CLOSED LOOP partners
CENTER FOR THE CIRCULAR ECONOMY

COMPOSTING CONSORTIUM

# BREAKING IT DOWN

## THE REALITIES OF COMPOSTABLE PACKAGING DISINTEGRATION IN COMPOSTING SYSTEMS

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# About the Center for the Circular Economy & the Composting Consortium

## About Closed Loop Partners

Closed Loop Partners is at the forefront of building the circular economy. The company is comprised of three key business segments. Closed Loop Capital Management manages venture capital, buyout and catalytic private credit investment strategies on behalf of global corporations, financial institutions and family offices. The Center for the Circular Economy unites competitors and partners to tackle complex material challenges and implement systemic change to advance circularity. Closed Loop Builders focuses on incubating, building and scaling circular economy infrastructure and solutions across the U.S. Closed Loop Partners is based in New York City and is a registered B Corp. For more information, please visit www.closedlooppartners.com.

## About the Center for the Circular Economy

The Center for the Circular Economy ('the Center') is the innovation arm of Closed Loop Partners. The Center executes research and analytics, unites organizations to tackle complex material challenges and implement systemic change that advances the circular economy. The Center for the Circular Economy's expertise spans circularity across the full lifecycle of materials, connecting upstream innovation to downstream recovery infrastructure and end markets.

## About the Composting Consortium

The Composting Consortium, managed by the Center for the Circular Economy at Closed Loop Partners, is a multi-year industry collaboration on a mission to build a world where organics are kept in circulation. The Consortium advances composting infrastructure and the recovery and processing of food-contact compostable packaging and food scraps in the U.S., to reduce food waste and mitigate climate impact. The Consortium brings together leading voices across the composting and compostable packaging value chain—from the world's leading brands to best-in-class composters running the operations on the ground. Through in-market tests, deep research and industry-wide collaboration, the Consortium is laying the groundwork for a more robust, resilient composting system that can keep food waste and compostable packaging in circulation.

## Acknowledgments

This project was made possible thanks to the collaboration and partnership of many organizations. The Composting Consortium's funding partners enabled the work while our industry partners including the US Composting Council (USCC), Biodegradable Products Institute (BPI), U.S. Plastics Pact and several other advisory partners including Compostable Research and Education Foundation (CREF) and BioCycle Associates supported the vision and project planning.

The Composting Consortium commissioned Resource Recycling Systems (RRS) and the Compostable Field Testing Program (CFTP), who co-developed our methodologies to carry out the field work and data analysis. The charts and graphs in this report were created by RRS who led the field data analysis. Our study would not have been possible without the committed participation of 10 compost facilities and their dedicated staff, who collected field data and welcomed our field teams onsite. An enormous thank you to our Compost Partners who participated in this study: Atlas Organics, Napa Recycling & Waste Services, Specialized Environmental Technologies, Windham Solid Waste Management, Black Earth Compost, Ag Choice Organics Recycling, Happy Trash Can Compost, Veteran Compost and Dayton Foodbank. Furthermore, this project involved lab-based sample analysis by Soiltest Farm Consultants and the RRS Lab Team.

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# Executive Summary

**The escalating issue of conventional plastic packaging waste has catalyzed innovation in reusable, recyclable, and compostable packaging solutions. However, the plastic waste dilemma is complex and there is no one-size-fits-all solution. This study analyzes the compatibility of certified compostable packaging with the diverse composting systems operating across the U.S. today, and highlights the nuanced approach needed to effectively recover this packaging type.**

Choosing the appropriate solution depends on the specific packaging application, format and regional context, such as the available recycling or composting infrastructure. While recycling and reuse remain important strategies, this report focuses on compostable packaging, a rapidly growing sector fueled by public demand for sustainable alternatives to single-use plastic.

Most of the United States lacks access to food scraps composting programs, which limits the ability to divert compostable packaging, as it is typically collected alongside food scraps. About 145 large-scale composters across the U.S. currently accept and process some format of food-contact compostable packaging[1], with the understanding that accepting these materials helps bring in more food waste to their facilities. However, for compostable packaging to reach its full potential, robust infrastructure for accepting and processing both food scraps and associated packaging is crucial.

This report explores a question not well served by existing data: **how well do diverse formats of certified, food-contact compostable packaging actually break down in real-world composting facilities?** Previously, scant information existed publicly on the performance of certified, food-contact compostable packaging, particularly around the composting operations environment (i.e., compost pile temperature, moisture, pH, etc.) present during the test. To fill a critical data gap on how certified, food-contact compostable packaging breaks down in real-world composting conditions, the Composting Consortium launched an 18-month study—the largest known field test of certified compostable packaging conducted in North America.

“The Composting Consortium seeks to replace anecdotes with data and opinions with insights, which can drive discussions, decisions and policymaking that will shape a more sustainable and circular future for composting and compostable packaging industries.”

More than 23,000 units of packaging were tested, encompassing 31 types of individual fiber and compostable plastic packaging and products, across 10 diverse composting facilities. This study is unique because it measured the disintegration of compostable packaging and products by mass and by surface area and took stock of the compost operating conditions that were present in the compost piles. This allowed the Composting Consortium to report not only on the disintegration performance of the packaging, but also comment on the operating conditions that best support disintegration of various materials.

The Composting Consortium was launched with a vision to scale food waste composting infrastructure that includes compostable packaging in the United States. The goal of our Compostable Packaging Disintegration Pilot, summarized in this report, is to improve the success of compostable packaging in commercial composting environments. By understanding how these materials break down under various conditions, researchers can provide insights for brands, packaging manufacturers, composters and policymakers.

The Composting Consortium, in collaboration with its brand and industry partners, the US Composting Council, the Compostable Field Testing Program and other groups, will leverage these findings to help inform policymaking around compostable packaging, update best management practices for composting facilities and shape a field test standard for evaluating compostable packaging disintegration at composting facilities. Data from this study will be donated to the Compostable Field Testing Program (CFTP), which will later launch an open-source database on the disintegration of compostable packaging. Additionally, the study aims to support a field-test standard under development with ASTM International for evaluating compostable packaging disintegration at composting facilities. These publicly available results will replace anecdotes with data to guide discussions and policies shaping a more sustainable future for composting and compostable packaging.

## TOP 10 TAKEAWAYS

**1** Our study evaluated the disintegration of over 23,000 units of compostable packaging at ten commercial composting facilities across the U.S.

**Data shows certified food-contact compostable packaging successfully disintegrates at commercial composting facilities that meet reasonable operating parameters* (e.g., moisture, temperature, oxygen).**

**2 On average, compostable plastic packaging and products broke down 98% by surface area when composted.****

This exceeds the 90% minimum threshold for disintegration established by compost industry groups.***

**3 Compostable plastic broke down successfully regardless of composting method or compost process time.**

We tested compostable plastic products across windrow, aerated static pile (ASP), covered ASP, and in-vessel composting technologies, which had varying processing timeframes.

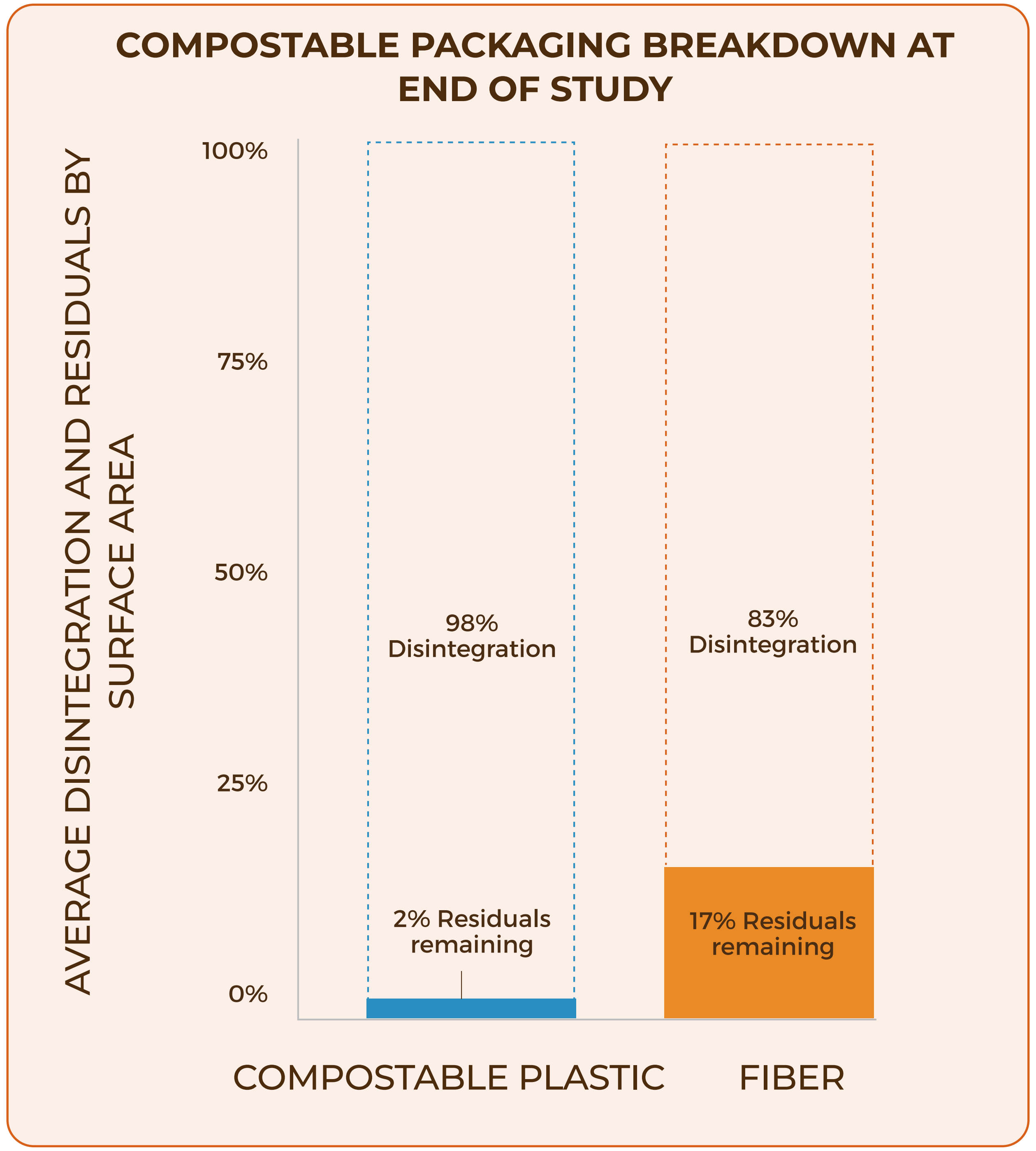
**4 On average, compostable fiber packaging and products broke down 83% by surface area when composted.****

This exceeds the 80% minimum threshold for disintegration established by compost industry groups.***

**5 Agitation helps fiber break down in compost piles.**

Facilities that utilize mechanical turning or agitation (e.g., windrow or in-vessel) broke down fiber materials more effectively than facilities that did not incorporate agitation.

**EXECUTIVE SUMMARY FIGURE 1. AVERAGE RESIDUALS AND DISINTEGRATION FOR FIBER AND COMPOSTABLE PLASTIC PACKAGING AT ENDPOINT**




* Reasonable operating conditions defined in Table 2.1 of *The Composting Handbook*.
** Data corresponds to mesh bag results only.
*** Compost Manufacturing Alliance (CMA) is a composting industry group that uses in-field disintegration thresholds, which are specific to each compostable material (i.e., compostable plastic, fiber)

## TOP 10 TAKEAWAYS (CONTINUED)

### 6 Consistent moisture levels above 50% support the disintegration of fiber packaging and products.

Facilities that had weekly moisture measurements above 50% saw greater fiber disintegration than those with fewer readings below this threshold.

### 7 It's critical that brands, packaging manufacturers, and the compost industry reevaluate composting best management practices to support composters who accept compostable packaging.

The operational data collected from the Composting Consortium's study can be used to start that process.

### 8 All compostable products in the Composting Consortium's Disintegration Study had notably higher disintegration under the dose method compared to the mesh bag method.

This suggests that either the mesh bag method may result in a conservative disintegration result and/or the dose method may result in an overestimate of packaging disintegration.

### 9 We recommend brands advocate for surface area measurements when testing their compostable products and packaging at compost facilities.

In the case of field testing, surface area serves as a more pertinent metric for gauging the disintegration of compostable packaging in contrast to weight because it directly correlates with composters' concerns, namely, the visible presence of packaging within the pile.

### 10

Successful disintegration of compostable packaging alone is not enough to ensure widespread acceptance of these new materials.

**Widespread adoption requires collaboration across the value chain, starting with clear labeling of compostable and non-compostable packaging, as well as investing in the appropriate infrastructure to collect these materials.**

# INTRODUCTION

## INTRODUCTION

**Conventional single-use plastic packaging waste remains a significant environmental challenge that consumer-packaged goods companies, NGOs, policymakers and investors have been tackling for over a decade.**

A suite of solutions is necessary to address the scale of the challenge, from upstream innovation around packaging design and reduction, to the innovation of reusable, recyclable and compostable packaging that is truly recoverable and recovered. Determining whether packaging in any of these formats will be recovered depends on several factors: the regional context, whether urban or rural, commercial or residential, what recycling or composting infrastructure is present and how developed the recovery markets are. This report delves into one growing alternative sought out to reduce single-use plastic waste: compostable packaging.

The market for compostable packaging is experiencing a surge, growing 4x faster than conventional plastic packaging, and projected to grow 16% year-over-year until 2032 according to PMMI and Ameripen.[2] This surge is driven by growing environmental awareness and the desire for sustainable alternatives to traditional plastic packaging. Compostable packaging exemplifies material innovation that holds promise, particularly for applications that support diverting food waste from landfills to composting facilities. However, for compostable packaging to reach its full potential, a robust infrastructure capable of accepting and processing these materials is crucial.

Success in the composting realm hinges on three key factors. First, compostable packaging should act as a vehicle to divert food waste from landfill and towards composting sites. This diversion offers several environmental and economic benefits including saving tax-payer dollars by reducing the amount of food waste sent to landfills where it emits methane[3] and instead creating valuable organic matter (i.e., finished compost) known to sequester carbon, improve soil health and reduce water runoff.[4] Second, composters should be adequately incentivized to accept these new materials into their process, and compostable packaging needs to be compatible with a diverse range of composting technologies.[5] Composting facilities employ various methods, from static pile composting to in-vessel systems, each with its own specific operating parameters and processing timeframes (e.g., 45 days to 180 days). Finally, the disintegration process of compostable packaging must not negatively impact the quality of the finished compost.[6] High-quality compost is essential for its marketability and plays a crucial role in maintaining healthy soils and promoting sustainable plant growth. Failure to meet this final criterion can create additional challenges for composting facilities and undermine the overall value proposition of compostable packaging.[7]

Packaging manufacturers and brands are actively developing new packaging materials and designs aligned with these critical needs. This report aims to contribute to the ongoing research effort, fostering the successful integration of compostable packaging into existing systems. By achieving this goal, we can significantly increase food waste diversion to composting facilities across the U.S. **This report will analyze the disintegration rates of various compostable packaging types–including compostable plastics like PLA and PHA, alongside compostable fiber products like paper plates and cups–within large-scale industrial composting environments.**

# PART 1.
# OUR STUDY OBJECTIVE AND METHODOLOGY

## WHY WE FIELD-TESTED COMPOSTABLE PACKAGING

Beginning in the Fall of 2022, the Composting Consortium and its partners launched an 18-month study to investigate the disintegration of food-contact compostable packaging items at a variety of full-scale composting facilities. Our team undertook this body of work recognizing a critical data gap in two areas. First, there was scant publicly available information on the performance of certified compostable packaging in "real-world composting conditions," and second, where disintegration information existed, the information did not include information about the composting conditions that created the disintegration result.

Our brand, packaging and compost partners committed at the onset of this project to making the results of the study public, in the interest of delivering objective results. By making the results of our study publicly available, we seek to replace anecdotes with data and opinions with insights, which can drive discussions, decisions and policymaking that will shape a more sustainable and circular future for composting and compostable packaging industries.

> "The Composting Consortium seeks to replace anecdotes with data and opinions with insights, which can drive discussions, decisions and policymaking that will shape a more sustainable and circular future for composting and compostable packaging industries."

### Objectives of the Compostable Packaging Disintegration Study

1. Test a wide variety of certified compostable materials and packaging to understand how they break down in various environments, facilities and with different composting technologies.

2. Provide insights and recommendations for composters, consumer goods brands and packaging manufacturers to improve the success of certified compostable packaging in commercial composting environments.

3. Support the development of a standard in field test method for evaluating the disintegration of compostable items at compost facilities. This standard continues to be developed within ASTM International, and our study served as the first testing period that piloted the draft in-field standard for ASTM Technical Committee WK80528.

4. Generate a large-enough dataset to contribute to the creation of an open-source database of compostable packaging disintegration results; the open-source database will be housed by the Compostable Field Testing Program.

## WHERE AND WHAT WE TESTED

### Composter Selection: Engaging Best-in-Class Compost Partners

Meeting our study objectives required working with a diverse set of composters that covered a range of geographies, climates and composting methods (i.e., aerated static pile, covered ASP, windrow, etc.). The Consortium partnered with 10 composters, all of whom currently accept and process certified food-contact compostable packaging. As part of the selection process, the team confirmed that each of the facilities consistently met the operating parameters outlined in the Compost Research and Education Foundation's (CREF) *The Composting Handbook,* which is well-regarded by the industry to reflect "best in class" operating guidelines.[8]

Pre-requisites for inclusion in the study included meeting reasonable ranges for compost operating conditions during the first stage of composting. Figure 1 offers details on the facilities in our study, their composting method, the field test method they utilized and the total number of days compostable packaging was in-field at their facility (as dictated by their unique operating process).

### What are reasonable and preferred ranges for composting conditions?

| Operating Parameter | Reasonable Range | Preferred Range |
|---|---|---|
| **C:N** | 20:1-40:1 | 25:1-30:1 |
| **Moisture** | 40-65% | 50-60% |
| **Oxygen** | > 5% | Much greater than 5% |
| **Particle Size** | 1/8-1/2 | Varies |
| **pH** | 5.5-9.0 | 6.5-8.0 |
| **Temperature** | 110°-150° F | 130°-140° F |

Source: Adapted from Recommend Conditions for Rapid Composting outlined in *The Composting Handbook* (Rynk, et al., 2022).

Our team collected field data from each composter and analyzed the data across various contributing factors noted in the table above. Overall the composters' temperature, moisture, oxygen, bulk density, pH and C:N data fell within reasonable or preferred ranges. No facility's data fell far enough outside expected ranges and trends to indicate that a particular field test's results could be considered invalid. Furthermore, the compost samples from all ten facilities successfully met the maturity and stability criteria by the conclusion of the study.

## FIGURE 1. 10 COMPOST PARTNERS AND KEY ATTRIBUTES OF EACH FACILITY

# WHERE WE TESTED: LOCATIONS, COMPOST METHODS AND TESTING TIMEFRAMES

COMPOST METHODS KEY

Methods are composting technology(s) used during the composting process. Orange text represents the primary technology used during the active composting phase.

**ASP:** AERATED STATIC PILE

**CASP:** COVERED AERATED STATIC PILE

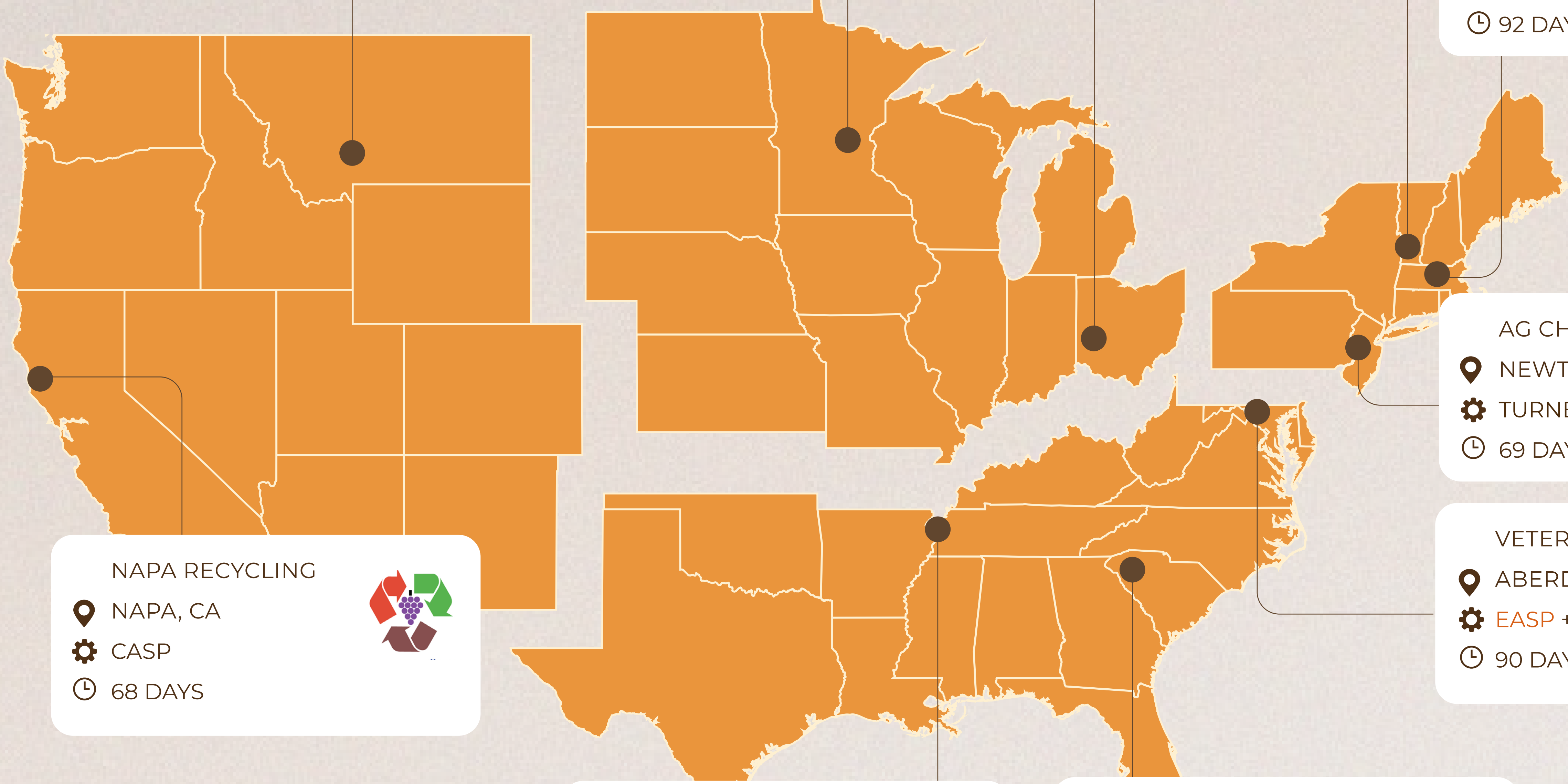
**EASP:** EXTENDED AERATED STATIC PILE

LEGEND

- LOCATION
- COMPOST METHOD
- ENDPOINT

NOTE

Endpoint refers to the second and final retrieval of the compostable packaging on-site. For most composters, the endpoint in our study is identical to their end of curing (i.e., reaching final compost). Variability in endpoints reflect different variations in compost process length by composter. Our study ended the windrow process when the compost met maturity standards, not when curing was complete.



