, although these efforts are usually designed around assessing or improving specific local programs. As a result, contamination data are reported in different units, mass bases (wet vs dry), or material categories, making generalization difficult. While municipal studies in Seattle, WA and Scotland documented slightly higher rates of paper, glass, and metal contaminants than observed here, they found similar levels of overall plastics in residential streams (Aspray and Tompkins 2019, Cascadia 2023). Research in Maine documented lower incidence of samples containing contaminants (57% compared to 80% here) but observed similar trends where the greatest prevalence of non-food items were observed in residential and food service settings (Thakali *et al* 2022). The challenges in benchmarking across contamination studies suggest a future opportunity to develop frameworks and protocols for standardized measurement and characterization of FW contaminants.

Other uncertainties may arise due to sampling at generators who actively participate in FW diversion programs, as results may underestimate the potential for contamination at generators where individuals carrying out source separation tasks have less familiarity, experience, or engagement with FW management practices. Contaminant categorization was strongly influenced by what regional FW valorization companies will accept, including compostable plastics, and may vary according to what other municipalities or private firms deem to be acceptable in their process. However, the underlying data are provided online with sufficient detail and disaggregation such that others could reanalyze findings with custom contaminant lists. The sampling process was designed to obtain random and representative samples from each generator across a period of time, but given underlying variability in FW generation (Armington *et al* 2020), results from individual sources could fluctuate seasonally or under unusual circumstances, an issue that requires greater study for contaminants and FW estimates in general.

Developing more comprehensive and representative contamination data will ultimately require increased sampling. However, hand separation, sorting, and characterization of contaminants from heavy, wet, and often odorous organic waste streams can be physically challenging and is time- and labor-intensive. There is clearly an opportunity for new technologies, particularly those leveraging AI-based classification algorithms, to enhance data collection on contaminants and foster plastic removal and management (Ali *et al.* 2026). For example, the use of hyperspectral imaging and machine learning shows significant potential for accurate identification and classification of plastic contaminants entering FW systems (Taneepanichskul *et al* 2025, Bhattarai *et al* 2026). Continued research in this area will be key to ensuring such technologies can reliably identify and differentiate plastic contaminants at the volume and degree of variability found in full-scale FW management systems.

6. Conclusions

Of the 38 samples collected from nine different types of commercial, institutional, and residential FW generators, over 80% contained plastic contaminants. The material composition, form, and source of

these contaminants varied widely across generators, but typically included food packaging (bags, wraps, condiment containers, plastic-coated paperboard), serve ware (plastic utensils, straws, and portion cups), food preparation items (gloves, cling films, fasteners), and food labeling (fruit and vegetable stickers, labels, and tags). FW streams also commonly contained compostable plastics, which were accepted by FW facilities engaged on this project, but which may be contaminants in other regions. The majority of contaminants were items that could be easily identified on visual inspection and readily removed during FW source separation. The fact that so many of these materials still enter the FW stream underscores the need for upstream interventions, including increased education and engagement of frontline workforce and consumers involved with source separating materials as well as policy and economic mechanisms that reduce overall amounts of plastic used in the food system. If the observed plastic contaminants enter FW valorization processes, they may create technical and economic challenges to FW management and may also become a source for downstream microplastic releases to agricultural soil and freshwater ecosystems. Proactive solutions are required to reduce these risks and enhance the overall sustainability of food systems and FW management.

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Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.6084/m9.figshare.31215619 (Park and Babbitt 2026).

Author contributions

Jennifer Park 0009-0000-9321-956X
Data curation (lead), Formal analysis (lead), Investigation (equal), Methodology (equal), Visualization (equal), Writing – original draft (lead)

Callie W Babbitt 0000-0001-5093-2314
Conceptualization (equal), Funding acquisition (lead), Investigation (supporting), Visualization (equal), Writing – original draft (equal), Writing – review & editing (lead)

Nathan C Eddingsaas 0000-0003-1539-5415
Investigation (supporting), Methodology (supporting), Validation (supporting), Writing – review & editing (equal)

Anna Christina Tyler 0000-0002-7845-995X
Investigation (supporting), Methodology (supporting), Validation (equal), Writing – review & editing (equal)

Thomas A Trabold
Conceptualization (equal), Investigation (supporting), Methodology (supporting), Writing – review & editing (equal)

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