HAPPY TRASH CAN
BOZEMAN, MT
CASP
91 DAYS

SET
MINNEAPOLIS, MN
ASP + STATIC PILE
90 DAYS

THE FOODBANK
DAYTON, OH
IN-VESSEL
49 DAYS

WINDHAM SOLID WASTE MANAGEMENT
BRATTLEBORO, VT
TURNED WINDROW
94 DAYS

BLACK EARTH COMPOST
GROTON, MA
EASP + TURNED WINDROW
92 DAYS

AG CHOICE
NEWTON, NJ
TURNED WINDROW
69 DAYS

VETERAN COMPOST
ABERDEEN, MD
EASP + TURNED WINDROW
90 DAYS

NAPA RECYCLING
NAPA, CA
CASP
68 DAYS

ATLAS ORGANICS
MEMPHIS, TN
EASP
72 DAYS

ATLAS ORGANICS
GREENVILLE, SC
CASP
71 DAYS

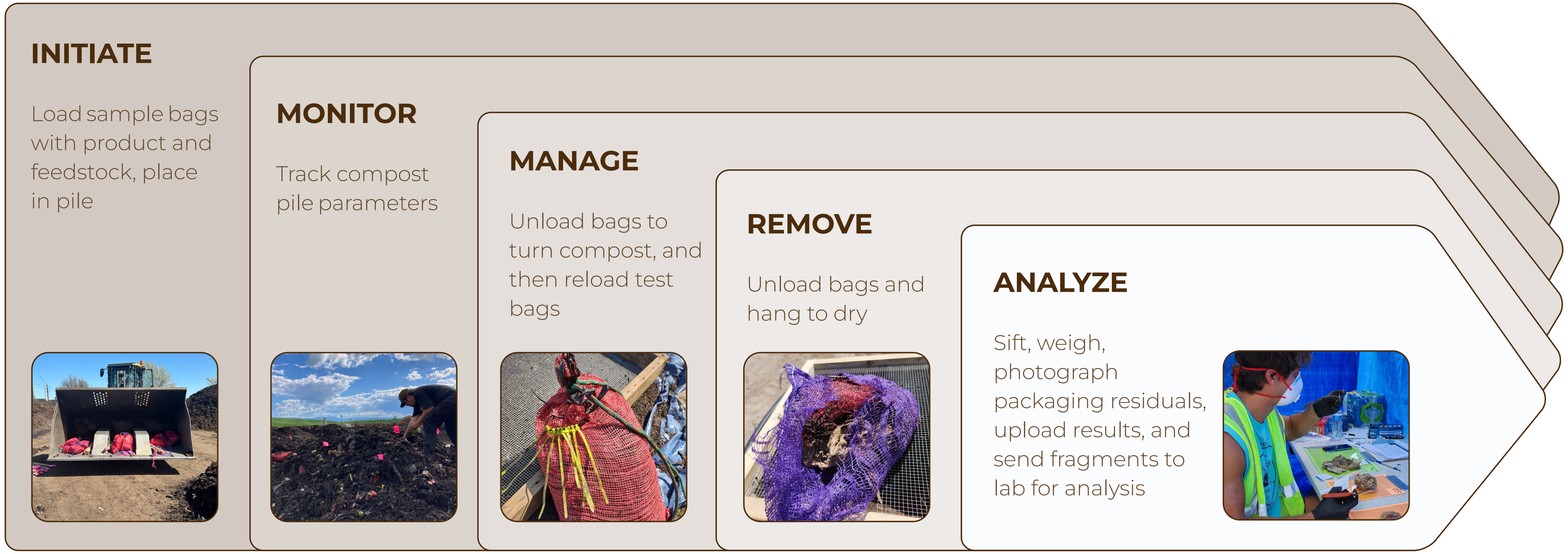
## FIELD TESTING METHODS: MESH BAG AND DOSE

This study deployed two methods to test compostable packaging in the field. The **mesh bag method** involved using a mesh bag to contain the tested compostable packaging during the field test. The mesh bags are then loaded into a given composting process (i.e., loaded into the pile). This method of field testing has been in use since ASTM biodegradation standards emerged in the 1990s and has been further developed through initiatives like the Compostable Field Testing Program (CFTP)[9] and Compost Manufacturing Alliance (CMA).[10] The method continues to be refined under ASTM International Sub-Committee WK80528. Eight of our composters utilized this field test method. They loaded 30 mesh bags containing a mix of compostable packaging and non-contaminated organic feedstock into their piles for our teams to retrieve half of the bags at the midpoint, and the other half at the endpoint.

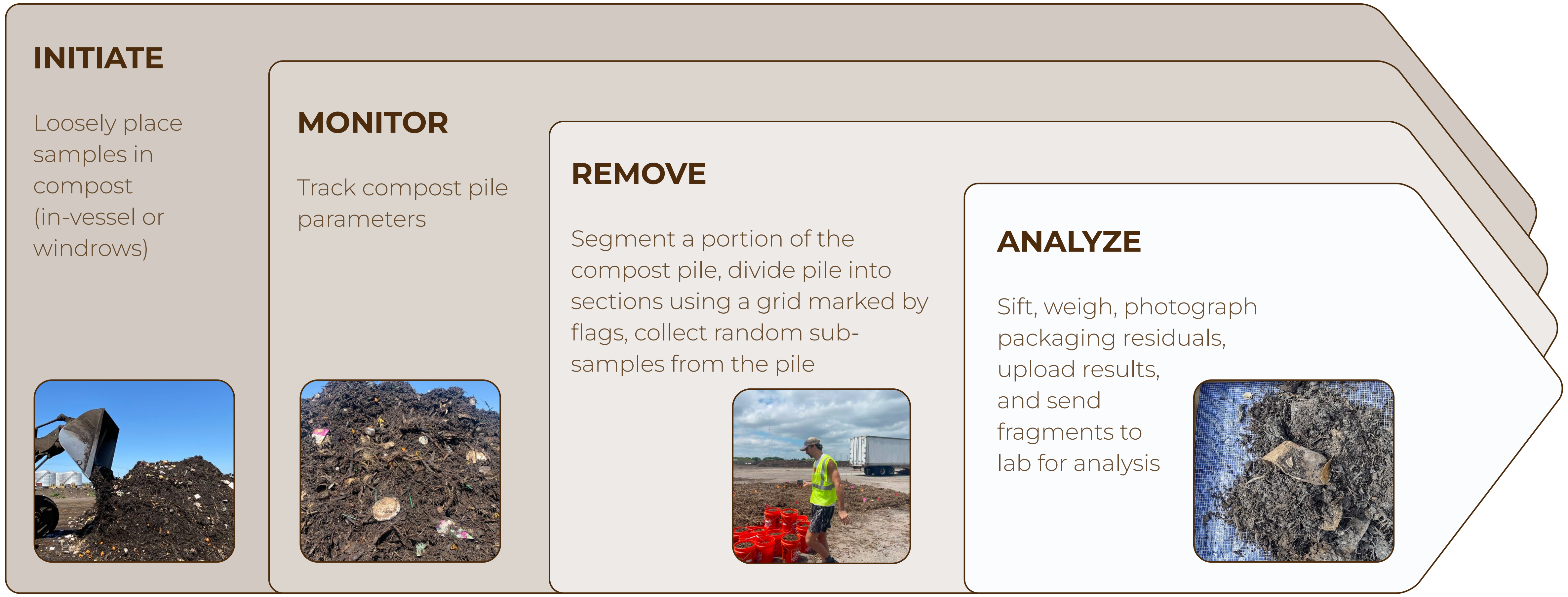
The second method, known as the **dose method**, involves mixing in the tested packaging directly into fresh non-contaminated feedstock. This emerging method was first piloted in 2013 by the CFTP and set aside for a decade before being further developed via collaboration under the ASTM International Sub-Committee WK80528.[11] The Composting Consortium was the first group to refine and trial the dose method at two compost facilities in this study. Feedstock was dosed with test items at a rate of 4 to 5%, respectively, by volume. To retrieve residuals, the dosed material is screened and the overs pile is flattened, marked, a visual scan undertaken, and then random samples are taken from the overs. The residuals found in the sub-sampled overs* are used to extrapolate the total residuals per item type. Figures 2 and 3 visualize key steps in each method and the Appendix includes each method in more detail.

* In composting, "overs" refers to material that has not fully decomposed during the composting process and may include larger chunks of food scraps, woody yard trimmings or other organic materials that haven't broken down into finished compost yet.

## FIGURE 2. MESH BAG METHOD IN THE FIELD




## FIGURE 3. DOSE METHOD IN THE FIELD



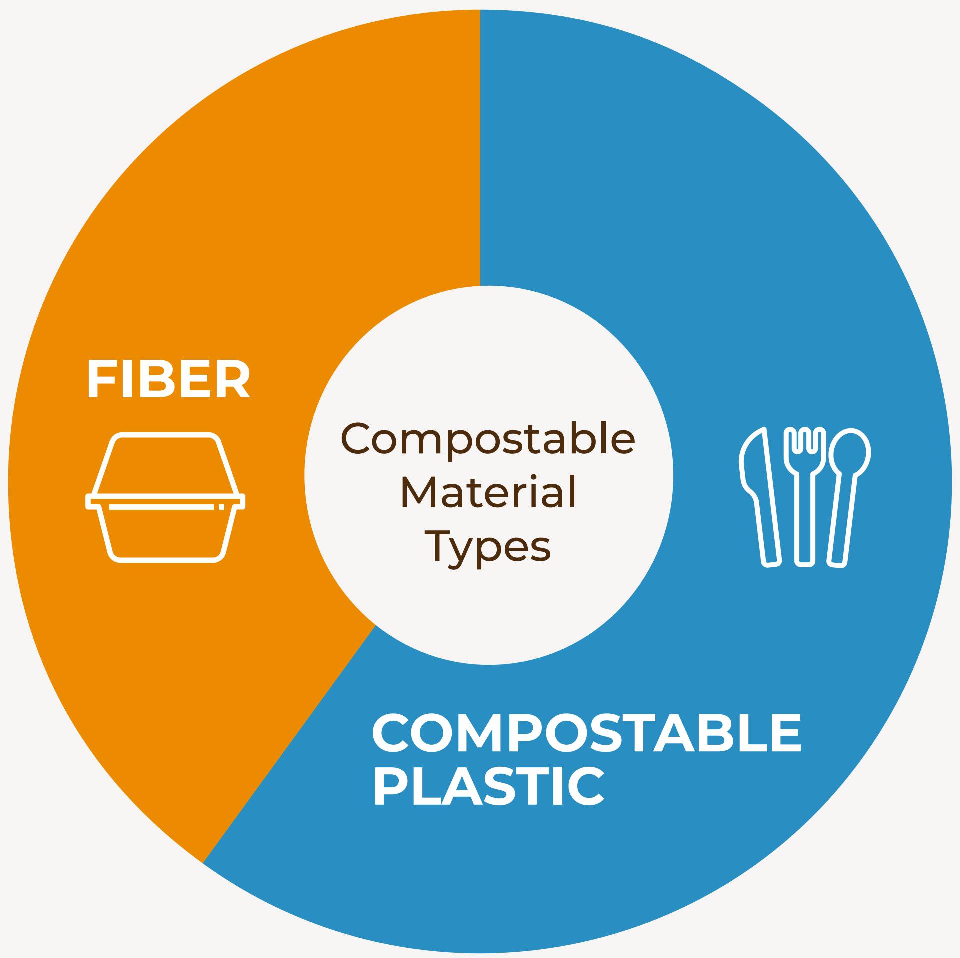

Note: Dose method requires substantially more resources and composter or staff time to facilitate field test.

This is the largest known field test of certified compostable packaging conducted in North America. In total, over 23,000 units of certified compostable packaging were tested–encompassing 31 types of individual compostable packaging and products, including three positive controls and one negative control. These items were made from materials including a range of compostable plastics, lined and unlined fiber packaging and products, and mixed material compostable packaging. Figure 4 characterizes the types of compostable plastic and fiber packaging tested across all ten compost facilities.

> “This is the largest known field test of certified compostable packaging conducted in North America. In total, over 23,000 units of certified compostable packaging were tested.”

**FIGURE 4. NUMBER AND TYPES OF COMPOSTABLE PACKAGING TESTED**

**30+ TYPES OF CERTIFIED COMPOSTABLE PRODUCTS**




**23,000+ UNITS TESTED***

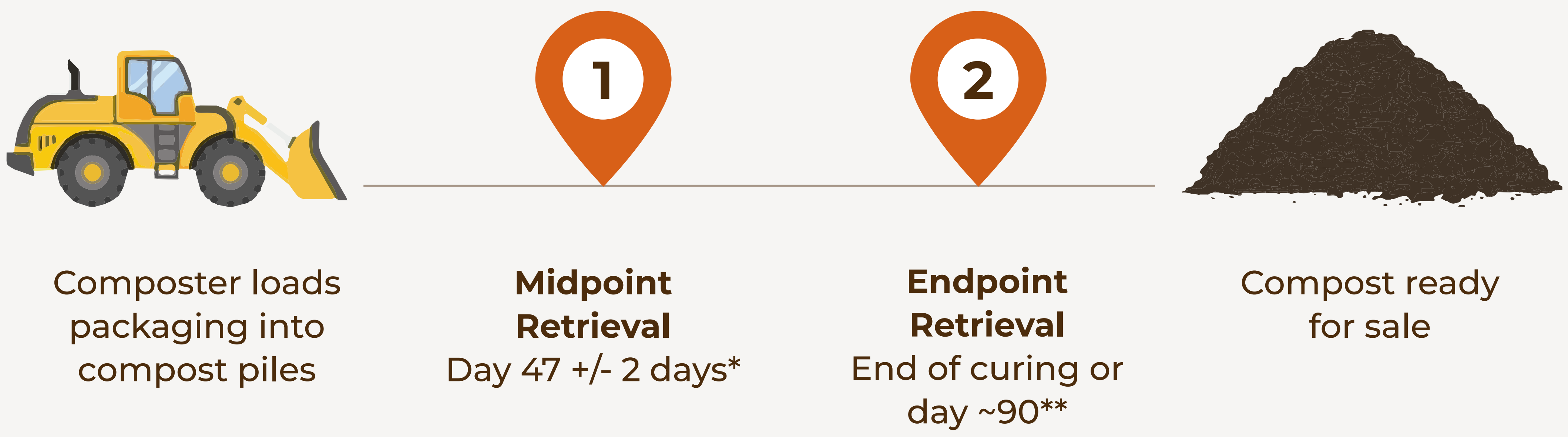

*Select examples of fiber and compostable plastic packaging tested in our study

## METHODOLOGY

### Packaging Disintegration

This study measured disintegration using two criteria: the percentage reduction in weight and percentage reduction in surface area of certified compostable packaging in the field. Samples of original packaging and its residuals were taken twice during the composting process. The first disintegration measurement was taken at the midpoint of the study–day 47 ± 2 days–and then again at the endpoint of the trial. The endpoint of the composting process is defined by each composter and facility and is largely driven by the composting method used. For example, an ASP composter can have a process that takes 60 days from start to finish, while a windrow facility could have a process that is 180 days in length. Windrow facilities kept materials in their process for up to 90 days +/- 2 days. At each of the participating windrow facilities, the endpoint measurement was taken when the compost in the surrounding pile registered as a mature compost. Figure 1 details the number of days the packaging was in the compost process, and Figure 5 illustrates the points during the study where a set of mesh bags or packaging was retrieved.

**FIGURE 5. DISINTEGRATION OF COMPOSTABLE PACKAGING MEASURED AT TWO POINTS IN COMPOSTING PROCESS**




*The Foodbank, Dayton midpoint was day 19, which was an exception to the rule.

**Endpoint was end of curing or day ~90, whichever came first.

## Composting Conditions

Beyond measuring the disintegration at two points of the composting process, a distinct feature of this study is that it considers composting parameter data (i.e., pile temperature, moisture) in tandem with disintegration results. The team was able to collect this granular compost operating data because our compost operators tracked and reported daily compost pile temperature, and weekly moisture and oxygen readings, as well as periodically measured bulk density, pH, C:N (i.e., carbon to nitrogen ratios), compost product maturity and compost stability measurements. These operating parameters were gathered both in-field and at the lab. Table 1 summarizes the operating conditions that were measured in-field and at the lab.

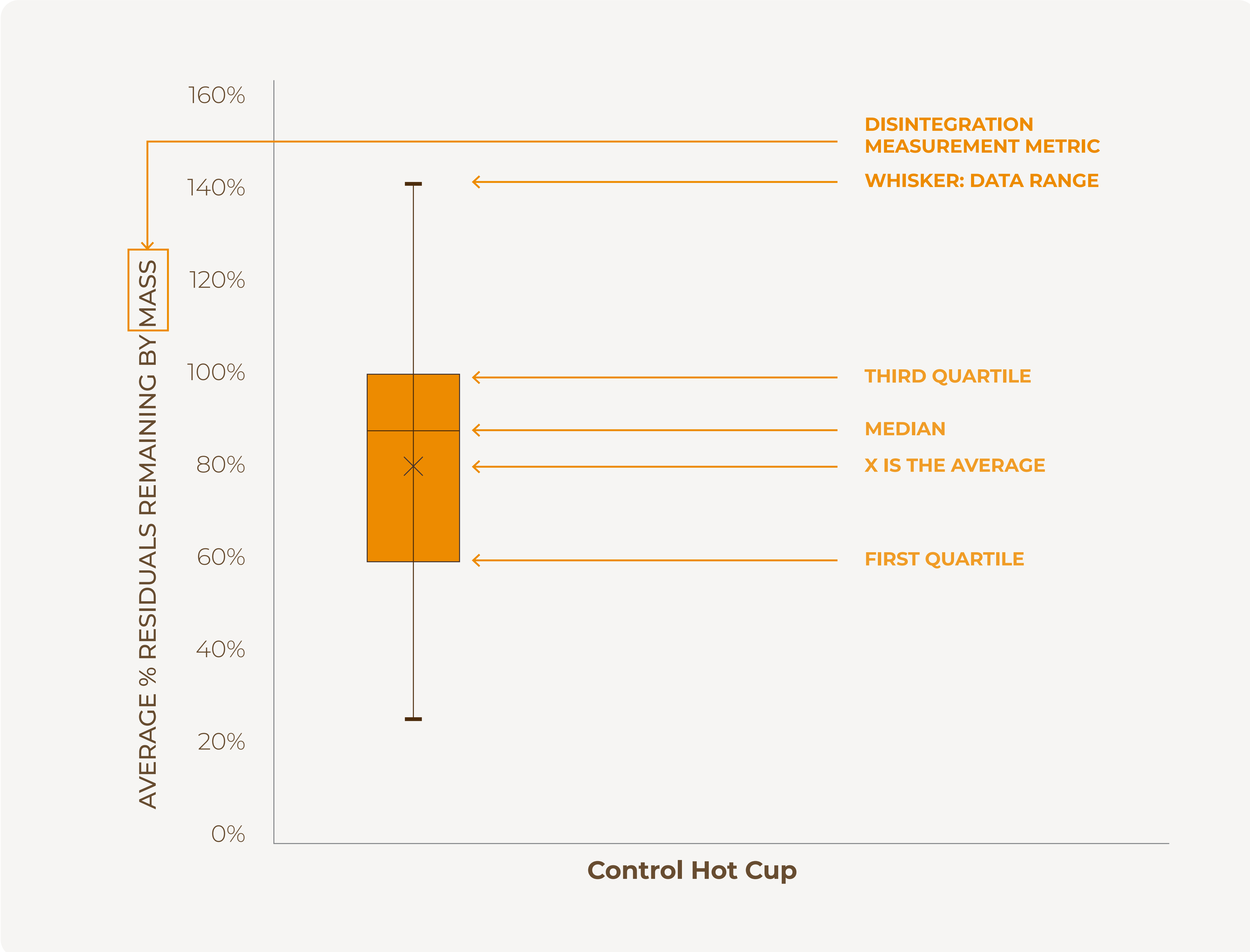
**TABLE 1. MEASUREMENTS TAKEN IN-FIELD VS. AT THE LAB**

| | Assessed In-field | Assessed In-lab (recorded at start, midpoint, endpoint) |
|---|---|---|
| **Operating Parameters (compost pile conditions)** | • Bulk density (start point, midpoint, endpoint)<br>• Moisture (weekly)<br>• Temperature (daily)<br>• Oxygen (bi-weekly)<br>• Maturity via Solvita test (midpoint and endpoint) | • Moisture<br>• C:N ratio<br>• pH<br>• Bulk density<br>• Stability via CO2 evolution<br>• Maturity via bioassay |
| **Environment and Disintegration Data** | • Site visit dates<br>• Ambient conditions<br>• Bag placement in pile and recovery<br>• Product residual recovery | • Product residual weights and surface area |

## How to Read the Charts in This Report

As previously noted, compostable packaging residuals were documented at two points in time (midpoint and endpoint) at each compost facility. The phrase "residuals remaining" represents the percent of the original product that was recovered at the midpoint or endpoint of the study. For example, 30% residuals remaining means that 70% of the compostable product disintegrated. Details on how to decipher the graphs and charts in this report are outlined in the Example Figure to the right.

**EXAMPLE FIGURE: RESIDUAL RATES FOR NEGATIVE CONTROL IN OUR STUDY (MESH BAG RESULTS)**



# What We Learned From Field Testing Compostable Packaging: Considerations for Brands and Packaging Manufacturers

## Measuring Disintegration by Weight vs Surface Area

Our team collected disintegration data by weight (i.e., dry weight to the hundredth gram) and by surface area (i.e., traced pixels). Weight was measured in the lab using a high-precision scale after the packaging fragments were dried and cleaned. Surface area was measured using an open-source software, ImageJ, which was more time intensive compared to taking weight measures. Quantifying surface area requires careful arrangement of packaging residual fragments on a white or black contrast, photographing the fragments straight-on, uploading the photos into the imaging software, scaling the photograph, and summing the total surface area generated by the software. Each metric has strengths and weaknesses and are nuanced. Appendix Table B outlines the strengths and weakness of each metric.

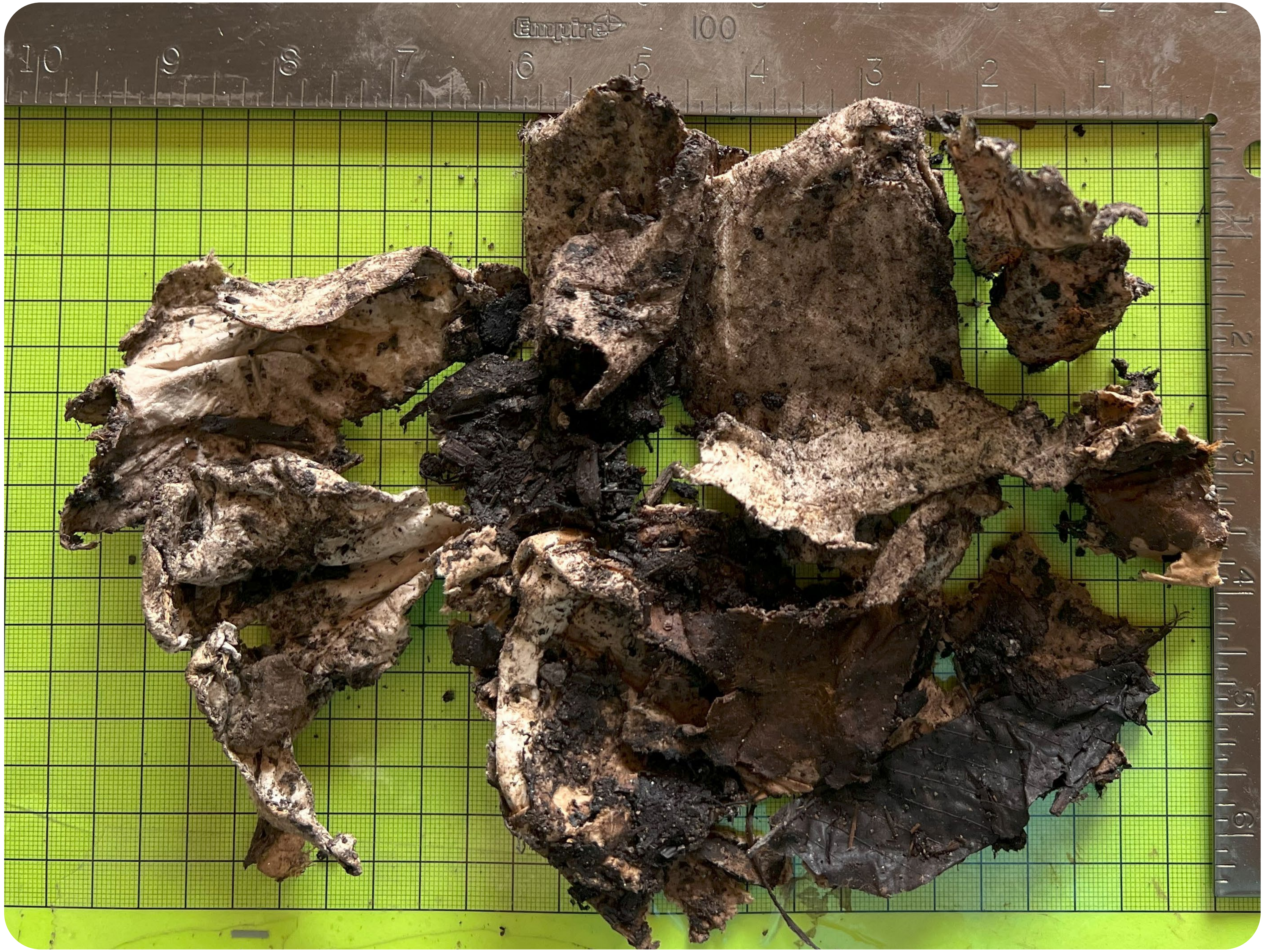
When evaluating across multiple factors to measure disintegration,[1] we concluded that surface area is a more reliable metric to measure compostable packaging disintegration in field testing; measuring by weight is more susceptible to sources of error and systematically underestimates disintegration results in field testing. When taking the weight of packaging fragments, compostable plastic and fiber packaging would often absorb oil and/or accumulate detritus, which is organic matter that would adhere to the packaging fragments. Figure 6 shows an example of the detritus stuck onto packaging fragments.

Even with careful handling and preparation in the lab, detritus and non-evaporable substances (i.e., oils) could not be removed. This added weight caused nearly a third of our weight measurements to result in readings over 100%, despite disintegration having taken place. For these reasons, we recommend that brands advocate for measuring disintegration using surface area when field testing their compostable packaging. Figure 7 illustrates the important differences that can occur when measuring disintegration by weight rather than surface area. Across all material categories, weight conflated the remaining residuals of the compostable products and controls.

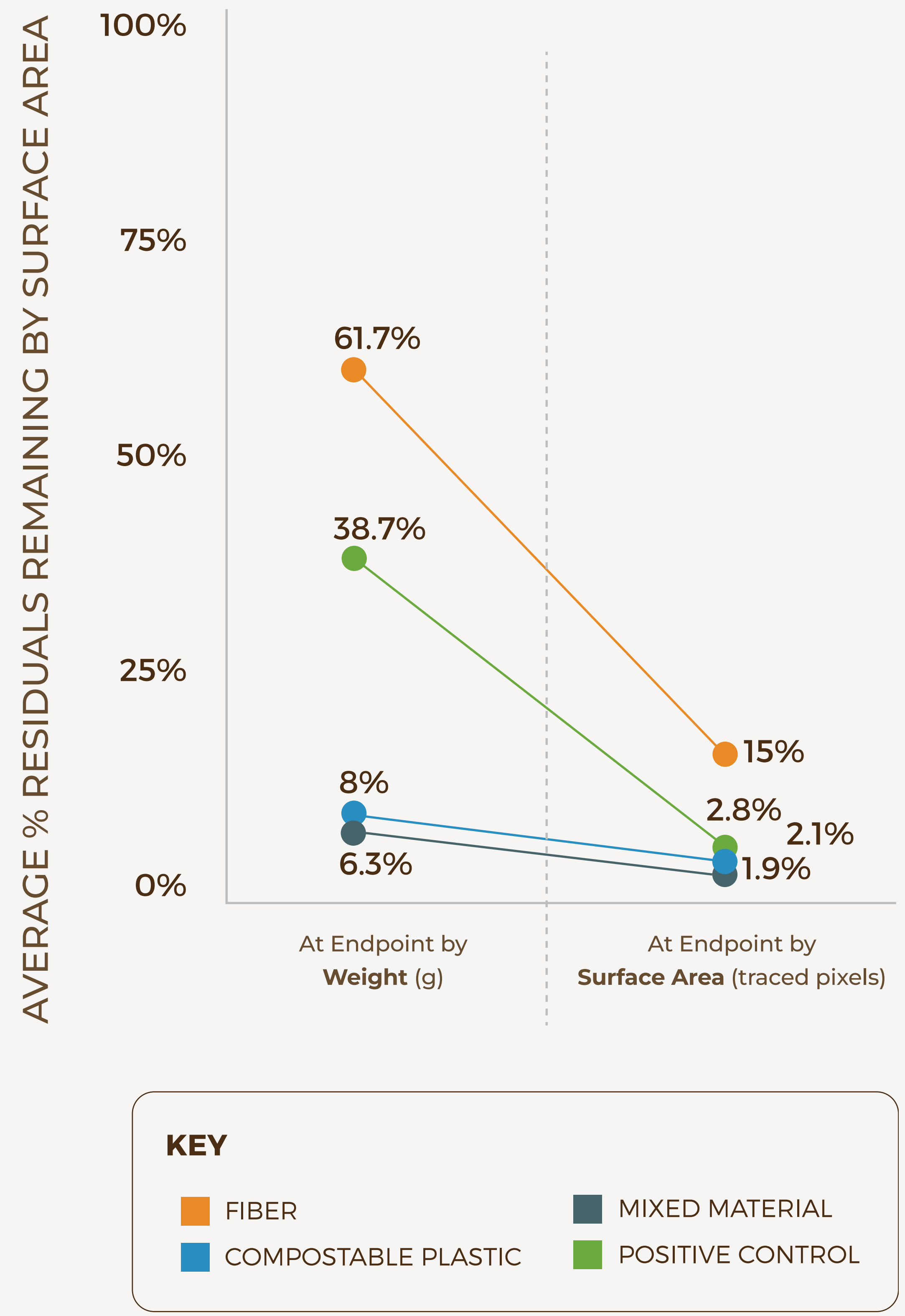
> “We recommend brands advocate for measuring disintegration using surface area when field testing their compostable packaging.”

1. Factors for evaluating disintegration: Potential for the geometry of a 3D object to bias the result; reliability for capturing thickness; directionality of bias of measure; ease of measurement; common sources of error

## FIGURE 6. DETRITUS STUCK ONTO PACKAGING FRAGMENTS IN THE LAB



## FIGURE 7. AVERAGE RESIDUALS AT POINT OF STUDY: WEIGHT VS SURFACE AREA MEASUREMENTS



## Mesh Bag Method vs Dose Method: Pros and Cons of Each

As previously noted, eight out of our 10 compost facilities utilized the mesh bag method while two facilities utilized the new and in-development dose method. There are notable benefits and downfalls to each method, which are summarized in Table 2.

Of note, newly released data from other compostable packaging field test studies have found that the microbial environment inside of the mesh bag does appear to be different and depressed compared to the microbial environment outside of the mesh bag. Use of the mesh bag therefore represents a compromise. On the one hand, the mesh bag method permits the ease of recovery of the tested compostable packaging, requires far fewer packaging samples than the alternative dose method, and can produce disintegration results at the unit-level. However, the mesh bag is also likely to create moisture content, gas exchange and agitation differences between the contents inside the bag and outside of the mesh bag.

> "All compostable products in the Composting Consortium's Disintegration Study had notably higher disintegration rates with the dose method compared to the mesh bag method."

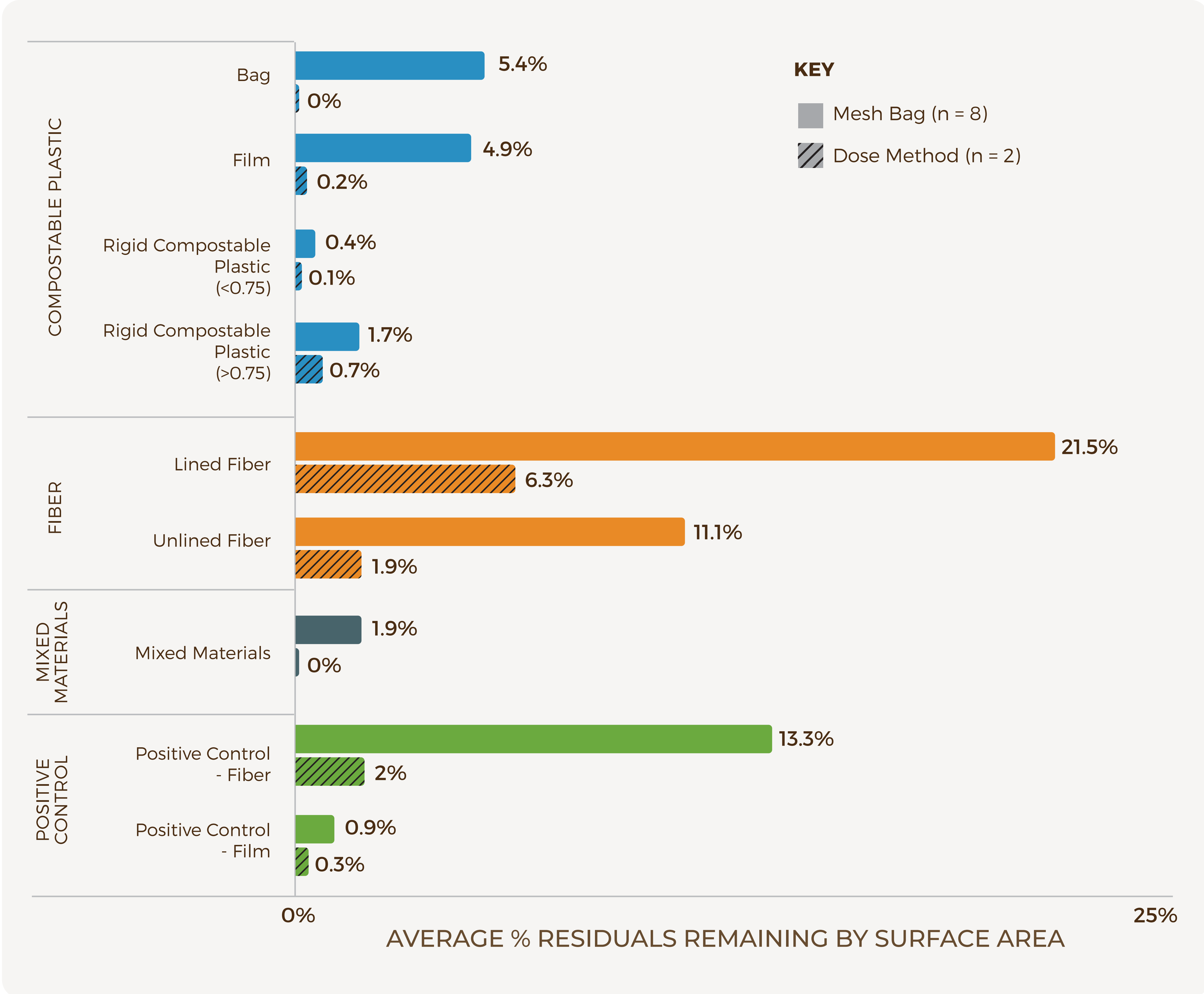
**TABLE 2. PROS AND CONS OF MESH BAG AND DOSE FIELD TESTING METHODS**

| | Pros | Cons |
|---|---|---|
| **Mesh Bag Method** | • Long-standing history and prevalence of use in field testing<br>• Reduces the likelihood of lost samples and/ or interface with contaminants<br>• Packaging disintegration results reported on a per-unit basis | • Mesh bag has potential to impede moisture, gas and microbial flow from surrounding outside material in compost pile<br>• There is little to no agitation of the test items in the bag<br>• Not feasible in all composting systems (i.e., does not work in agitated in-vessel systems) |
| **Dose Method** | • Replicates real composting conditions since packaging is loosely placed in the pile<br>• Feasible to use across all composting technologies (i.e., systems with agitation) | • Method is nascent and still in development<br>• Potential to under- or over-report disintegration due to sub-sampling method at retrieval<br>• Resource and labor intensive<br>• Product-level disintegration analysis unavailable (i.e., results framed per one unit of packaging) |

While the exact impact on the test results is uncertain, the use of the mesh bag should be considered a conservative approach, since the differences in the key conditions would tend to decrease disintegration. A positive result (increased disintegration) within the bags would be even more likely had the test items not been in the bag. This aligns with the residual rate results we see between the two methods. All compostable products in the Composting Consortium's Disintegration Study had notably higher disintegration rates with the dose method compared to the mesh bag method. Figure 8 shows the results of mesh bag versus dose final residuals, grouped by material type and format. Compostable plastics appear to have strong disintegration performance in both field test methods, while compostable fiber packaging and products appear to perform significantly better under dose methods. Average residuals for compostable plastic products at the end study were <1% at dose facilities and 2.2% at mesh bag facilities. Average residuals percentages for fiber packaging and products at the end of the study were between 1.9% to 6.3% for dose facilities and between 11.1% to 21.5% residuals at mesh bag facilities. *For results on a mass basis, please refer to Figure A in the Appendix.*

As such, it behooves brands and packaging manufacturers to contribute to further developing and maturing the dose method, which is still being developed under ASTM as of Spring 2024. However, both field testing methods are reasonable pathways to measure the disintegration performance of compostable packaging.

**FIGURE 8. MESH BAG VS DOSE METHOD AVERAGE RESIDUAL RATES ACROSS MATERIAL FORMAT**



## Study Controls

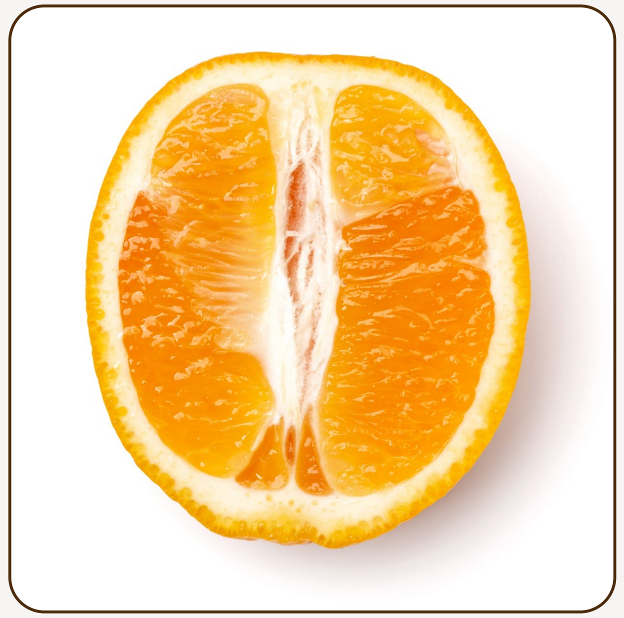
Control materials are used in field testing to assess the validity of the test results. A positive control is a material that is known to sufficiently disintegrate within the specified field trial timeframe given appropriate composting conditions. Positive controls are expected to fully degrade within the time frame of the test to indicate that the operating conditions were adequate for complete disintegration. If a positive control remains intact at the end of testing, the results for that test may be considered invalid for other test items.[12] In contrast, negative controls are items known to resist disintegration within the timeframe of the field trial. Negative controls should still be present at the end of testing to validate the results for the remaining test items.

The determination of the most suitable controls for field testing is an ongoing process. Our study tested the viability of three positive controls, which were selected under the guidance of the ASTM Technical Committee WK80528. Our three positive controls are the single-ply kraft butcher paper, cellulosic film, and a navel orange peel (Figure 9). The outcomes of these control materials are discussed and recommendations are provided regarding their suitability for future field test method development.

**FIGURE 9. POSITIVE CONTROLS IN OUR STUDY**

**Butcher paper**


**Cellulose Film**

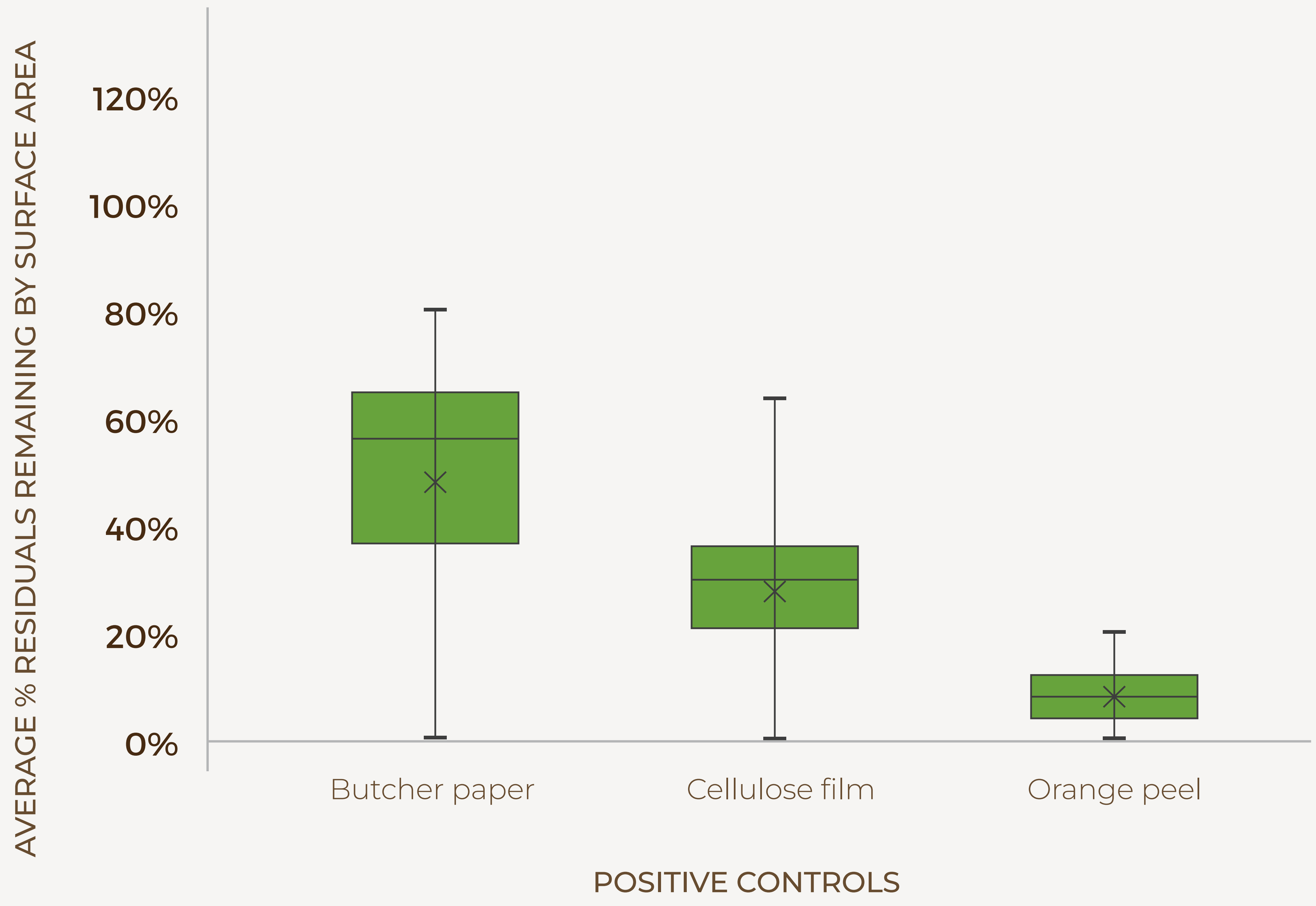


**Halved Orange**

For the butcher paper and cellulose film, each positive control had residual percentages greater than 15% by the end of the study. Figure 10 illustrates the performance of all positive controls in the mesh bag method, by surface area. The average residuals remaining for all positive controls, by surface area, are as follows: 41% residuals for the butcher paper, 17% residuals for the cellulose film and 5% residuals for the halved orange. The only positive control that met a residual rate <10% was the halved orange in the mesh bag. *For results on a mass basis, please refer to Figure B in the Appendix.*

The research team has worked and conferred with field testing experts including the Compostable Field Testing Program (CFTP) and Compost Manufacturing Alliance (CMA) to explain and compare the results of our study. Through these interviews, our team learned that butcher paper commonly underperforms in the mesh bag method. Some groups even use rigid PLA as a positive control instead of butcher paper because the performance of the PLA is more reliable as a positive control. The variability in disintegration results of the butcher paper and cellulose film suggest that neither are effective positive controls in field testing.

**FIGURE 10. RESIDUAL RATES FOR POSITIVE CONTROLS IN OUR STUDY (MESH BAG RESULTS)**



# PART 2.
# COMPOSTABLE PLASTICS: WHAT WE LEARNED

**Compostable plastics were patented and began to commercialize in the 1990s.**[13] Polylactic acid (PLA) was initially the most common compostable plastic, but substantial material innovation has improved PLA and introduced new compostable plastics to the market including PHA, PBAT, PVOH, to name a few. The Composting Consortium opts to use the term compostable plastics, rather than compostable biopolymers, because not all compostable plastics are bio-based (e.g., made from corn). Our study tested 18 different food-contact compostable plastic packaging and products, which encompass nine different compostable plastic materials. Appendix Table A further details the packaging and material types that were tested.

Compostable plastics are a fractious topic among composters, regulators, brands and manufacturers and environmental groups in recent years. Some stakeholders do not support compostable plastics that are not entirely bio-based. However, under specific composting conditions, certified food-contact compostable plastic packaging and products are designed to break down into $CO_2$, water, inorganic composts and biomass irrespective of whether they are bio-based or not. Additionally, compostable plastics are not currently considered an allowable input in organic compost manufacturing (see call out box on right). Lastly, some states that have compost quality requirements do not allow finished compost to contain more than 1% of plastic, glass, and metal by dry weight, which creates reluctance among composters to accept compostable plastics since they are difficult to decipher from conventional plastics in the finished compost. We tested compostable plastics using the mesh bag and dose method to provide objective data to evaluate the viability of compostable plastics as a feedstock input.

## Ongoing Debate: Allowing Compostable Plastics as Compost Feedstocks

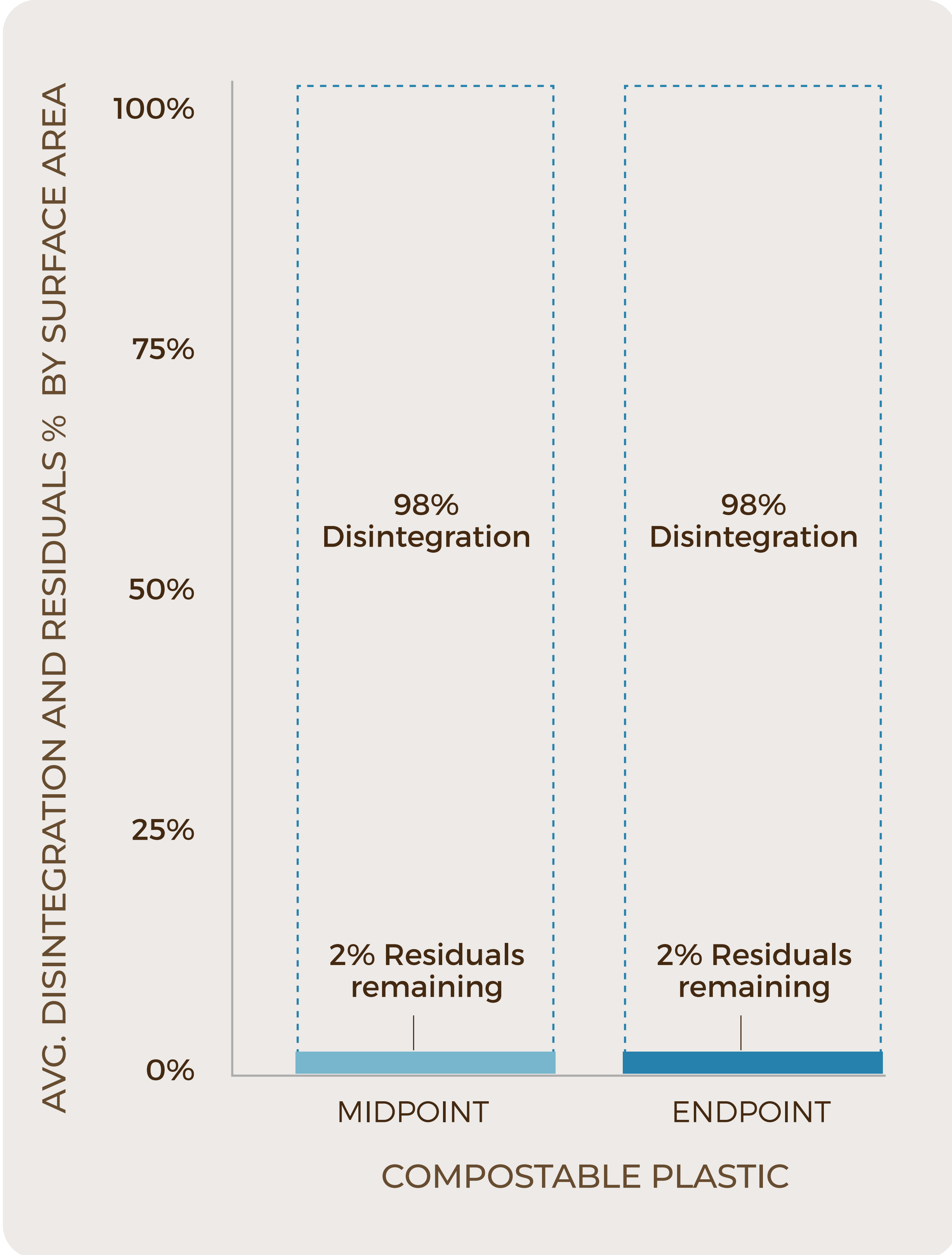
There is an ongoing debate in states like California on whether compostable plastics should be allowed as an input at compost sites producing organic compost. An organic compost manufacturer in the United States is not certified by the Organic Materials Review Institute (OMRI) body, but OMRI certifies the inputs that go into organic production or compost, fertilizer, animal feed, etc.[14] OMRI looks at the ingredients and manufacturing of products to make sure they comply with organic standards set by the USDA National Organic Program (NOP). According to definitions of organic set forth by the NOP, composters who sell organic compost can only accept unlined fiber packaging and still meet the requirements to be listed as selling organic compost. Compostable plastics do not meet the current definition of organic by the NOP, and groups like the Biodegradable Products Institute (BPI) have petitioned for a more science-based approach and update to the definitions of organics. The petition asks for a simple but impactful update to the national definition of “organic” to match the state’s definition of organics.

▶ Learn more about the petition

## Mesh Bag Results

Our data confirms that compostable plastics perform well in the field, irrespective of compost technology, field test method or material type. The average residual (%) remaining for all compostable plastic packaging tested in our study was 2% by surface area at the endpoint of the study. Interestingly, at the midpoint of the study–which was roughly 47 days after the compostable packaging was loaded into the compost piles – the majority of compostable plastic packaging had successfully broken down in the pile. This is illustrated by Figure 11, which shows the average midpoint and endpoint residual rates for all 18 compostable plastic packaging tested. These results are not surprising as compostable plastics tend to achieve most of their disintegration during the mesophilic phase of the compost process (see call out box on next page). In contrast, fiber packaging, which typically takes more time to break down, relies on both mesophilic and thermophilic phases of composting to break down. *For results on a mass basis, please refer to Figure C in the Appendix.*

**FIGURE 11. AVERAGE RESIDUALS AND DISINTEGRATION OF ALL COMPOSTABLE PLASTIC PACKAGING (MESH BAG RESULTS)**

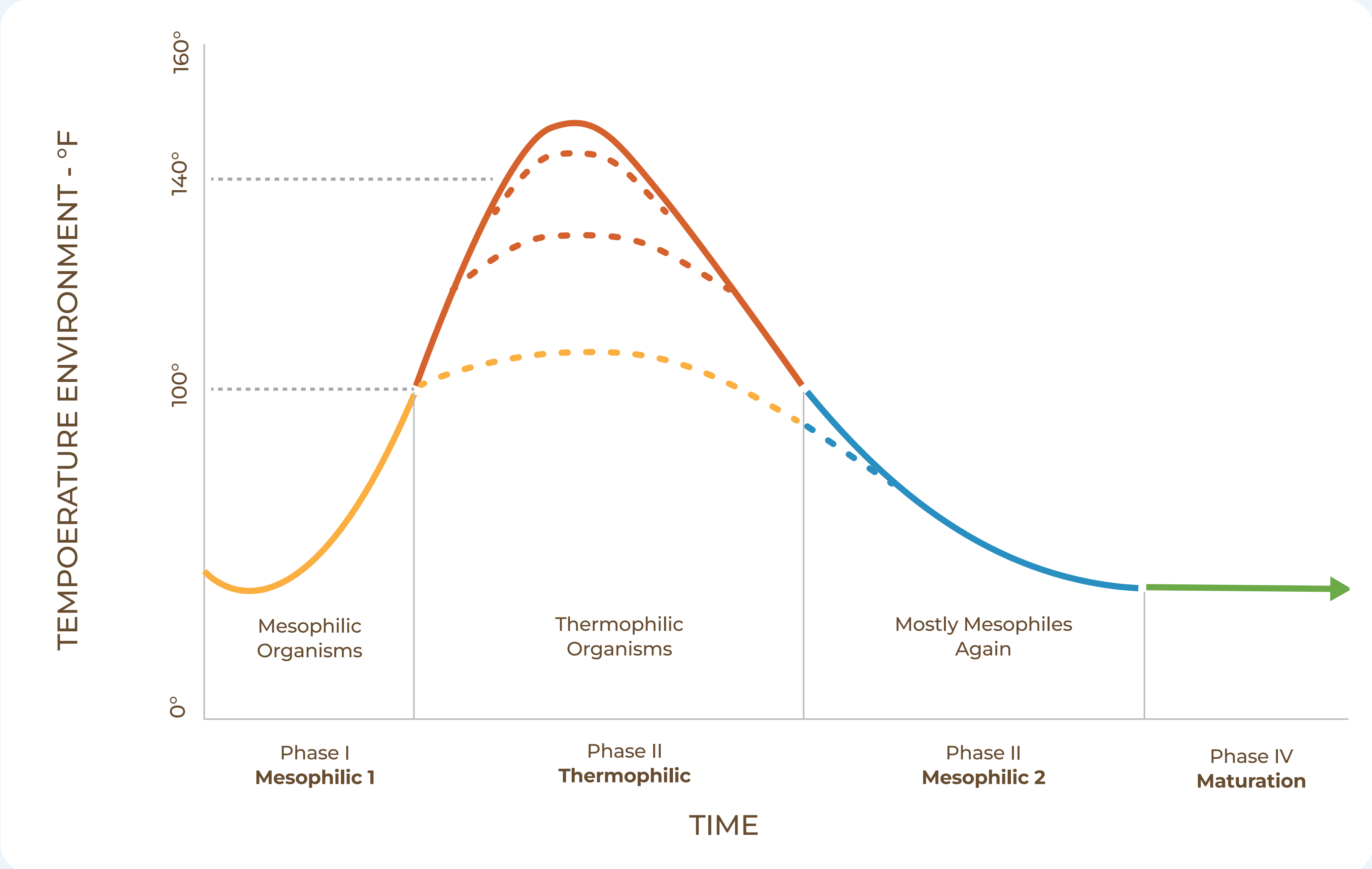


## Mesophilic and Thermophilic Phases of Compost

The composting process can be broken down into two key phases distinguished by the temperature and dominant decomposers involved. In the initial mesophilic stage, mesophilic bacteria and fungi, thriving in a temperature range of 21°C to 60°C (70°F to 140°F), readily decompose readily biodegradable materials such as sugars and starches. This initial decomposition generates heat, prompting a rise in temperature. As the temperature climbs, the thermophilic stage commences, favoring the activity of heat-loving bacteria (140°F to 160°F). These organisms effectively degrade more complex materials like wood fibers. Notably, the heightened temperatures during this stage contribute to the elimination of weed seeds and pathogens within the compost pile. Ultimately, with the depletion of readily available food sources and a subsequent decline in temperature, the mesophilic community reemerges to complete the decomposition process, alongside fungi which play a critical role in breaking down complex materials. Figure 12 illustrates the transition between these stages.[15]

Understanding the breakdown sequence is crucial. Compostable plastics primarily break down as pile temperatures rise. Conversely, fiber-based packaging materials require the subsequent mesophilic and maturation stage for the degradation of lignin-rich fibers.

**FIGURE 12. THE TEMPERATURE AND MICROBIAL PHASES OF COMPOSTING**



Viewing the results at the product-level, the study found that 13 out of 18 compostable plastic products averaged <10% residuals. While our study did not measure disintegration in order to "pass" or "fail" specific items, groups like the Compost Manufacturing Alliance (CMA), which field tests compostable packaging, require compostable plastic packaging to meet at least a 90% disintegration threshold. ASTM D6400, the standard specification for labeling compostable plastics designed for municipal and industrial composting facilities, also requires that compostable materials break down by at least 90% under controlled laboratory composting conditions. By this measure, 13 of the compostable plastic packaging products would have passed.

Indeed, there was a degree of variability in disintegration across the compostable plastic items in the mesh bag method. Cups and cup lids consistently achieved high disintegration. Meanwhile, film items demonstrated higher variability in disintegration. Notably, Non-Metalized Flexible Film A (PHA multi-laminate film) was concurrently undergoing ASTM D6400 certification while being tested in-field in our study. Despite its constituent materials holding individual compostable certifications, Non-Metalized Flexible Film A surprisingly failed the ASTM D6400 test.

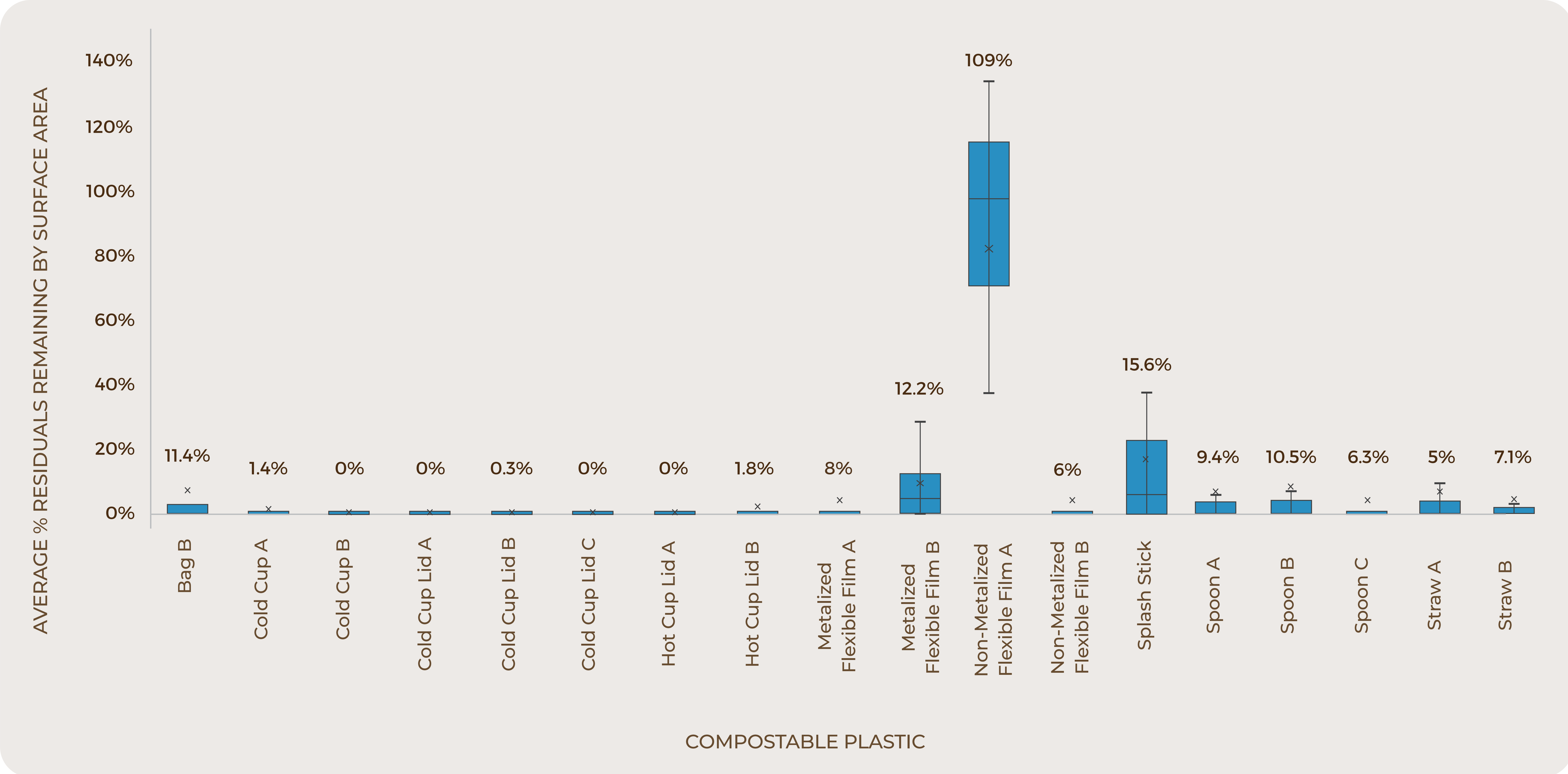
In this instance, seemingly minor interactions between the certified components within the compostable product may have impeded its disintegration in both the laboratory and field settings.

Rigid PLA had the highest level of in-field performance, averaging less than 2% residuals across six packaging products (Cold Cup A, Cold Cup B, Cold Cup Lid A, Cold Cup Lid B, Cold Cup Lid C, Hot Cup Lid B). Figure 13 summarizes the average residual rates across all 18 compostable plastic packaging types tested in our study. *For results on a mass basis, please refer to Figure D in the Appendix.*

## Dose Results

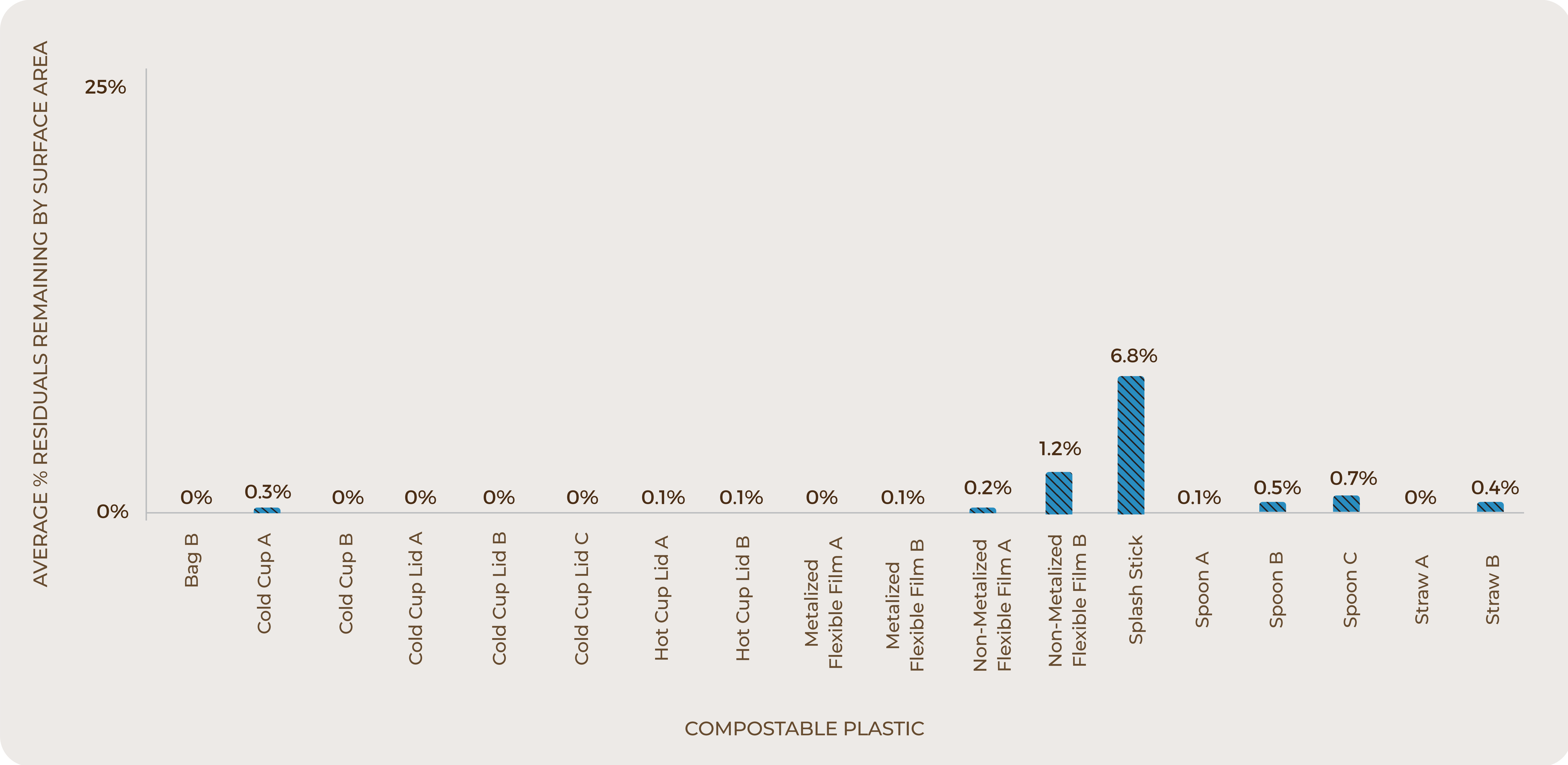
With the dose method, most compostable plastic products have on average < 1% residuals remaining at the trial endpoint, as shown in Figure 14. The exception is the splash stick which had a handle that was the thickest compostable plastic material tested in our study. Most often, the handle of the splash stick did not break down while the remaining thinner portion of the product did.

**FIGURE 13. AVERAGE RESIDUALS OF COMPOSTABLE PLASTIC PACKAGING AT ENDPOINT (MESH BAG RESULTS)**




Notes: Average % residual noted above each box plot and by the "x" in each box plot.
Non-Metalized Flexible Film A failed ASTM D6400 testing while being trialed in field during our study.

**FIGURE 14. AVERAGE RESIDUALS OF COMPOSTABLE PLASTIC PACKAGING AT ENDPOINT (DOSE RESULTS)**



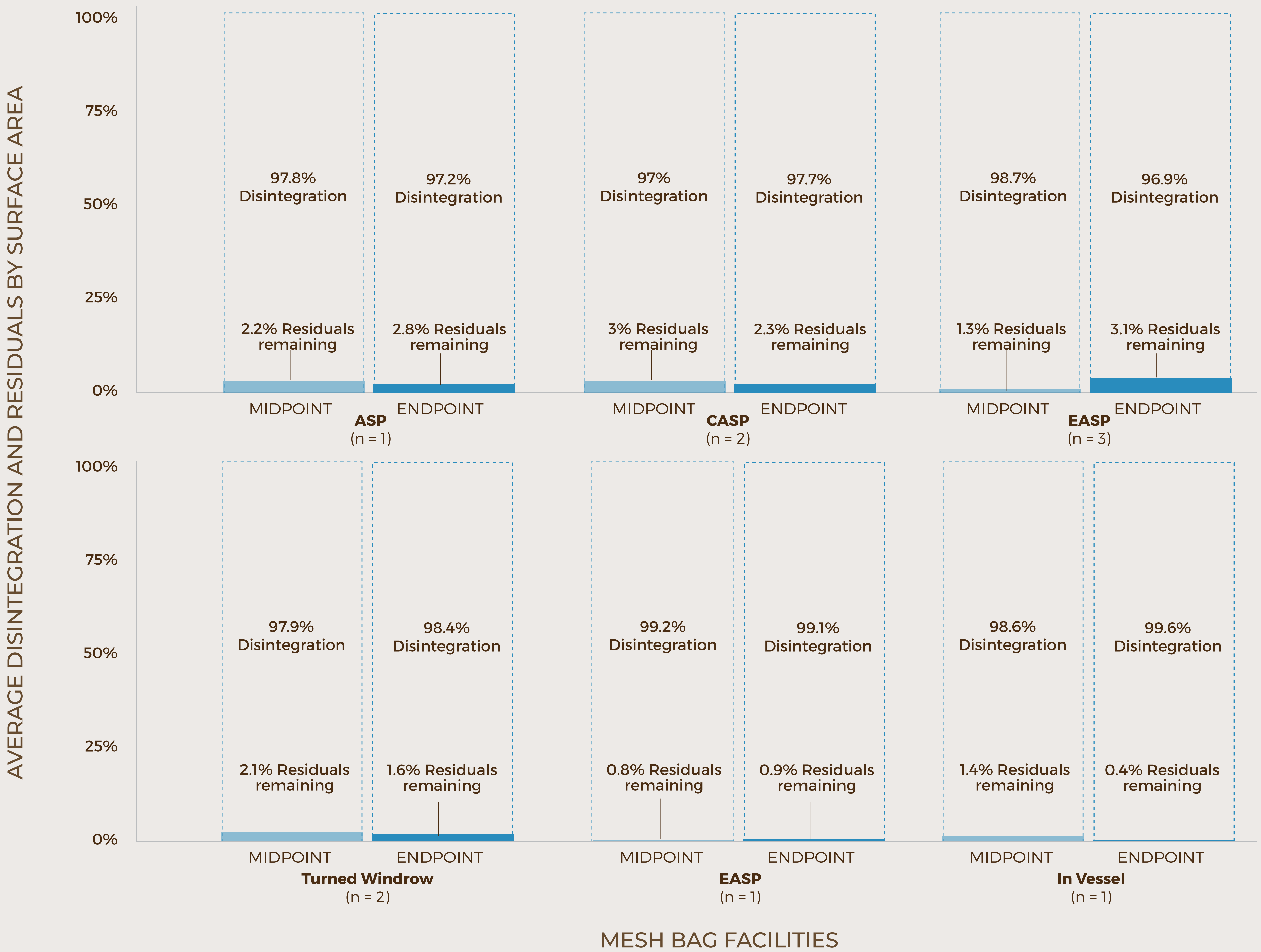

Notes: Average % residual noted above each box plot and by the “x” in each box plot.

## Compostable Plastics Disintegration Performance Across Composting Technologies

Our study also found that composting technologies or the field-test method did not seem to create a variation in the disintegration rates of the materials. Compostable plastics seemed to successfully distintegrate in every composting technology process tested, from windrow to in-vessel, to aerated static pile–and whether the mesh bag method or the dose method was used to test the packaging. Across the dose method and the mesh bag method, the vast majority of disintegration occurred between the trial start and midpoint. Figure 15 summarizes the disintegration between the midpoint and endpoint across all composting facilities and both field test methods.

> “Compostable plastics seemed to successfully disintegrate in every composting technology process tested, from windrow to in-vessel, to aerated static pile.”

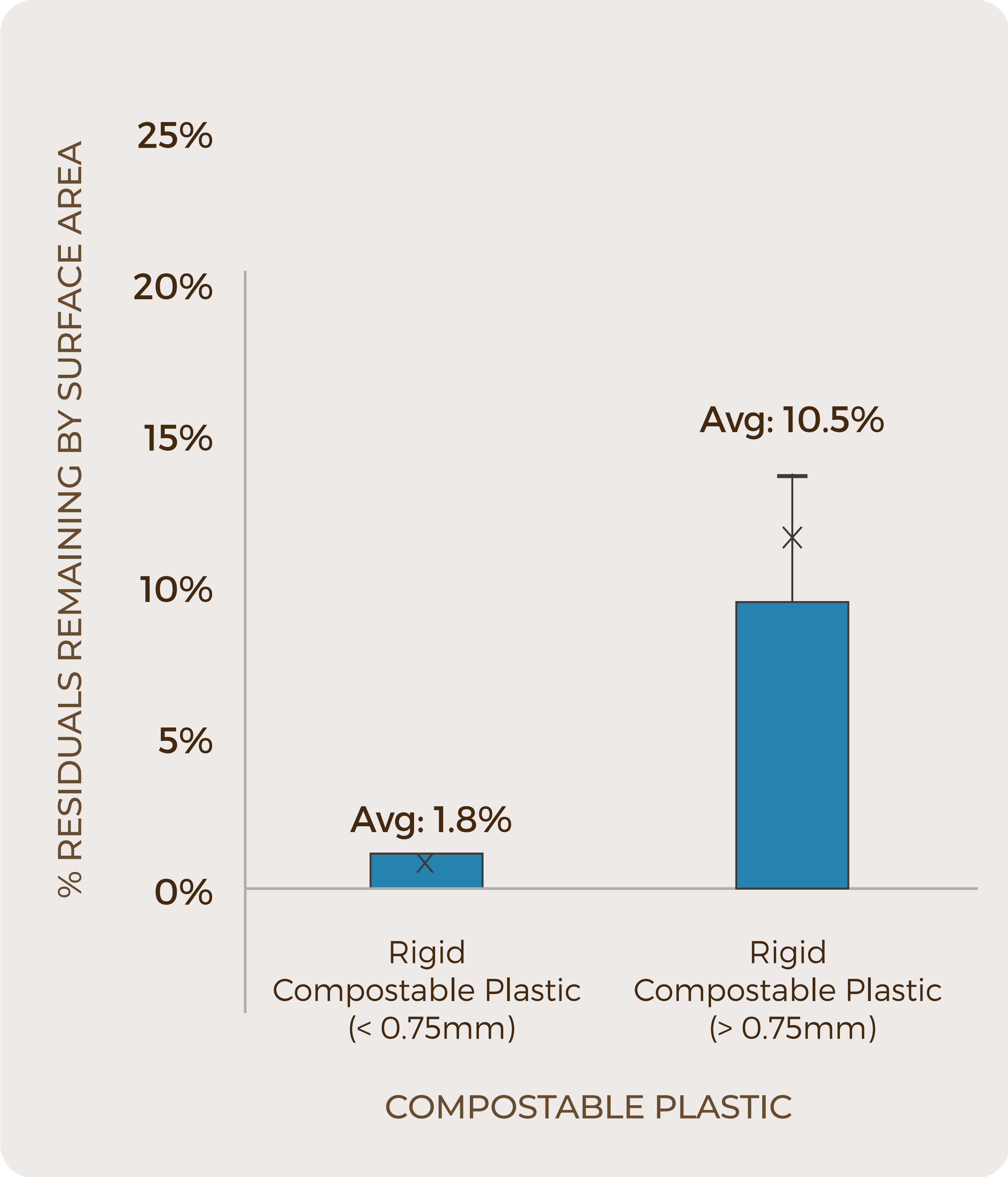
**FIGURE 15. DISINTEGRATION AND RESIDUAL RESULTS OF ALL COMPOSTABLE PLASTIC PACKAGING ACROSS FACILITIES AND FIELD TEST METHODS**



## What Design or Operational Factors Influence Disintegration of Compostable Plastics?

Our team poured over dozens of hypotheses to understand what best influences disintegration of compostable plastics. There were no strong correlations between any compost operating parameters (i.e., moisture, temperature, pH level, etc.). However, the team found a relationship between the thickness of the packaging and the disintegration results at the endpoint of the study. Thinner compostable plastics had higher disintegration rates compared to thicker compostable plastics. More specifically, rigid compostable plastics that were more than 0.75mm tended to have higher residual rates than those packaging that were thinner. While we found this relationship between thickness and disintegration within rigid compostable plastics, it's important to note that rigid compostable plastics had strong disintegration performance, as a whole. Figure 16 illustrates disintegration results by product thickness. *For results on a mass basis, please refer to Figure E in the Appendix.*

**FIGURE 16. AVERAGE % RESIDUALS OF RIGID COMPOSTABLE PLASTIC PACKAGING AT ENDPOINT (MESH BAG RESULTS)**




Note: When both rigid and flexible compostable plastics are viewed as a group, there is no relationship between thickness and disintegration.

# PART 3.

# COMPOSTABLE FIBER PACKAGING: WHAT WE LEARNED

**Composters across the United States tend to favor compostable fiber packaging for two reasons.** First, the fiber provides structural support to the compost, enabling porosity (i.e., air space within the compost pile) in the compost pile. Second, many composters do not consider fiber packaging a contaminant when fragments remain in their finished product because fiber packaging is not included as a contaminant in compost quality requirements. For example, in California, compost must contain less than 1% total dry weight of plastic, glass and metal combined, with film plastic specifically limited to less than 0.1% dry weight. As such, composters tend to be more open and accepting of fiber packaging and/or their disintegration performance is held to different expectations and standards compared to compostable plastics.

Our study tested a total of eight compostable fiber packaging and products, including tree fiber and bagasse products that are lined with compostable plastic (i.e., PLA, PHA) and unlined fiber packaging. The fiber packaging and products included several foodservice ware formats including hot cups, fiber plates, molded fiber bowls and a clamshell. Since the mesh bag and dose method produce different levels of detailed results (i.e., product level vs general disintegration percentages) the results of each field test method have been separated.

## Mesh Bag Method Results

Fiber packaging and products did see a decrease in average residual remaining between the midpoint and endpoint of the study, confirming our understanding of the effect of the second mesophilic stage of the composting process (see page 28). Figure 17 shows the average residual percentage by surface area for all eight fiber products in the mesh bag method. On average, fiber packaging and products had 17% of the product remaining at the endpoint through the mesh bag method. Notably, the average disintegration of all fiber products in our study met industry thresholds to achieve at least 80% disintegration. *For results on a mass basis, please refer to Figure F in the Appendix.*

A closer look at the disintegration rates across packaging products gives a more nuanced understanding of fiber packaging performance in the field. All fiber products tested had high degrees of variation in disintegration performance, illustrated by the wide boxplot range in Figure 18. Average residuals remaining by the endpoint were between 32-59%. Our research acknowledges recent findings that show a less active microbial environment within mesh bags compared to outside. This suggests the mesh bag may underestimate disintegration rates in real-world conditions, and should be taken into consideration when reviewing our results. *For results on a mass basis, please refer to Figure G in the Appendix.*

**FIGURE 17. AVERAGE RESIDUALS AND DISINTEGRATION OF ALL FIBER PACKAGING AND PRODUCTS (MESH BAG RESULTS)**

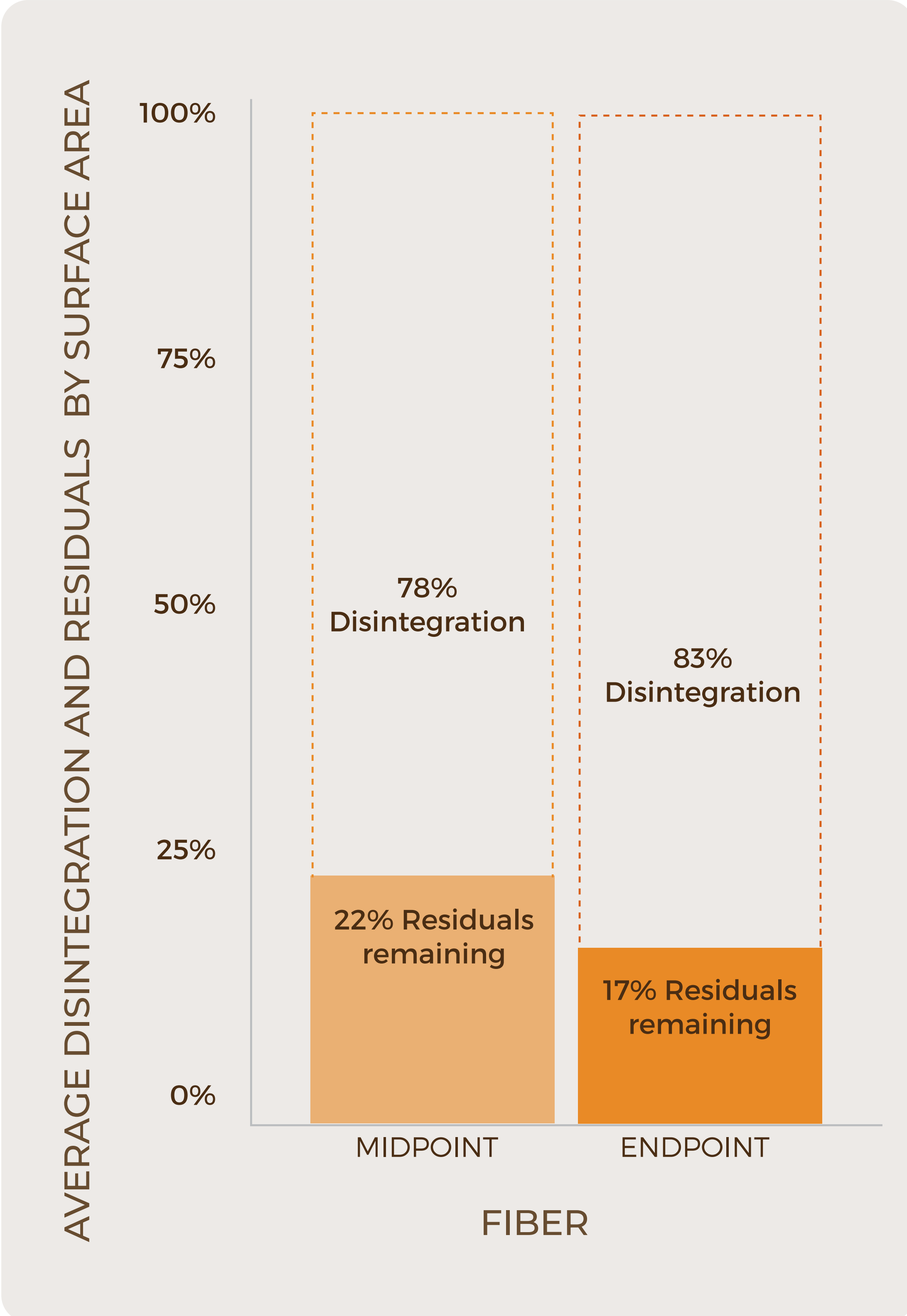
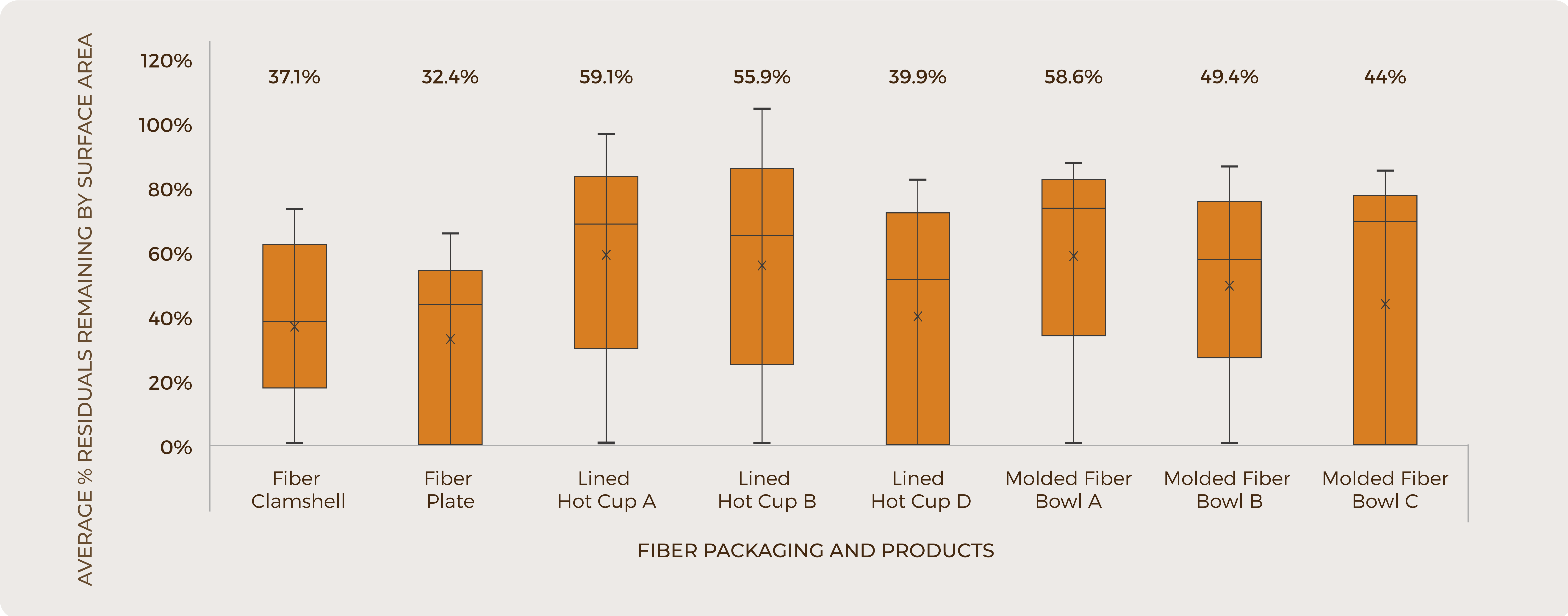


**FIGURE 18. AVERAGE RESIDUAL REMAINING OF FIBER PRODUCTS AT ENDPOINT OF STUDY (MESH BAG RESULTS)**

“Many composters do not consider fiber packaging a contaminant when fragments remain in their finished product because fiber packaging is not included as a contaminant in state compost quality requirements.”



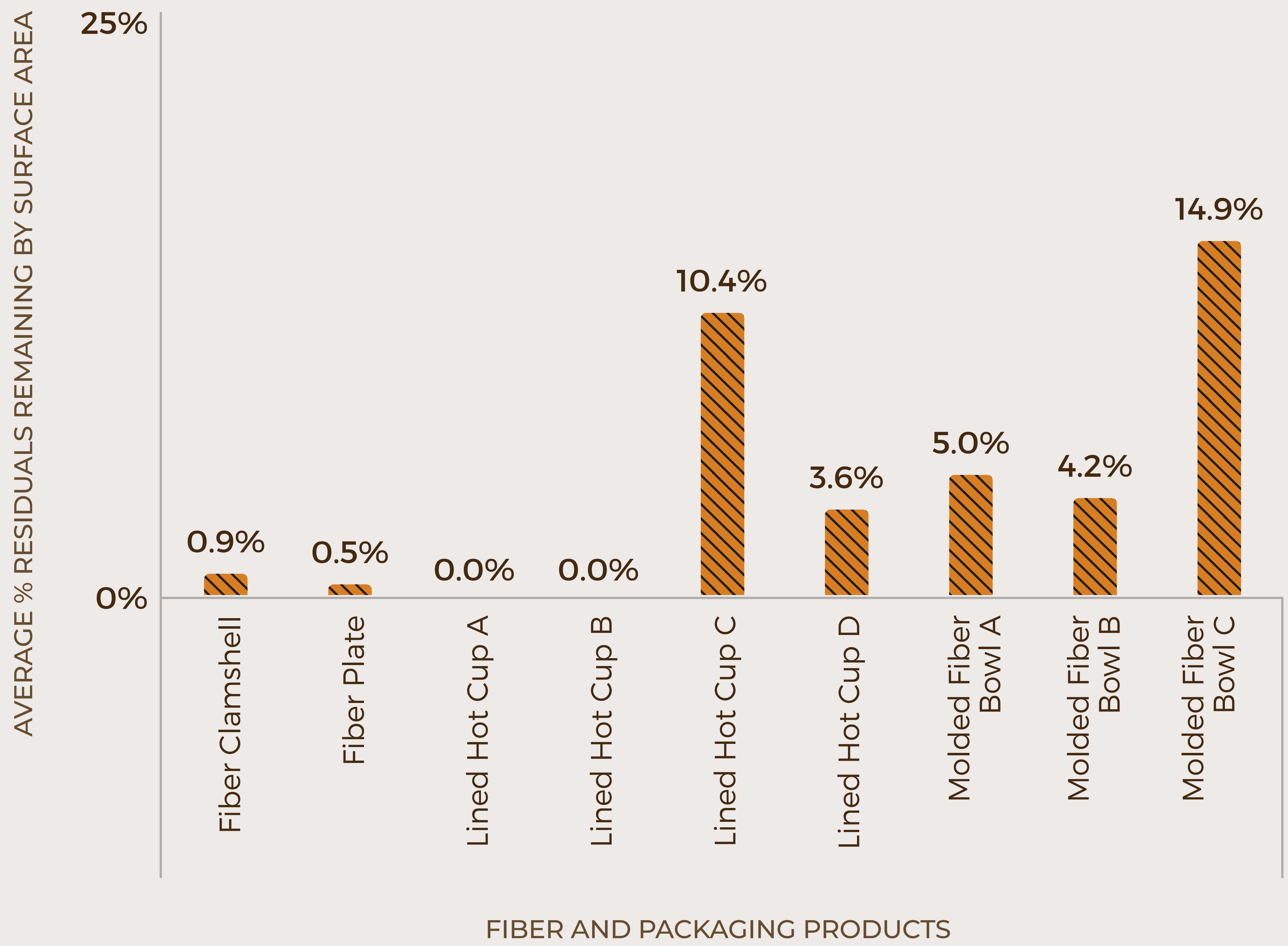

Note: Average % residual noted above each box plot and by the “x” in each box plot

## Dose Method Results

Fiber disintegration results using the dose method showed a marked difference compared to the fiber results in the mesh bag method. In-field fiber packaging performance appears to improve outside of the mesh bag. With the dose method, fiber products' average residuals remaining ranged between 0-15% residuals at the study's endpoint, meaning that fiber packaging tested using the dose method performed at least 30% better than the same packaging that underwent the mesh bag method. Figure 19 shows the average remaining residuals for each product across both dose facilities.

Furthermore, when looking at the dose results at the facility-level (see Figure 20), it appeared that there were no trace amounts of fiber packaging found at the in-vessel facility, at the midpoint

**FIGURE 19. AVERAGE % RESIDUALS OF COMPOSTABLE FIBER PACKAGING AT ENDPOINT BY SURFACE AREA (DOSE RESULTS)**



or the endpoint. Considering that the facility's total residency time in the in-vessel unit is only 19 days, the results are remarkable. One explanation could be its automated auger. The hypothesis sparked a series of analyses where our team pored over thousands of field data points to uncover correlations that would explain the difference in disintegration results between the dose and mesh bag method. Our conclusions, though preliminary, are an important discovery to support successful approaches to the disintegration of fiber packaging and guide best practices for composters looking to accept and process these materials.

## What Supports Fiber Disintegration?

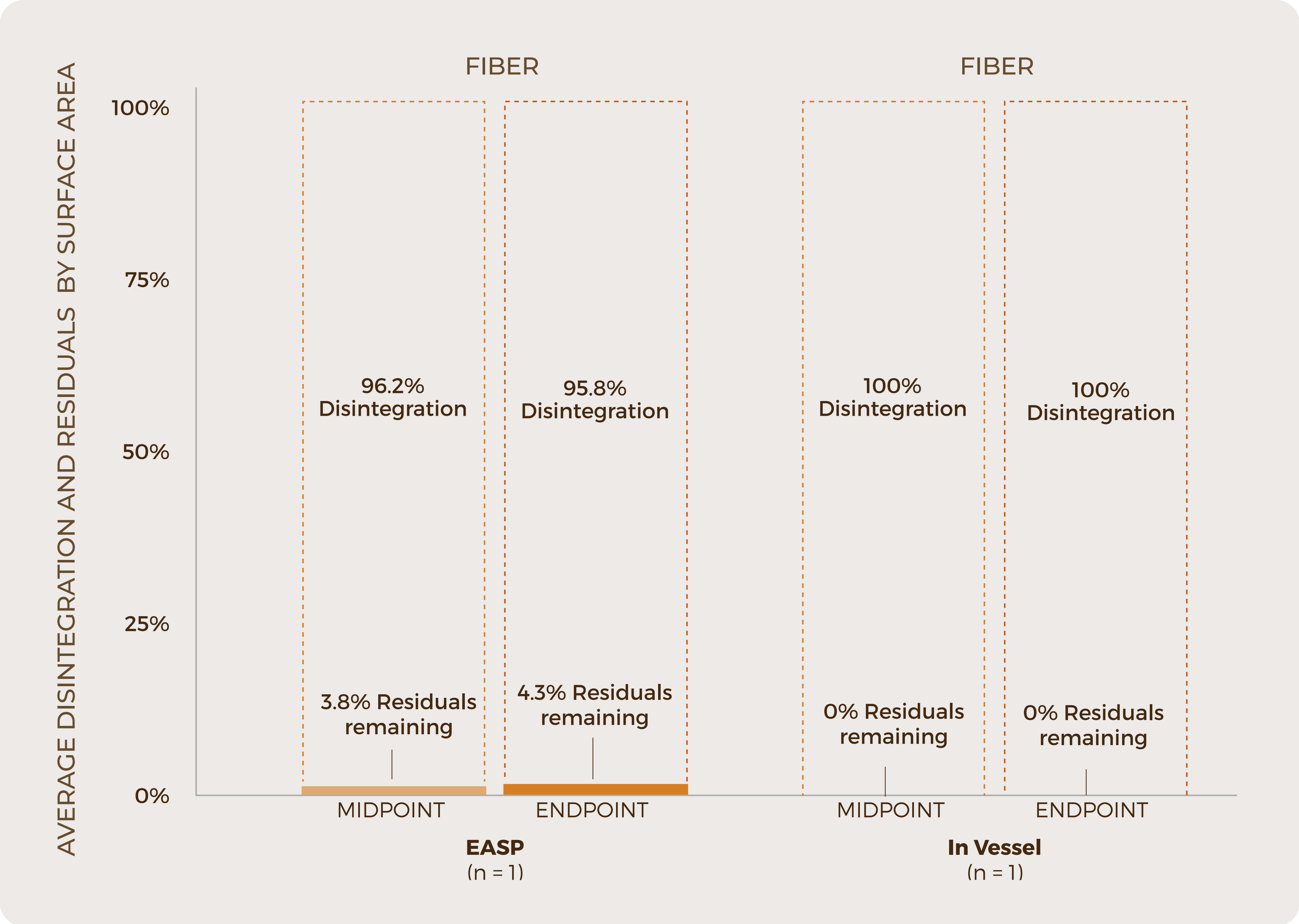
Through this study, our team found that fiber packaging disintegration improves under certain conditions and composting technologies. First, fiber packaging performed best in turned windrow facilities, compared to other compost technologies (See Figure 21). Windrow facilities typically have a longer residency time (i.e., 120-180 day compost process) and as their name suggests, compost piles also undergo regular agitation using a windrow turner.

Even though the compostable packaging does not undergo agitation while in the mesh bag, the agitation and length of the process seem to have a positive effect on disintegration. In contrast, aerated static piles (ASP) and extended ASP had the highest residual results for fiber packaging. ASP systems blow air through the compost pile (i.e., positive aeration) or suck air down through the compost pile (i.e., negative aeration). Covered ASP (CASP) will have a positive or negative aeration feature; however, the compost pile is also contained in a non-porous blanket-like covering (i.e., GORE cover).

When looking at specific features of each facility, our results indicate that turning has the most positive influence on fiber packaging disintegration in the compost pile (Figure 22). Facility 1, 5 and 10 each had residual rates less than 10% at the end of the study, even when using the mesh bag results. Facilities 2, 6, 8, and 9 all had a forced aeration feature in their compost process and had residuals rates ranging from 26-53%. *For results on a mass basis, please refer to Figure H in the Appendix.*

> "Our results indicate that turning and mechanical agitation has the most positive influence on fiber packaging disintegration in the compost pile."

**FIGURE 20. AVERAGE RESIDUALS REMAINING OF FIBER PACKAGING BY FACILITY (DOSE RESULTS)**




## Composting Technology Trends

The majority of composting facilities in the United States today operate a windrow process.[16] Windrow facilities have a longer overall process compared to other types of compost technologies like aerated static piles (ASP) and in-vessel technologies.[17] Over the last decade, more compost manufacturers are opting for shorter compost processing time because the majority of a composters' revenue comes from tip fees, and as such, maximizing speed and throughput supports their business model. In-vessel composting technologies, compared to ASP and windrow, have a fraction of the capacity an ASP or windrow facility might have.[18] Several companies around the world sell in-vessel composting solutions as on-site food waste solutions.

## FIGURE 21. AVERAGE RESIDUALS OF FIBER PACKAGING BY COMPOST TECHNOLOGY (MESH BAG RESULTS)

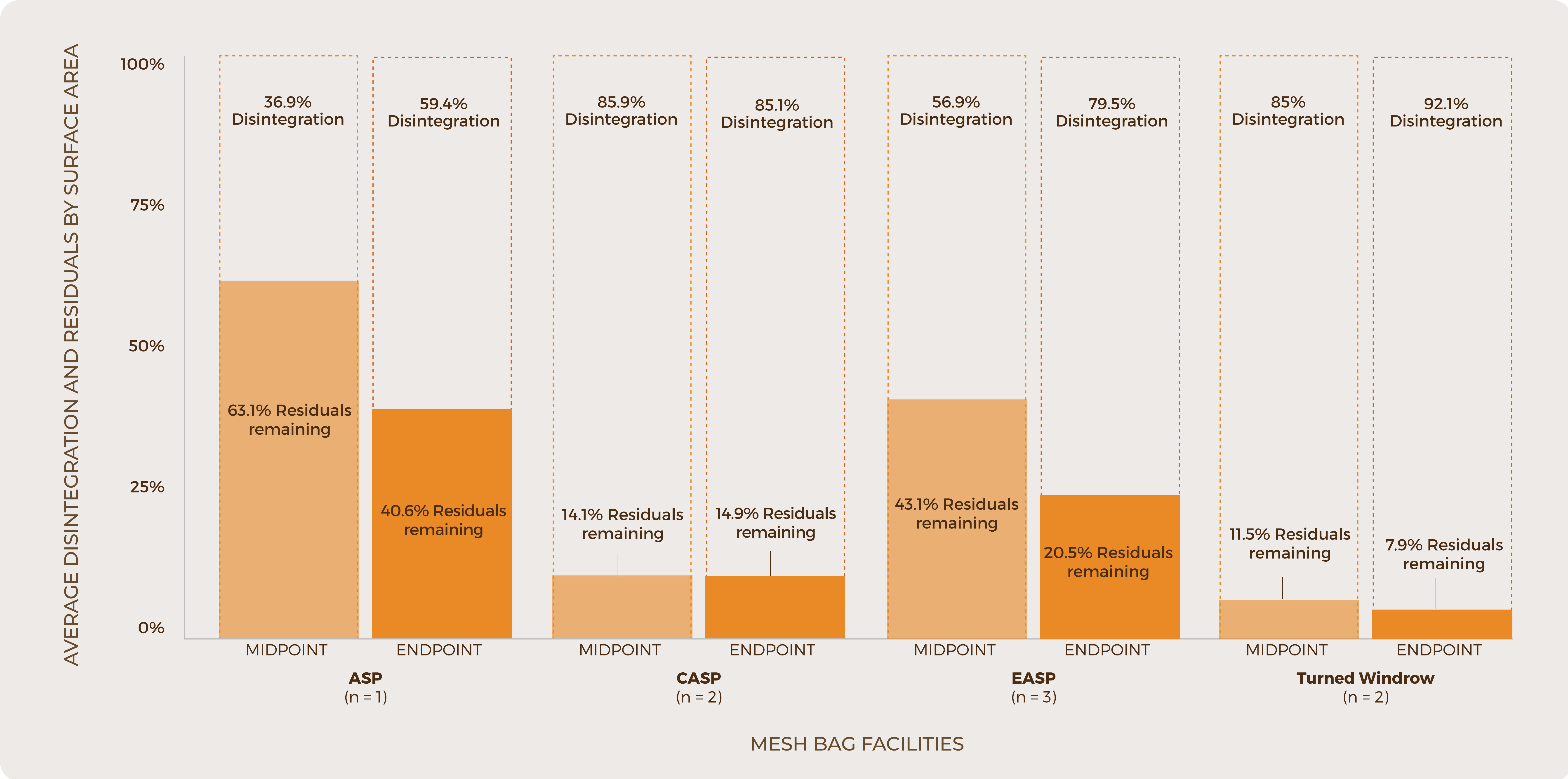
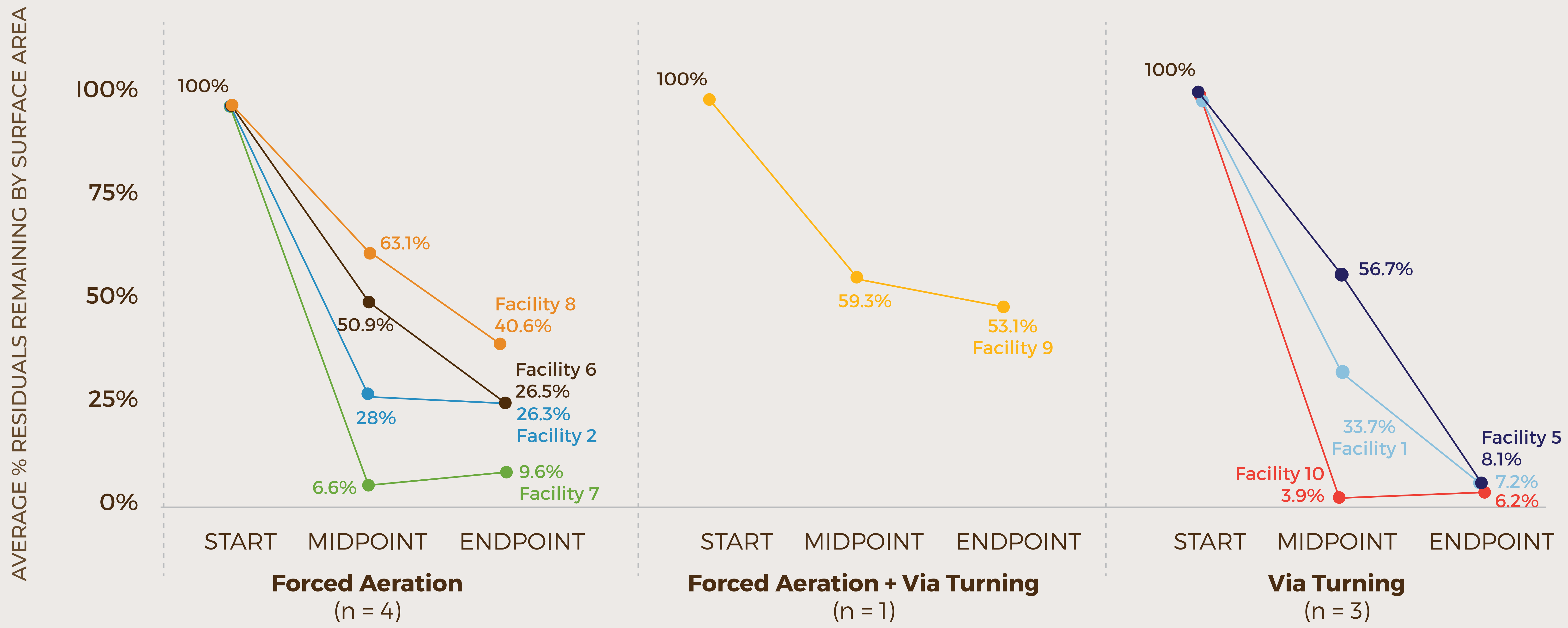


**FIGURE 22. AVERAGE RESIDUALS REMAINING OF FIBER COMPARED BY FORM OF TURNING AND AERATION AT ENDPOINT (MESH BAG RESULTS)**

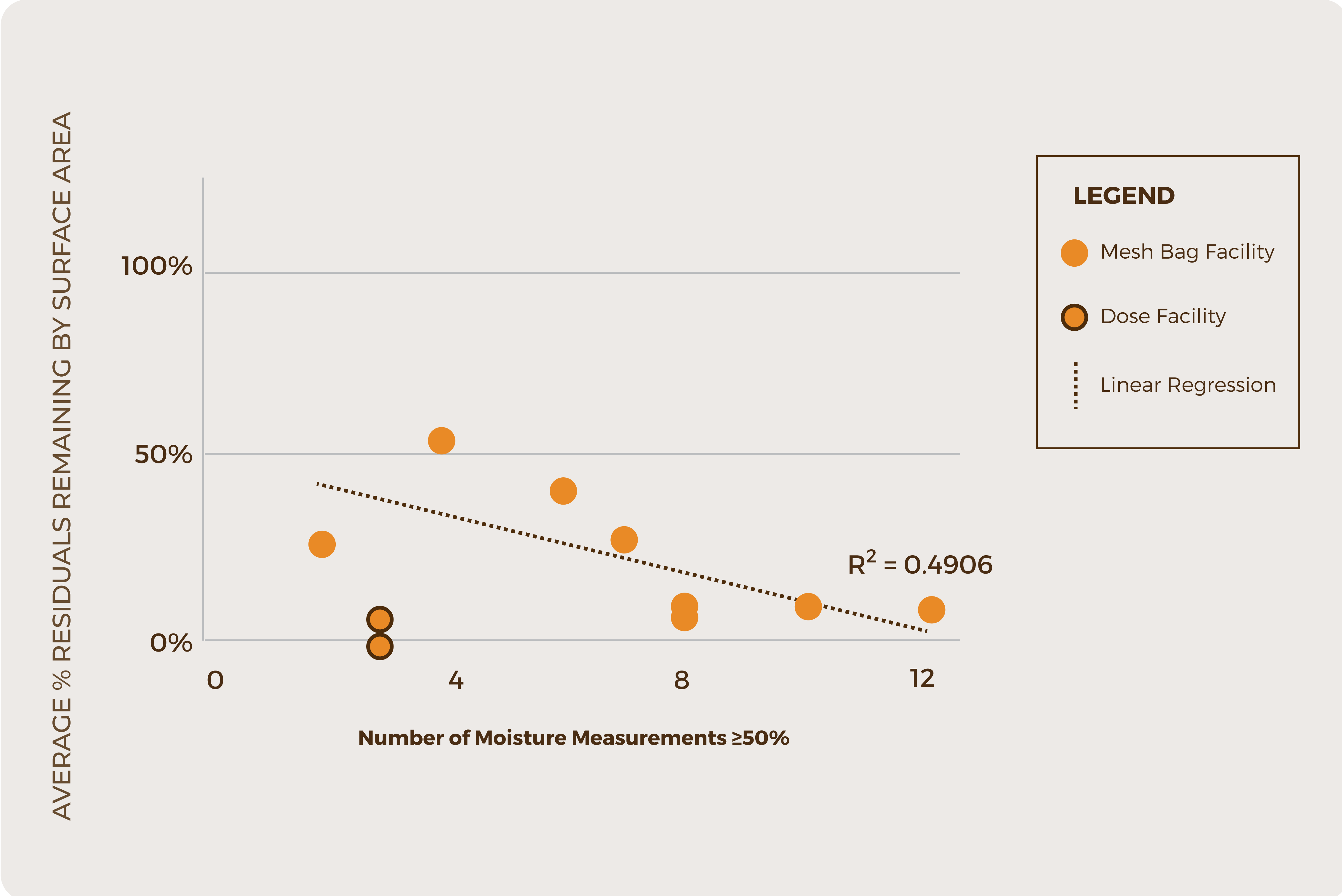



Note: Each plot point represents the disintegration average for that category of products at a given facility.

Moisture also seems to have a strong influence on fiber packaging disintegration. Our compost partners submitted weekly compost pile moisture readings. This enabled our team to measure the number of times their piles were in a specific moisture range. Greater consistency of moisture levels above 50% supports fiber disintegration. Figure 23 notes the number of times moisture measurements read above 50% during the study, and the average fiber packaging residual remaining (%) is indicated by a point on the graph. As the dotted line illustrates, the greater the incidence of moisture above 50%, the lower the fiber residuals. *For results on a mass basis, please refer to Figure I in the Appendix.*

> “Greater consistency of moisture levels above 50% supports fiber disintegration.”

**FIGURE 23. RECORDED INCIDENTS OF MOISTURE MEASUREMENTS >50% AND THE IMPACT OF DISINTEGRATION FOR FIBER PACKAGING (MESH BAG AND DOSE RESULTS)**




Note: When reading this graph, each dot represents a single facility's average results.

# PART 4. WHAT NEEDS TO BE TRUE FOR COMPOSTABLE PACKAGING TO SUCCEED IN THE MARKET?

**While certified food-contact compostable packaging has the potential to be a viable alternative to replace food-contact single-use conventional plastic, our work with composters and the composting industry has highlighted that successful disintegration of compostable packaging alone is not enough to ensure widespread acceptance and adoption of these new materials. To achieve this, a collaborative effort across the entire value chain is necessary.**

One critical factor for success lies in the design of the certified food-contact compostable packaging itself. Brands, retailers and packaging manufacturers have a responsibility to formulate these packaging and products in a manner that aligns with the diverse technologies and methods employed by composters. Ineffective design, leading to incomplete breakdown, can negatively impact compost quality and overburden composters with sorting challenges. This, in turn, erodes their confidence and willingness to accept certified food-contact compostable packaging materials, hindering the system's overall effectiveness.

Effective labeling and consumer education are equally important. As the compostable packaging industry continues to evolve rapidly, stakeholders must work together to standardize design approaches and marketing messages. Consumers often struggle to distinguish between compostable, recyclable and conventional packaging.[19] Research by the Composting Consortium and Biodegradable Products Institute (BPI) identified clear consumer preferences for the design of certified food-contact compostable packaging that utilizes two to three design elements (e.g., color scheme, text size) to communicate compostability effectively.[20] This, alongside other valuable findings, is detailed in the linked consumer perception report on this page.

Composters concerns around contamination from look-a-like conventional packaging is a barrier to compostable packaging acceptance. Increasing acceptance of compostable packaging across the U.S. will require solutions to solve for contamination in the organics stream. A whopping 78% of composters who process food waste but do not allow compostable packaging cite confusion with conventional plastic packaging and products as the main reason.[21] Our own research into this challenge in composting reveals that 85% of the contamination that a composter receives is rigid and flexible conventional plastic; more data and information on contamination can be found in our full report linked on this page.

## OTHER RESOURCES


Composters also play a vital role in the success of certified food-contact compostable packaging. Our research indicates that compost facilities adhering to the "reasonable conditions" outlined in *The Composting Handbook*[22] are best positioned for processing of certified food-contact compostable packaging. These conditions foster optimal composting environments that promote sufficient packaging breakdown. Therefore, promoting best practices specifically tailored to certified food-contact compostable packaging handling is essential.

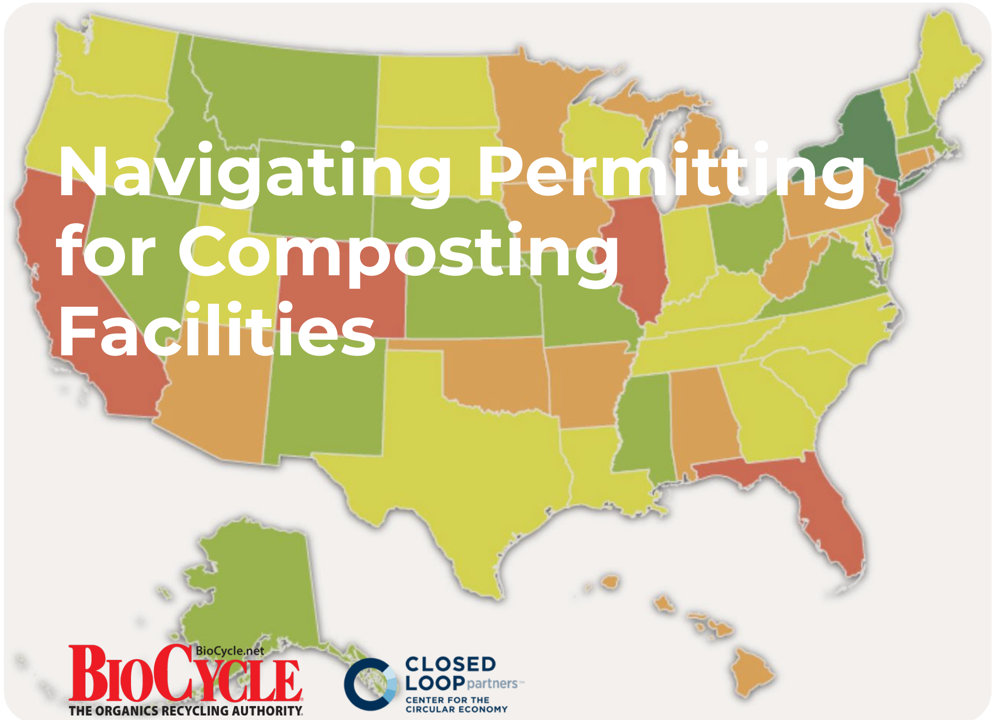
Educating composters on proper handling and processing techniques will build trust and equip them to manage new material inputs effectively. Collaboration between brands, manufacturers and composters is crucial to maximizing the environmental benefits of certified food-contact compostable packaging–and is a key focus of the Composting Consortium's work, with its corporate partners and industry groups like the US Composting Council.

Scaling up infrastructure is critical to ensure sufficient capacity for processing certified food-contact compostable packaging, diverting it from landfills and capturing its environmental benefits. The U.S. composting industry, historically focused on yard waste alone, is undergoing an exciting waste diversion from landfills. This shift towards embracing a wider range of organic materials, including food waste, presents a tremendous opportunity for not only certified food-contact compostable packaging to become a mainstream alternative to conventional plastics but to also scale processing capacity that can divert food waste from landfill and reduce greenhouse gas emissions.

While many yard-waste composting facilities may require upgrades to accept food waste and meet state permitting requirements, such as installing impermeable flooring or enclosing specific areas,[23] these are achievable. The Composting Consortium has even evaluated the organics permitting laws of all 50 states to understand the ease of transitioning yard-waste compost sites to process both food scraps and certified food-contact compostable packaging. This analysis, linked on this page, offers valuable insights for stakeholders navigating this transition.

**In conclusion, unlocking the full potential of certified food-contact compostable packaging demands a multi-faceted approach. Collaborative efforts to design packaging with composter compatibility in mind, coupled with clear labeling and consumer education, as well as investment into scaling infrastructure are all essential. Furthermore, promoting best practices among composters and incentivizing their acceptance of compostable materials will ensure a robust system for processing certified food-contact compostable packaging. By addressing these crucial aspects, we can usher in a new era of sustainable packaging solutions, significantly reduce landfill waste and emissions, and create a more circular economy for organic waste.**

## OTHER RESOURCES



# CONCLUSION

## CONCLUSION

**This comprehensive study by the Composting Consortium has provided valuable insights into the disintegration of compostable packaging in real-world composting facilities. Our findings offer strong evidence for the efficacy of compostable packaging as a sustainable alternative to conventional plastics.**

Key takeaways highlight the successful breakdown of both compostable plastic and fiber packaging across various composting technologies and operating conditions. On average, compostable plastic packaging achieved a remarkable 98% disintegration, while compostable fiber packaging reached an average disintegration of 83%, which meets existing field testing thresholds to meet certification. These disintegration results underscore the significant progress made in developing compostable materials that effectively break down in commercial composting environments that meet reasonable operating parameters (i.e., moisture, temperature, oxygen, etc.)

Our research also identifies areas for further study. For example, the results from this study reveal discrepancies in disintegration rates depending on the testing method employed (i.e., mesh bag vs dose method). These findings highlight the need for ongoing research and standardization of testing methodologies to ensure an accurate assessment of compostable packaging performance in the field. While there is a growing number of compost facilities who are accepting and processing food waste and food-contact compostable packaging, scaling up composting infrastructure remains crucial. This necessitates a collaborative effort between brands, packaging manufacturers and composters themselves.

**Moving forward, a three-pronged approach is essential to unlock the full potential of compostable packaging.** First, ensuring packaging design functions seamlessly across various composting technologies is paramount. Second, clear and consistent labeling will be crucial for consumer education and proper disposal practices. that mitigate contamination. Finally, continued investment in expanding composting infrastructure across the United States will be necessary to accommodate the expected influx of compostable packaging materials. By addressing these key areas, we can also divert significant organic waste from landfills, capture the environmental benefits of compostable packaging and create a more circular economy.

The Composting Consortium remains committed to collaborating with stakeholders across the entire value chain to realize this vision for a sustainable future for food waste and food-contact compostable packaging. To learn more and to get involved, visit https://www.closedlooppartners.com/composting-consortium/.

# APPENDIX

# TERMINOLOGY

**Active composting**: The phase after any pre-processing and before curing where feedstocks are decomposed by microorganisms under controlled conditions.

**Aerated Static Pile (ASP)**: A system of composting that involves forcing air through the processing mass from pipes below the pile. The air can be either pushed (positive mode) or pulled (negative mode). In negative mode, the captured air can be scrubbed for odors and/or used in various ways.

**ASTM:** ASTM International (formerly known as American Society of Testing & Materials).

**ASTM standard:** A document specifying the requirements for the quality and safe use of materials, which has been developed and established within the ASTM's consensus and approval processes.

**ASTM test method:** A standard which specifies how to assess a particular quality of a material, or "definitive procedures that produce a result. They usually include a detailed description of a procedure for determining a property or constituent of a material, an assembly of materials, or a product. These details include the apparatus, test specimen, procedure, and calculations needed for satisfactory results."

**Bulk Density:** Mass per unit volume of the sample.

**Certified compostable products:** Products capable of being processed by composting as verified by a third-party certification which uses recognized standards & independent testing labs for biodegradation testing.

**Compostable Field Testing Program (CFTP):** An international non-profit research platform bringing field testing to composters across North America and beyond, founded in 2016 by the Compost Research and Education Foundation and BSIbio Packaging Solutions.

**C:N:** Carbon-to-nitrogen ratio.

**Compost:** An organic soil amendment formed through the aerobic biodegradation of feedstocks including food scraps, leaf and/or yard waste, which has achieved stability and maturity.

**Compostable products and packaging:** Products and packaging that are designed and intended to be managed at end of life through composting.

**Covered Aerated Static Pile (CASP):** A composting process that involves covering an ASP either with a fabric or polyester cover or biolayers of organic materials (biocovers).

**CREF:** Compost Research & Education Foundation. One of the founding partners of the Compostable Field Testing Program.

**Curing period:** The phase after active composting that allows the compost to develop the desired characteristics for its intended use (The Composting Handbook, 2022).

**Detritus:** Organic debris, often found on residual fragments after composting.

**Disintegration:** Loss of mass or surface area through fragmentation into small pieces during a finite period of composting.

**Dose method:** A field test where no containment is used for the items being tested; they are directly in contact with the material being composted throughout the test.

**Endpoint:** The second and final bag removal period for facilities using the mesh bag method and the second and final material removal period for facilities using the dose method.

**Extended Aerated Static Pile (EASP):** An ASP composting system that has new compost cells constructed directly next to the preceding ASP.

**Field Testing:** Assessing the breakdown of compostable items in real-world composting conditions.

**Finished compost:** Compost that has been properly composted and cured, and often screened.

**Incoming feedstock ("feedstock"):** The organic materials needed for composting that come from a variety of sources such as yard waste, food waste, commercial and residential, etc.

**In-vessel composting:** A system of composting where the material is contained within a container or vessel for the duration of the composting process.

**Maturity (Solvita®):** The ability of compost to support plant growth. Measured in a lab with a bioassay using seed growth. Measured in the field measured using the Solvita test, which uses $CO_2$ and $NH_4$ emissions as a surrogate.

**Mesh bag method:** A field test where items being tested are contained in a mesh bag with other feedstock throughout the test.

**Midpoint:** The first bag removal period for facilities using the mesh bag method and the first material removal period for facilities using the dose method.

**Percent Residuals Remaining:** A value representing how much of an original item remains at the point of analysis. The percent residuals is the inverse of the disintegration rate, e.g., an item which has disintegrated 20% has 80% residuals remaining.

**Percent Residuals Remaining by Mass:** The value from calculating percent residuals using initial test item weights and final residual weights.

**Percent Residuals Remaining by Surface Area:** The value from calculating percent residuals using initial surface area and final residual surface area.

**Residuals:** The remains of the test items recovered during analysis. Also, may be the aggregate of individual fragments of test items.

**Screened overs (“overs”):** Material that does not pass through a screen. This includes both larger pieces of organic feedstocks, like pieces of wood, and non-organic contaminants, like plastic, rock and metal, that are too large to pass through the screen.

**Screened unders (“unders”):** The material that falls through the final screen in a compost facility and eventually becomes the final product.

**Stability (CO2 Evolution):** The measurement for an estimate of compost maturity based on the relative of microbial activity in a compost. It is measured by capturing carbon dioxide from a defined amount of compost for a defined amount of time.

**Static pile:** Freestanding compost piles that utilize little to no turning.

**Test items:** The foodservice packaging items and products tested in the study.

**Turned Aerated Piles (TAP):** Organic material piles typically formed into long rows (windrows) that are aerated by a forced air system and periodically agitated or turned.

**Windrows (or Turned Windrows):** Long narrow piles of organic feedstocks that are periodically turned or agitated.

**Unit of packaging:** A quantity of packages loaded into a mesh bag or dose environment. In the mesh bag trials, often one unit of a given type of test item was loaded per mesh bag, and for smaller test items (e.g. straws), multiple units of a given test item were loaded.

## FIELD TEST METHODS

The mesh bag method which served as the basis for this study was provided by the CFTP with amendments informed by the work of the ASTM D34 Committee WK80238. The components of the draft standard as of December 2022 were used, including the proposed positive control materials for evaluation, as well as the two removal and analysis periods ("midpoint" and "endpoint"). The dose method was developed based on early field tests conducted by the founders of the CFTP, with input from the ASTM WK80528 committee and from the composters who used the method. Both methods are outlined in step-by-step detail below.

### MESH BAG FIELD TEST METHOD

#### LOADING PROCEDURE:

**Preparation (Before Loading):**

1. **Choose a Test Location:** Select a suitable site for the mesh bags, considering ease of access and specific criteria. For existing piles and rows, choose a fresh, central section at least 10ft from the end. The pile should be immature with high moisture content. For a dedicated pile, construct a separate pile large enough to hold all bags with proper spacing (minimum 2ft between bags, 3ft from edges). Ensure the pile size approximates typical operating conditions (temperature, moisture).
2. **Prepare Bag Sets Indoors:** Pre-fill mesh bags with designated test items indoors for easier loading. Utilize the bag packing checklist and example bags for reference. Store filled bags indoors until loading day.
3. **Prepare Orange Peels:** Acquire 30 navel oranges and prepare peels for loading and documentation. Weigh and photograph each peel before or on loading day, following the "Orange Peel Data Log" and photo instructions.

**Loading Day (or 1-2 Days Prior):** Prepare a representative sample of your facility's feedstock for filling the mesh bags. The feedstock should be similar to your typical operations in terms of C:N ratio and no more than 2 days old.

**Packing Mesh Bags:** Thoroughly mix the set-aside feedstock according to your usual practices. Fill the mesh bags with the premixed feedstock, layering in the test items as you go. Remove any visible contaminants from the feedstock and avoid nesting test items. Take photos of the packed bag with its label and the feedstock used.

**Fill and Secure Bags:** Use a scoop or shovel to strategically layer feedstock and test items into the bags. Distribute test items evenly throughout the interior. Consider using a rigid cylinder to hold open the bag while loading. Aim for a consistent amount of feedstock in each bag to minimize variation. Ensure all test items are fully surrounded by the feedstock when the bag is full. securely close each bag with a black tie, knot, and a long zip tie woven into the knot for added security. Maintain visibility of the labeling zip ties.

**Data Collection:**

1. **Collect Feedstock Sample:** Take a 1-gallon composite sample of the mixed feedstock for lab analysis. Refer to the Compost Research & Education Foundation sampling videos for proper technique. Label the sample with facility name, date and testing stage. Ship it in an insulated container with an icepack if not

shipped immediately. Record this action in the "Parameters at Loading" datasheet.

2. **Record Initial Parameters:** Assess and document initial operating parameters like weather conditions, bulk density, ambient temperature and feedstock composition in the "Parameters at Loading" datasheet. Refer to the 'bucket test' method of bulk density assessment.

**Loading Bags into Pile/Windrow:** Securely attach ropes to each bag through and around the knot, leaving enough tail for a length to remain outside the pile. Adjust rope lengths as needed during loading. Carefully load the packed bags into the compost pile at the designated test location, ensuring they meet the minimum distance requirements from edges (3ft) and other bags (2ft). Once buried, mark the test area with highly visible flagging tape attached to the remaining rope ends.

**Document and Report:** Record the bag locations in the "Bag Locations Log" and take photos of bag placement. Optionally, draw diagrams to share. Upload all photos and completed datasheets to your facility's Google Drive folder. If data was recorded on paper, digitize it into the online "Composters Data Entry - [Facility Name]" spreadsheet.

## MONITORING PROCEDURE:

### Parameters to Monitor:

- **Temperature (Daily):** Using the "Daily Temperature Log," record readings from at least five to ten points around the test area, taken at least two feet below the pile's surface.
- **Moisture (Weekly):** Assess moisture content using a squeeze test on five samples collected around the test area. Weekly data is recorded in the "Weekly Measurements Log." Oven drying and lab testing are optional procedures during this phase.
- **Oxygen (Bi-weekly):** Evaluate oxygen levels at five locations around the test area every two weeks using an oxygen probe. Utilize the "Weekly Measurements Log" for reporting.

**Monitoring Afer First Analysis:** Following the bag removal and analysis on Day 45, initiate bi-weekly testing for compost maturity using the Solvita Basic Compost Maturity Test. Record the results in the dedicated "Solvita Measurements Log" tab within the "Composters Data Entry" spreadsheet. A 6-pack of the Solvita Basic Compost Maturity Test will be provided. The included manual provides instructions for proper use. Remember to refrigerate the kits when not in service to maximize their lifespan.

**Field Analysis:** On Day 90, or upon curing completion (whichever occurs first), perform the final bag removal and analysis. Your team has 3-7 days to remove and sift the bags after extraction.

**Data Management:** Consistently upload all logged data, including photos and digital entries in the "Composters Data Entry" spreadsheet, to your facility's data folder. Maintain a bi-weekly data submission schedule throughout the trial period.

## MANAGING INTERVIALS – REMOVAL AND RELOADING PROCEDURE

**Removing and Reloading the Mesh Bags:** Mesh bags remain in the composting system for a minimum of 45 days, potentially up to 120 days. During this period, removals may be necessary for turning the pile/row or transitioning the bags from active composting to curing.

### Removal:

1. Prior to turning, carefully remove the bags by hand or with machinery assistance. If using machinery, prioritize safety and coordinate with the operator.
2. Hand-dig the bags if machinery is unavailable.
3. Record all retrieved bags in the "Bag Recovery Record" datasheet. Only repack close-to-failure bags (intact but near tearing).
4. Discard ripped or torn bags with potential product loss.

**Repacking:**

1. Empty the bag contents onto a clean tarp.
2. Reattach the colored zip tie label from the old bag to a new double-layered bag using a neutral zip tie.
3. Repack the new bag with the original contents, maintaining product separation and placement as in the original loading. If pile moisture is increased, add a similar amount to reloaded bags.

**Reloading:**

1. Reload the bags following the same procedures used for initial loading.
2. Place the bags back in their original test area whenever possible unless moving them to curing.
3. Track new bag locations in the "Bag Locations Log" if seeking remote team feedback on placement.
4. Share all photos and completed datasheets in your facility data folder. This includes the latest "Bag Recovery Record" (mandatory) and "Bag Locations Log" (optional).

## REMOVAL FOR ANALYSIS PROCEDURE:

*Remember to schedule bag removal 3-5 days before analysis to permit drying. Removal for analysis first happens at Day 45. The second and final removal for analysis happens either at the specified trial end-date for your site (target Day 90) or at the end of your typical curing time – whichever comes first.*

**Mesh Bag Removal for Analysis:** Carefully remove bags by hand or machine, as described in the management of removals and reloads. Record all retrieved bags in the "Bag Recovery Log," noting any differences in bag depth, surrounding moisture, temperature, and compost composition. These factors might influence product disintegration. On Day 45 only, submit the "Bag Recovery Log" for immediate guidance on reloading specific bags and those designated for analysis. Contact your team for instructions as needed.

In the "Parameters at Removal" datasheet, log temperature, moisture, bulk density, and any other observations regarding pile conditions where the bags were located. Refer to the provided sampling videos by the Compost Research and Education Foundation to collect samples promptly after removal. Refrigerate the samples until shipment. After shipping, note the shipment date in the "Parameters at Removal" datasheet.

**Drying and Reloading Bags:** Hang or lay the bags selected for analysis flat, ensuring they don't touch each other. Drying takes 3-7 days and depends on local conditions. Optimal dryness is achieved when compost easily falls out of the bag's holes when shaken. On Day 45 only, for bags designated for further composting, follow the reloading procedure. Repack any close-to-failing bags following the management interval instructions.

**Shipping and Reporting:** Ship lab samples in the provided coolers and cold packs to the lab. Refrigerate samples if not shipped the same day. Share all photos and completed datasheets in your facility data folder.

## ANALYSIS PROCEDURE:

**The following steps detail the two analysis procedures, occurring at Day 45 (latest Day 49) and the trial's end. Field support will lead the first analysis with your team's assistance.**

**Preparation:** Use reference bags to identify product fragments during sifting. Group mesh bags by set (color-coded) to the designated sifting area.

**Set up the sifting area:** Arrange a comfortable sifting station (e.g., table) to avoid excessive bending. Designate areas for discarding fines, photographing, and storing sifted materials. Prepare a photo station with a phone, tripod, and grid paper. Locate necessary equipment (scissors, sifting screens) and establish discard locations for fines and overs.

**Sifting and Residual Collection:** Sift one bag set at a time to simplify residual identification. Discard materials passing through the screen (fines). You may need to use a stick or fork to aerate heavily compacted bags. Identify and collect product fragments as you sift. Use sorting trays and reference bags to aid in matching residuals. Log all recovered residuals in the "Residual Recovery Log." Gently brush residual compost matter off fragments without causing damage. Do not discard any results.

**Photographing Residuals:** Place residuals on the grid paper with the date, facility name, and product ID label. Group and photograph fragments from the same product together, replicating the original shape if possible. If no residuals are found for a product, photograph the grid paper with the ruler and ID label for documentation. Photograph any control material residuals (orange peel, film, paper, cup) following the same protocol.

**Packing, Shipping, and Reporting:** Individually bag each residual set for shipment, then place them in an insulated container with an icepack. Label the bags and ship to the lab promptly. Refrigerate if not shipped the same day. Upload all photos and completed datasheets (including digital entries in the "Composters Data Entry" spreadsheet) to your facility data folder. Inform the designated contact upon data upload completion.

## DOSE FIELD TEST METHOD

### LOADING PROCEDURE:

**Preparation and Dosing:** We recommend wearing gloves and a respirator during this procedure. Choose a test location. Select an accessible, manageable area unlikely to be disturbed during the trial. Open test item boxes and loosely arrange them in containers for dosing. Refer to the product inventory spreadsheet to familiarize yourself with the items and their quantities (no need to recount). In the Loading Datasheet, report the number and fullness of containers used to hold the de-nested items.

**Collect Feedstock Sample:** Use the provided videos to create a 1-gallon composite sample enclosed in a Ziploc bag. Label the Ziploc bag with facility name, date, and testing stage. Ship it in an insulated container with ice (refrigerate if not shipped immediately) to the lab. In the "Parameters at Loading" datasheet, log weather conditions and measure bulk density using the "bucket test" method explained in the appendix. Collect the required amount of premixed feedstock in a designated location. Ensure it's either your typical mix or comparable in C:N ratio. Report any variations from your usual feedstock in the records.

**Dose and mix:** Gather the required quantity of premixed feedstock. *Important note: the feedstock must be no more than two days old. Remove any contamination or non-test kit compostable packaging before dosing.* Layer, mix and spread the test items as evenly as possible throughout the feedstock pile. If windy, create troughs in the feedstock, sprinkle the mixed items in, and fold the pile over them. During dosing, take photos of the feedstock (pre-dosing), loading process, and dosed pile with marker items. Upload these photos to your facility data folder.

### MONITORING PROCEDURE:

**Parameters to Monitor:** Regularly update and submit your completed monitoring datasheets, at least bi-weekly, throughout the trial to your facility data folder.

- **Temperature (Daily):** Using the "Daily Temperature Log," record readings from at least five to ten points around the test area, taken at least two feet below the pile's surface.
- **Moisture (Weekly):** Assess moisture content using a squeeze test on five samples collected around the test area. Weekly data is recorded in the "Weekly Measurements Log." Oven drying and lab testing are optional procedures during this phase.
- **Oxygen (Bi-weekly):** Evaluate oxygen levels at five locations around the test area every two

weeks using an oxygen probe. Utilize the "Weekly Measurements Log" for reporting.

If included in your test protocol, after a midpoint sampling and analysis, you may begin bi-weekly testing for compost maturity using the Solvita Basic Compost Maturity Test (refer to separate instructions for Solvita test if applicable). A 6-pack of the Solvita Basic Compost Maturity Test will be provided. The included manual provides instructions for proper use. Remember to refrigerate the kits when not in service to preserve their lifespan.

## REMOVAL PROCEDURE:

**Sample Removal and Management:** Material removal must occur 1-3 days before planned sifting to optimize efficiency. There are two analysis points: midpoint (between composting phases) and endpoint. Endpoint analysis occurs on Day 90 (standard curing time), or when the trial concludes. Field support will be present at the midpoint analysis to assist and demonstrate the process.

**Extraction and Material Management:** In the "Parameters at Removal" datasheet, record temperature, moisture, bulk density (using composite samples) from the dosed area, and any observations about the pile's condition. Take a 1-gallon composite sample for lab analysis using the Compost Research & Education Foundation's methods. Ship the sample to the lab using the provided coolers and cold packs. Refrigerate the sample if not shipped immediately.

Before moving the material, take down marking flags or pylons from the dosed area. Remove the dosed compost, mixing it thoroughly to ensure even distribution of test items throughout the material. Avoid incorporating any un-dosed material during this process.

**Separate Material:** Set aside half the dosed material for screening and sorting. At the midpoint only, move the remaining dosed material to curing, marking its new location and recording any observations in the "Parameters at Removal" datasheet. If the material is very wet on removal day, spread it in a thin layer (24" or less) to dry before screening. Avoid drying during high winds or rain to prevent loss of product fragments or excessive moisture absorption. Upload all logged data (photos and datasheets) to your facility's data folder.

## RESIDUALS RECOVERY PROCEDURE:

**The following steps outline the process for screening and analyzing compost material to recover test item residuals. Ideally, screening occurs at least one day before sorting fragments for efficient analysis.**

**Preparation:** Move designated dosed material to the screening area. Establish a designated area to deposit "overs" (material remaining after screening) for further sorting. Secure this area to prevent disturbance.

**Screening:** Screen the entire designated dosed material at once, if feasible. Record the volume of "overs" containing test item residuals and wiffle balls (tracer objects). Reintroduce fines (material passing through the screen) back into the composting process, away from the test area. Spread the "overs" into a thin layer for visual analysis.

**Visual Analysis:** A team of two to three members will visually inspect the "overs" pile, counting all visible residuals and wiffle balls. Record counts and observations about residual condition on the provided datasheet.

**Sample Collection and Sifting:** Set up a designated area for sorting residuals, including a work surface, weighing stations, photo stations, and data recording areas (digital or paper). Overlay a numbered 1 foot x 1 foot grid on the "overs" pile using pylons and flags. Use a random number generator to select at least 15 sampling locations. Collect sub-samples from each designated sampling area using a 5-gallon bucket.

**Sifting and Residual** Recovery: Sift through the collected sub-samples to recover test item fragments. Use reference products and inventory photos to identify residuals. Record all recovered residuals in the "Residual Recovery Log," noting any variations in product disintegration. Gently brush residual compost matter off fragments without causing damage. Photograph each product residual and any control material residuals individually.

**Shipping and Reporting:** Pack residuals from the same item together in individual Ziploc bags. Place the bags in an insulated container with an ice pack for shipping. Label the bags and ship to the lab promptly. Refrigerate if not shipped the same day. Upload all logged data and photos to your facility data folder.

## ANALYSIS PROCEDURE:

**Disintegration Rate Calculations in Lab:** Due to the large volume of dosed material, a sub-sampling method is used to estimate test item disintegration rates. The data provided by facilities is processed off-site, in lab, to calculate disintegration rates. Residuals (fragments) are recovered from a portion of the screened material and extrapolated to represent the entire pile.

The percent residuals remaining can be calculated based on either the volume sampled or the presence of the negative control, in this case wiffle balls. Note: the wiffle ball calculation method is experimental for the purposes of this study, and the volume-based disintegration calculation is preferred.

### Disintegration Calculation (Volume-based):

1. Obtain total volume of "overs" from the facility-submitted data.
2. Calculate the volume of sampled "overs". Number of samples x volume per sample.
3. Calculate the sampled ratio. Divide the volume of sampled overs by the total volume of overs.
4. Calculate the volume adjustment factor. Multiply 0.5 (half the material is screened per analysis) by the sampled ratio.
5. Determine weight and surface area of the residuals recovered, per item type. Using the in-lab methods for weighing and determining surface area, add the values for all fragments recovered for a particular item type. Since items are likely to fragment into several pieces during decomposition, it is not feasible to calculate disintegration based on a single item residual against a single intact item weight/surface area.
6. Calculate the Residuals Remaining. Residuals remaining = weight or surface area of recovered residuals / [weight or surface area of intact product x quantity loaded x volume adjustment factor]

### Disintegration Calculation (Wiffle Ball - Experimental):

1. Minimum Threshold: The number of recovered wiffle balls must meet a minimum threshold based on the dosed quantity and volume adjustment factor. This represents the "expected count" in the samples.
2. Usability: If the recovered wiffle ball count falls outside ±10% of the expected count, wiffle balls cannot be used for disintegration calculations (assumes homogenous distribution).
3. Calculation: If enough wiffle balls are present, follow the volume-based calculation steps, but use the recovered vs. loaded wiffle ball ratio instead of the volume adjustment factor.

### If No Residuals Are Found:

Since only a portion of the "overs" is sampled, representing 1% to 7% of the total "overs", it's possible that residuals exist elsewhere in the pile and were not captured in the sub-samples. Absence of residuals in the sub-samples should not necessarily be interpreted as complete disintegration.

## APPENDIX TABLE A: OUR STUDY TESTED 30 DIFFERENT TYPES OF CERTIFIED COMPOSTABLE PLASTIC AND FIBER PACKAGING

### 14 Types of Certified Compostable Products

**Food**
Cutlery
Plates
Clamshells
Bowls

**Snacks**
Metalized films
Non-metalized films

**Beverage**
Straws
Splash sticks
Hot cups
Cold cups
Hot cup lids
Cold cup lids
Coffee pods

**Miscellaneous**
Liner bags

### 9 Compostable Plastic Material Types

PHA
PLA
cPLA
PBAT/multi-laminate
Metalized PLA multi-laminate
Metalized PLA/PHA multi-laminate
PHA/cellulose film
PHA multi-laminate
Cellulose (control)

### 7 Fiber Material Types:

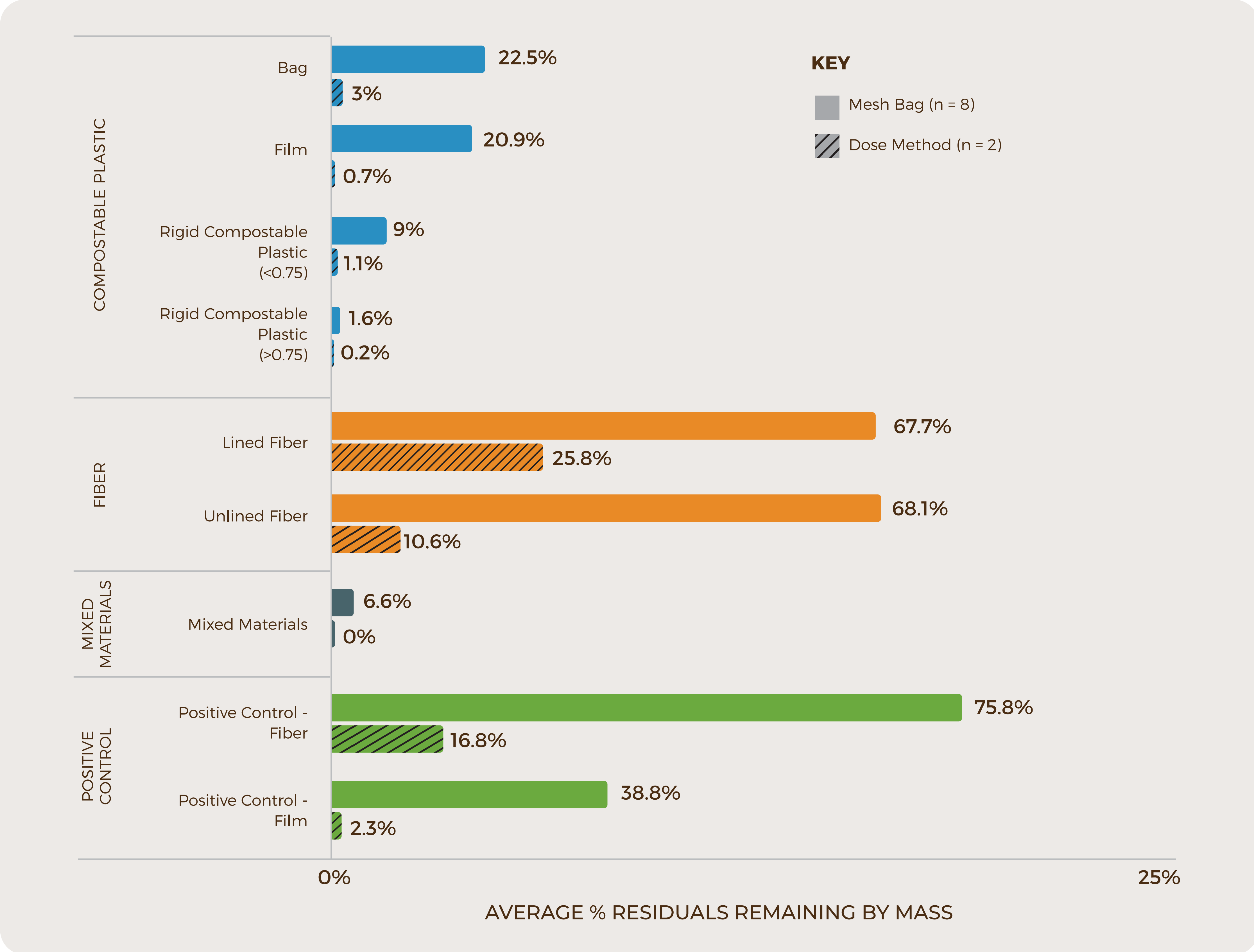
Biopolymer-lined fiber
PHA-lined tree fiber
PLA-lined tree fiber
PLA-lined sugarcane fiber (bagasse)
Unlined sugarcane fiber (bagasse)
Unlined molded fiber (mixed fibers)
Butcher paper (control)

## APPENDIX TABLE B. CONSIDERATIONS FOR UNDERSTANDING THE STRENGTHS AND WEAKNESS OF MASS AND SURFACE AREA AS METRICS FOR DISINTEGRATION

| CONSIDERATION | MASS | SURFACE AREA |
|---|---|---|
| **Potential for the geometry of a 3D object to bias the result** | Non-issue. Mass measurements are unaffected by the geometry of test item residuals. | Notable issue. Test items are not always flattenable for accurate measurement. Brittle residuals have the potential to break when flattening. |
| **Reliability for capturing thickness** | Captures all dimensions, including thickness. | Only captures two of the three dimensions of a test item. If a test item is originally thick, and thins due to disintegration during the trial, surface area measurements will not capture this change. |
| **Directionality of bias of measure** | Values for percent residuals remaining are systematically inflated (by detritus and absorption of non-evaporable substances). This means disintegration may be underestimated when using mass as the metric. This study illustrates this bias is most severe for fiber items. | Values for percent residuals remaining are deflated if the item has folds or is not flattened fully. The percent residuals remaining values are inflated if item has stretched (especially possible for biopolymer films), has come apart into its multiple layers (for multilayer or lined products), or if holes are not measured and subtracted from image processing. The directionality of bias for surface area is variable, and not as predictable as mass. |
| **Ease of measurement** | Straightforward, overall. Weighing items is time consuming, because it is important to take a dry weight, which requires air drying or use of a dehydrator. Accurate mass measurements require a high-precision scale. | Difficult, overall. Quantifying surface area requires careful arrangement of residual fragments for photographing with contrast, favorable lighting and a straight angle, as well as the use of image processing software (or labor-intensive measurements). This is time-intensive and expensive due to high labor costs. |
| **Common Sources of Error** | Detritus; absorption of non- evaporable substances | Crumbling of brittle residuals; difficulty flattening 3D for measurement; holes in films not detected by image processing |

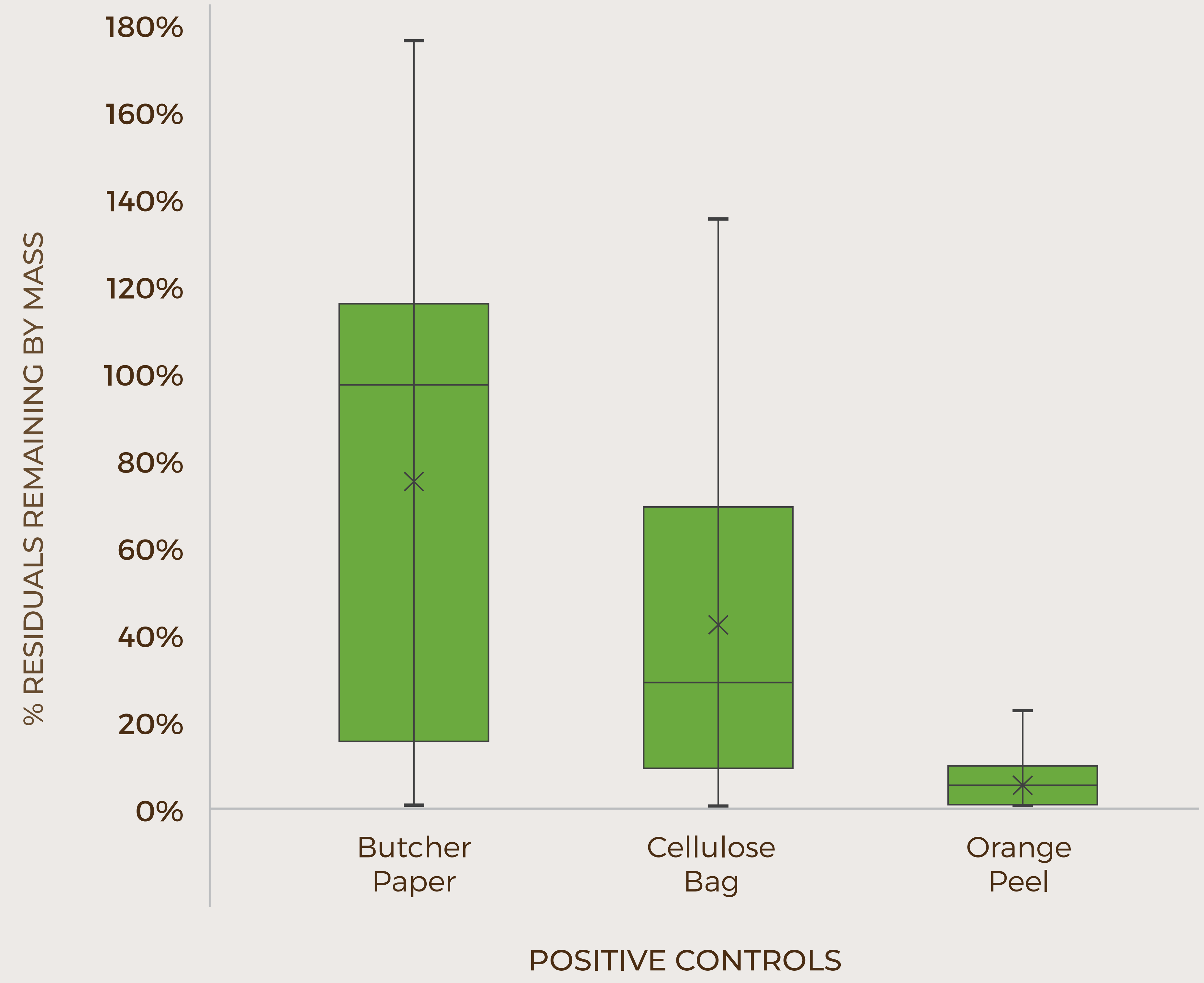
## FIGURE A. MESH BAG VS DOSE METHOD AVERAGE RESIDUAL RATES, BY MATERIAL FORMAT

Figure A shows the results of mesh bag versus dose final residuals, grouped by material type and format. Average residuals for compostable plastic products at the end study were between 0% to 3% at dose facilities and between 2% to 23% at mesh bag facilities. Average residuals percentages for fiber packaging and products at the end of the study were between 10% to 26% for dose facilities and 68% residuals at mesh bag facilities.



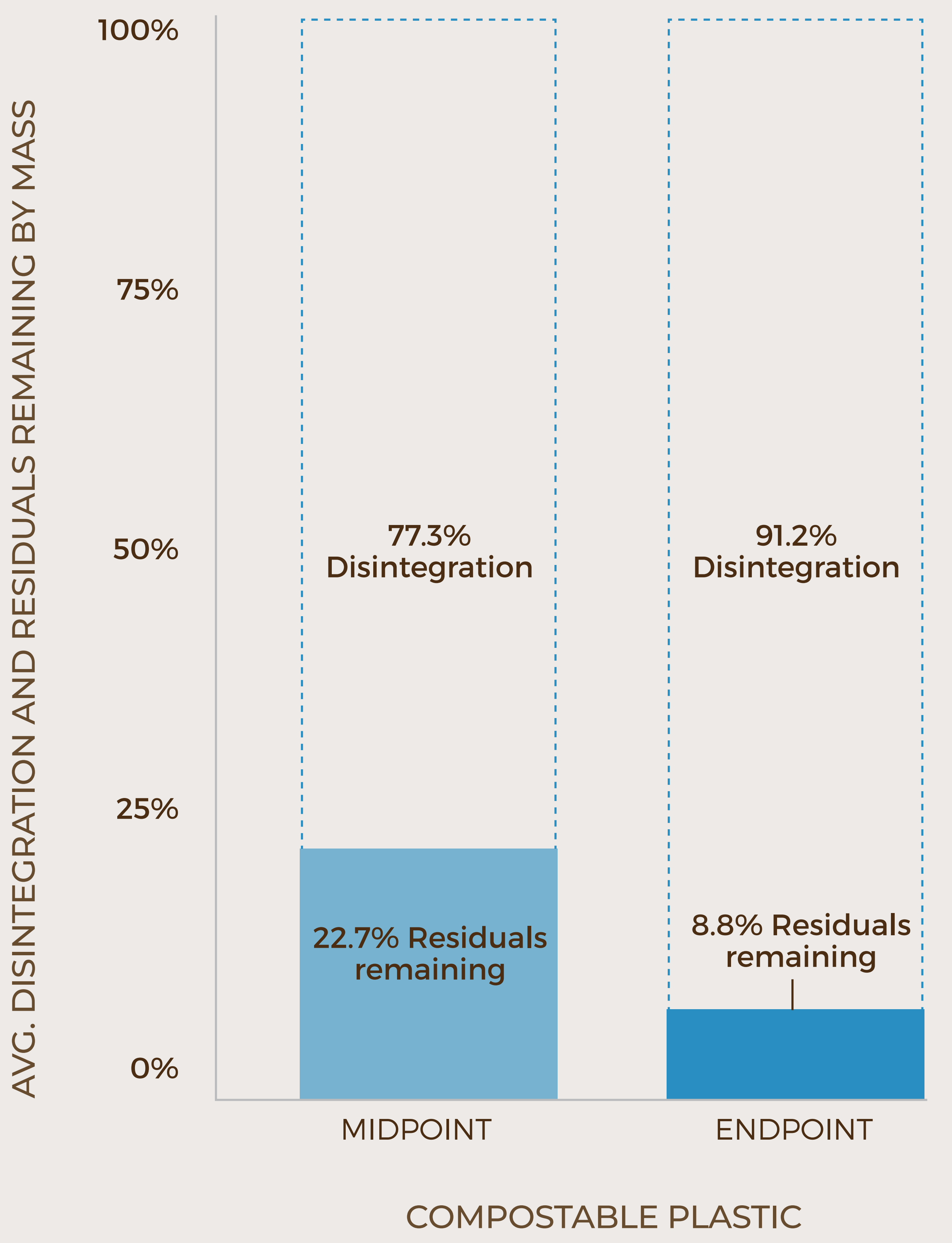
### FIGURE B. RESIDUAL RATES FOR POSITIVE CONTROLS IN OUR STUDY (MESH BAG RESULTS)

Figure B indicates a slightly wider degree of variation in the performance of positive controls in our study when observed on a weight basis.

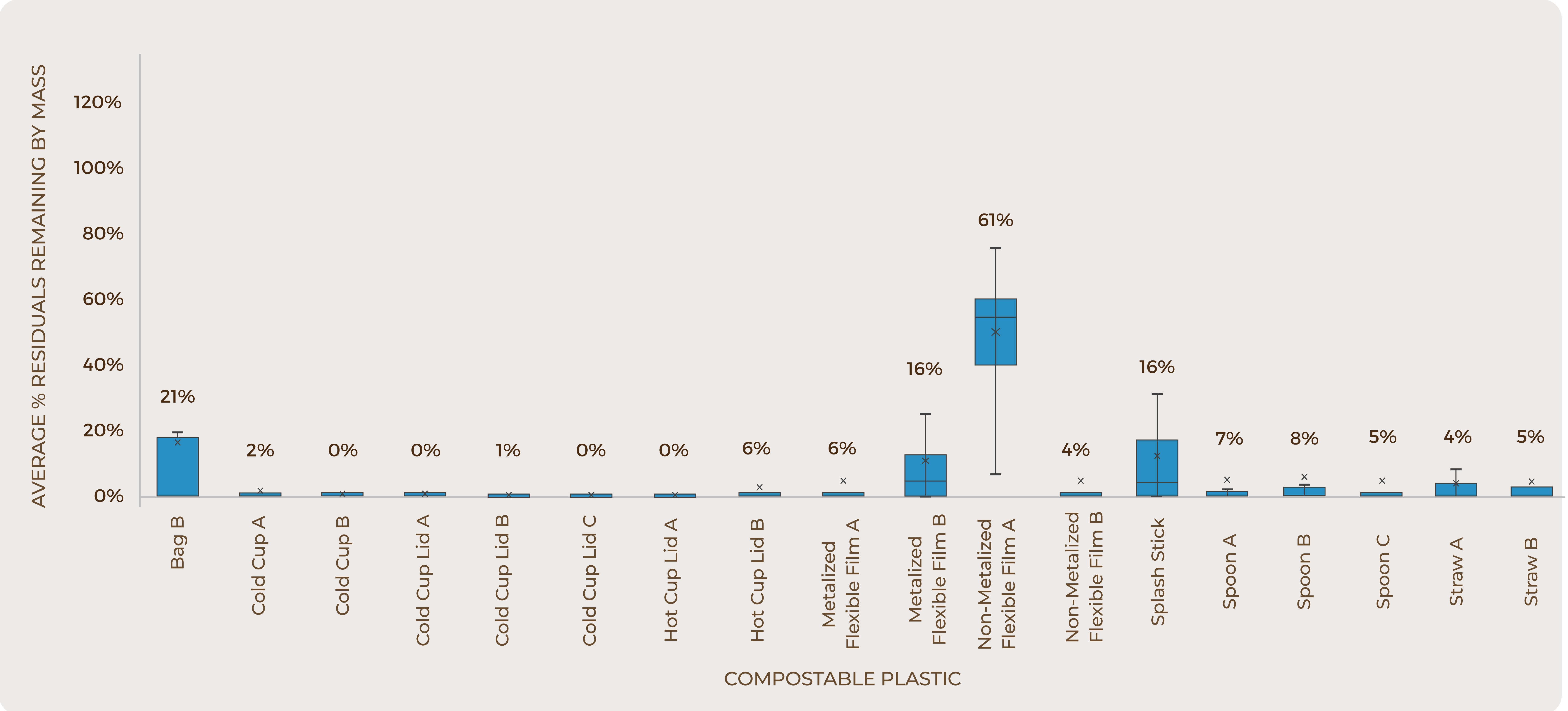


### FIGURE C. AVERAGE RESIDUALS REMAINING OF ALL COMPOSTABLE PLASTIC PACKAGING (MESH BAG RESULTS)

Figure C shows the average midpoint and endpoint residual rates for all 18 compostable plastic packaging tested on a weight basis. On average, compostable plastic packaging and products had 9% residuals remaining at the endpoint through the mesh bag method.



## FIGURE D. AVERAGE RESIDUALS OF COMPOSTABLE PLASTIC PACKAGING AT ENDPOINT (MESH BAG RESULTS)

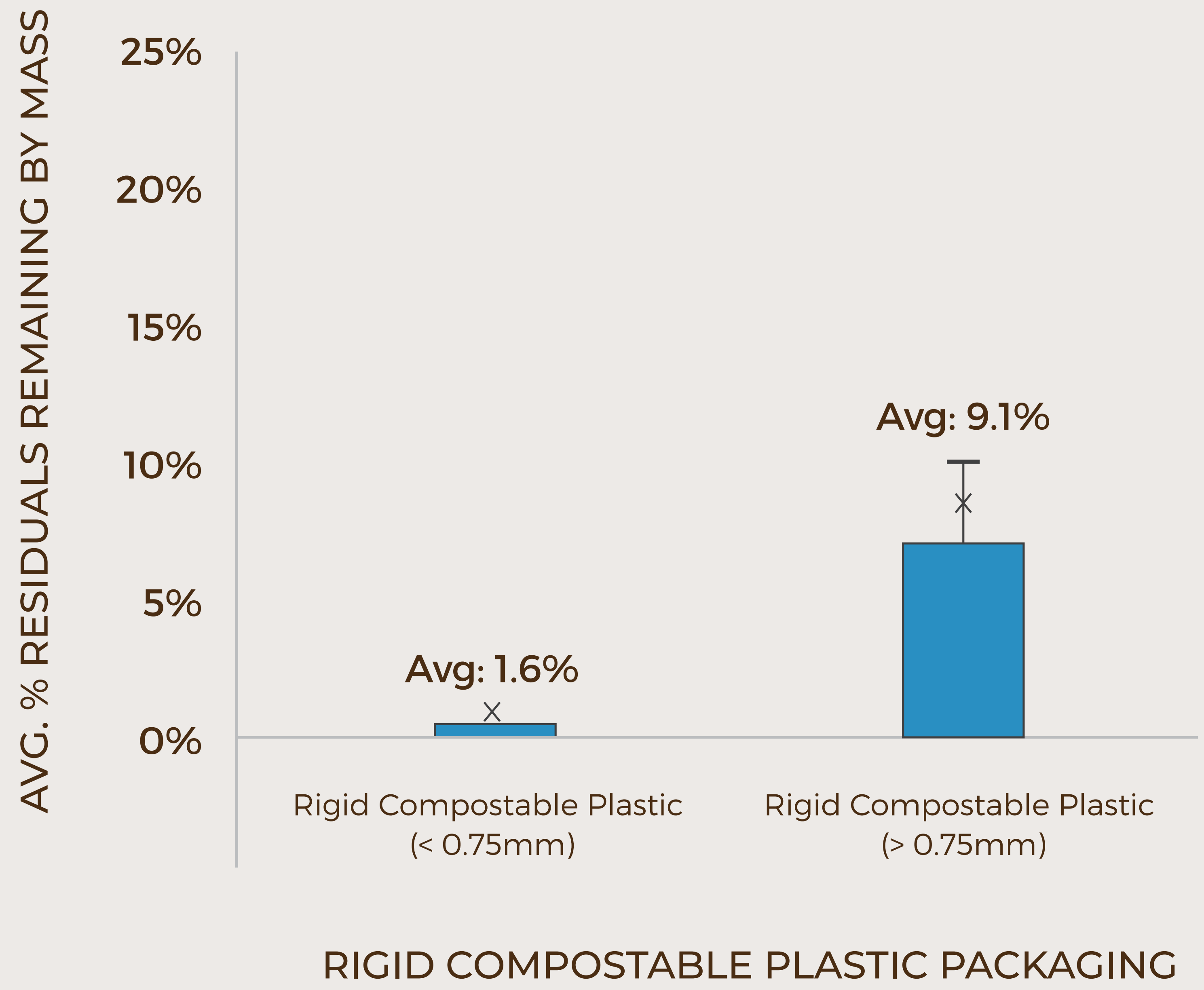



Notes: Average % residual noted above each box plot and by the "x" in each box plot.

Non-Metalized Flexible Film A failed ASTM D6400 testing while being trialed in field during our study.

**FIGURE E. AVERAGE RESIDUALS OF RIGID COMPOSTABLE PLASTIC PACKAGING AT ENDPOINT (MESH BAG)**

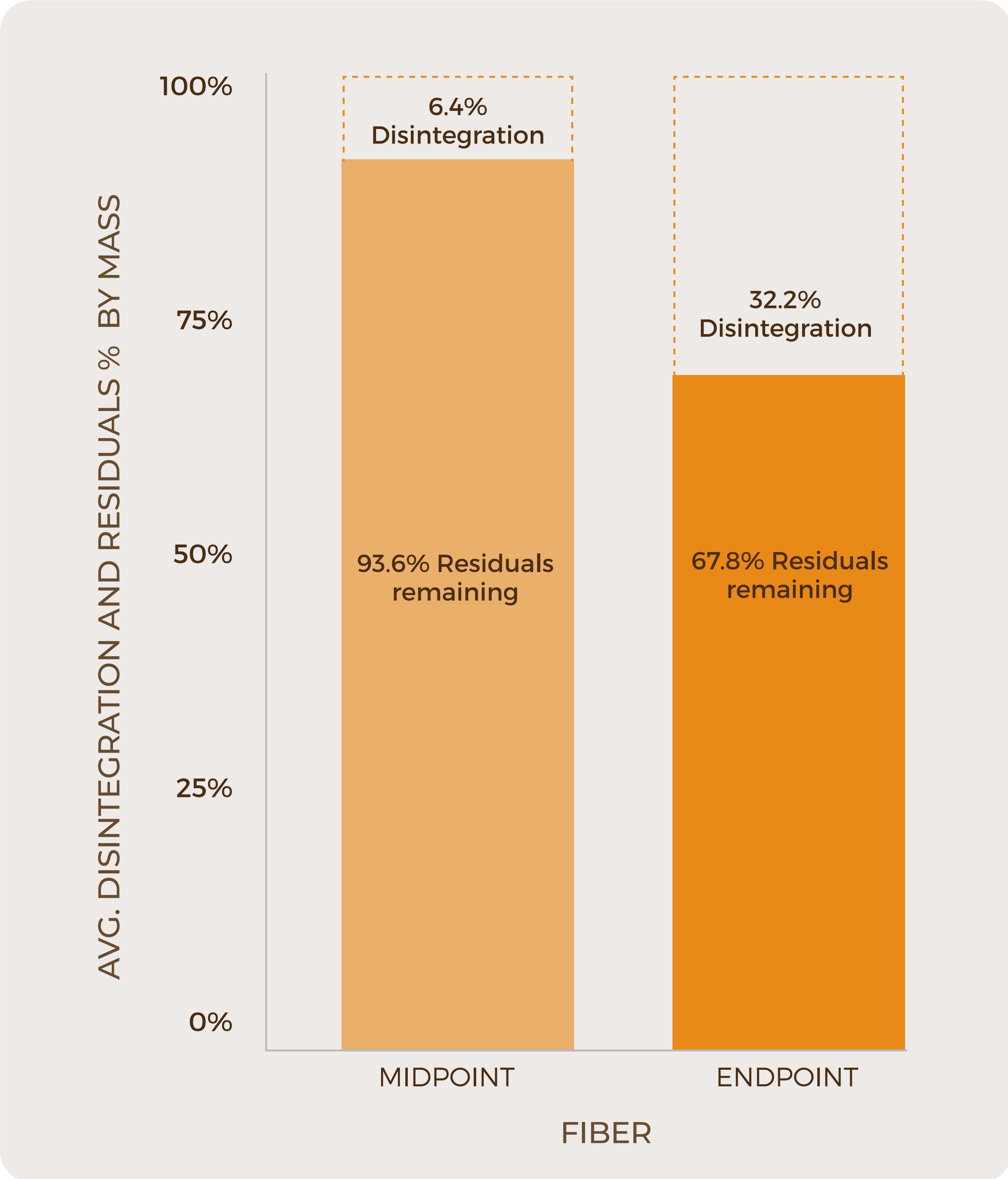
Figure E illustrates disintegration results of rigid compostable plastics by product thickness on a weight basis.




Note: When both rigid and flexible compostable plastics are viewed as a group, there is no relationship between thickness and disintegration.

### FIGURE F. AVERAGE RESIDUALS REMAINING FOR FIBER PACKAGING AND PRODUCTS AT MIDPOINT AND ENDPOINT OF STUDY (MESH BAG RESULTS)

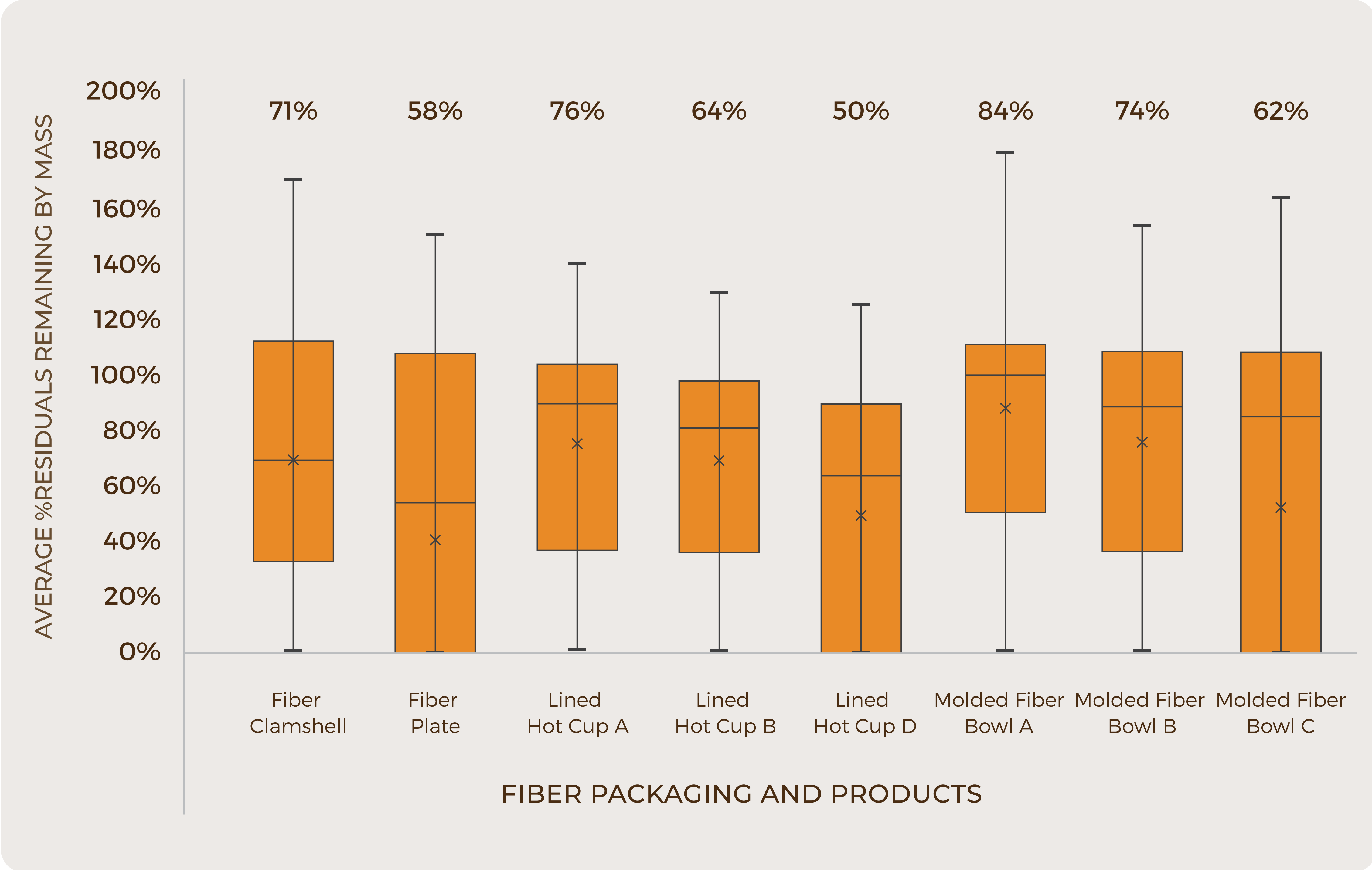
Figure F shows the average residual percentage by weight for all eight fiber products in the mesh bag method. On average, fiber packaging and products had 68% of the product remaining at the endpoint through the mesh bag method.




Note: In some instances, the average remaining fraction of residuals was found to be slightly greater at the endpoint than at the midpoint

**FIGURE G. AVERAGE RESIDUAL REMAINING OF FIBER PRODUCTS AT ENDPOINT OF STUDY (MESH BAG RESULTS)**

The average residuals remaining of fiber products by the endpoint were between 50-84% on a weight basis, bolded above the box plots.




Note: Average residual % noted in orange

**FIGURE H. AVERAGE RESIDUALS REMAINING OF FIBER COMPARED BY FORM OF TURNING AND AERATION AT ENDPOINT (MESH BAG RESULTS)**

As Figure H shows, the relationship between turning, aeration and disintegration of fiber packaging is less notable when observed on a weight basis. Of note, at the midpoint, many fiber products appear to increase in weight, which may be due the accumulation of detritus or absorption of oily substances.

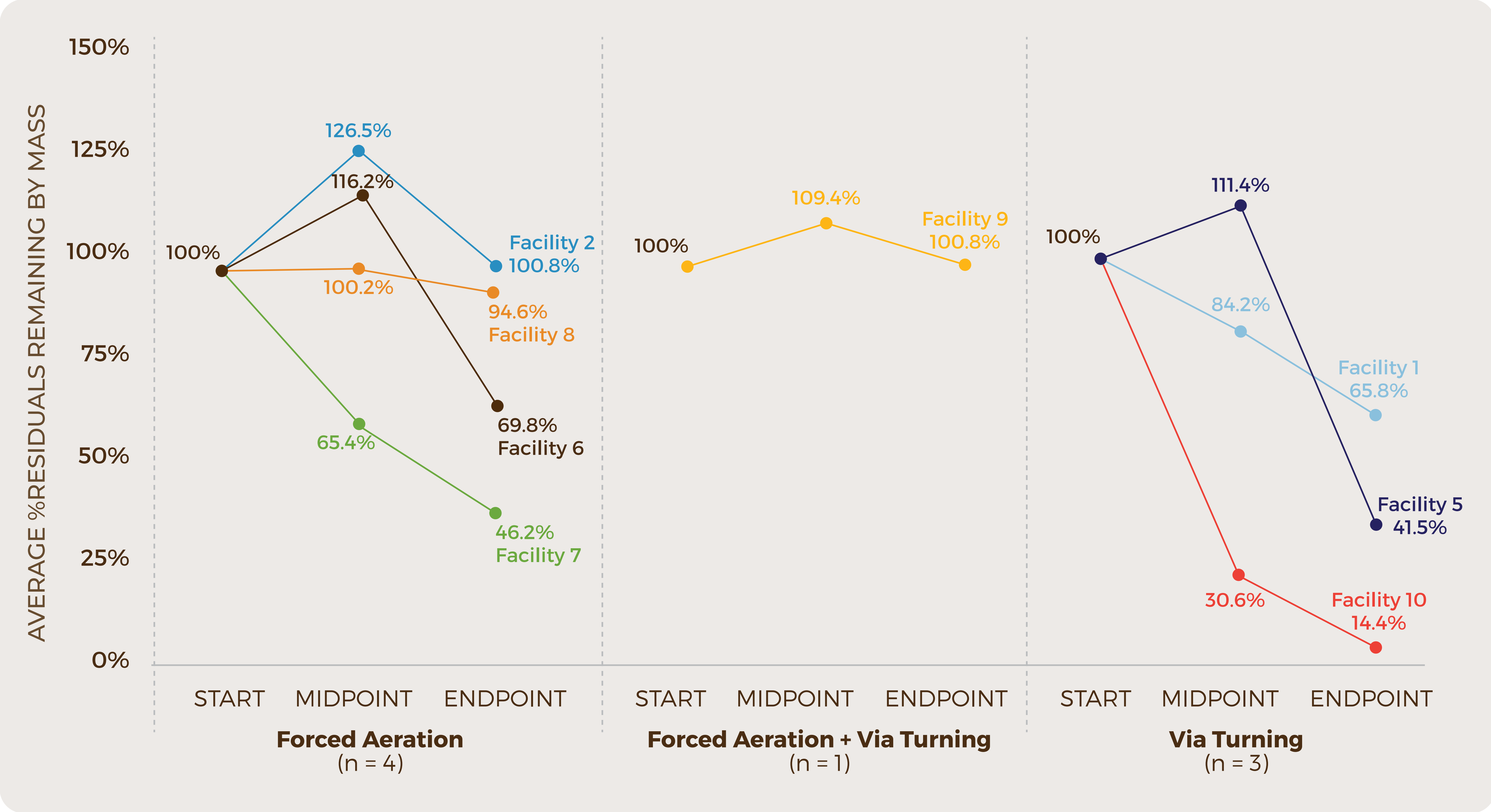
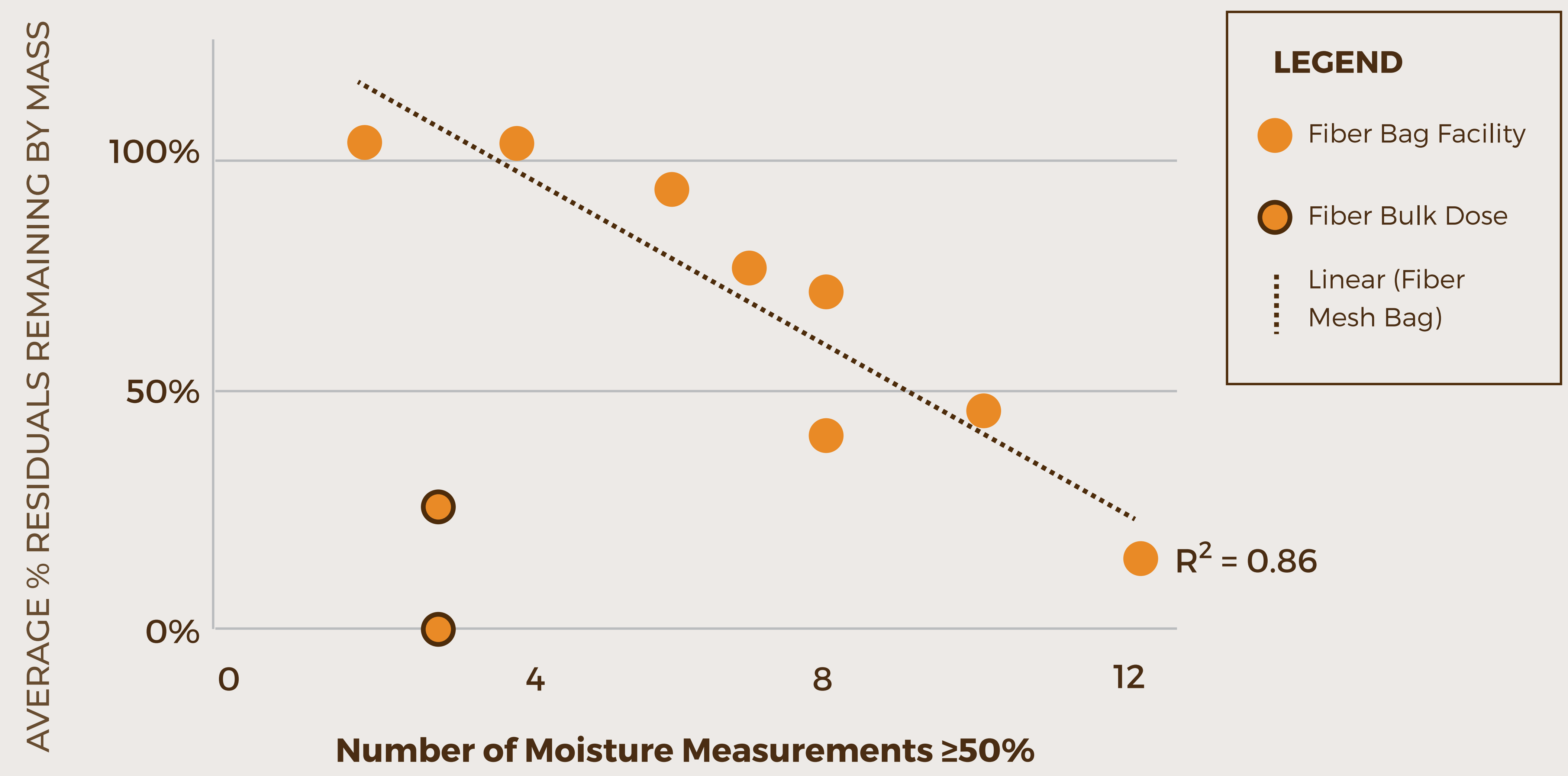


**FIGURE I. RECORDED INCIDENTS OF MOISTURE MEASUREMENTS >50% AND THE IMPACT OF DISINTEGRATION FOR FIBER PACKAGING (MESH BAG AND DOSE RESULTS)**

Figure I notes the number of times moisture measurements read above 50% during the study, and the average fiber packaging residual remaining (%) is indicated by a point on the graph. As the dotted line illustrates, the greater the incidence of moisture above 50%, the lower the fiber residuals.




Note: The linear regression model is analyzing mesh bag results only, it does not account for the dose values.

## ENDNOTES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