CASE STUDY REPORT

#3083

Material Analysis Summary Report

On Behalf of

Glass Packaging Institute

Executive Summary

PFE (Plastics Forming Enterprises), in collaboration with the Small Format Coalition, conducted an evaluation of plastic materials that were not successfully recovered by conventional sorting systems and instead reported to the glass stream at a material recovery facility (MRF). The objective of the study was to better understand the composition, recyclability, and ultimate destinations of small-format plastic items that bypass existing plastic recovery processes. Although the study focused primarily on small-format plastics, the material received from the glass processing stream included both small items and larger items, or "overs." A meaningful portion of these larger items appeared suitable for conventional plastics recycling, demonstrating an additional opportunity to recover recyclable material. The material recovered from the glass stream was first sorted by MSS into five plastic categories and then shipped to PFE for further analysis:

- Polyethylene terephthalate (PET)
- Polypropylene (PP)
- Polyethylene (PE)
- Black plastics
- Mixed plastics

Upon receipt, PFE reviewed each material category and removed items that would to be detrimental to reprocessing. Following sortation, each material stream was processed through a series of recycling operations; PET, PE, and PP were successfully injection molded into plaques suitable for comprehensive mechanical testing. Only limited amounts of the Black Plastics and Mixed Plastics streams were successfully injected due to excessive fuming and poor resulting part quality, indicating limited potential for further evaluation. All activities included weight measurements, allowing material yields and losses to be tracked. This summary report highlights three primary areas of investigation:

- Material yield and recovery throughout the processing steps
- Characterization and testing results for each material stream
- Findings related to the destination and recovery potential of both small-format plastic items and larger "overs" within the recycling system

Additional details, including stream-specific processing results, material characterizations, and testing outcomes, are provided in the individual reports corresponding to each material category.

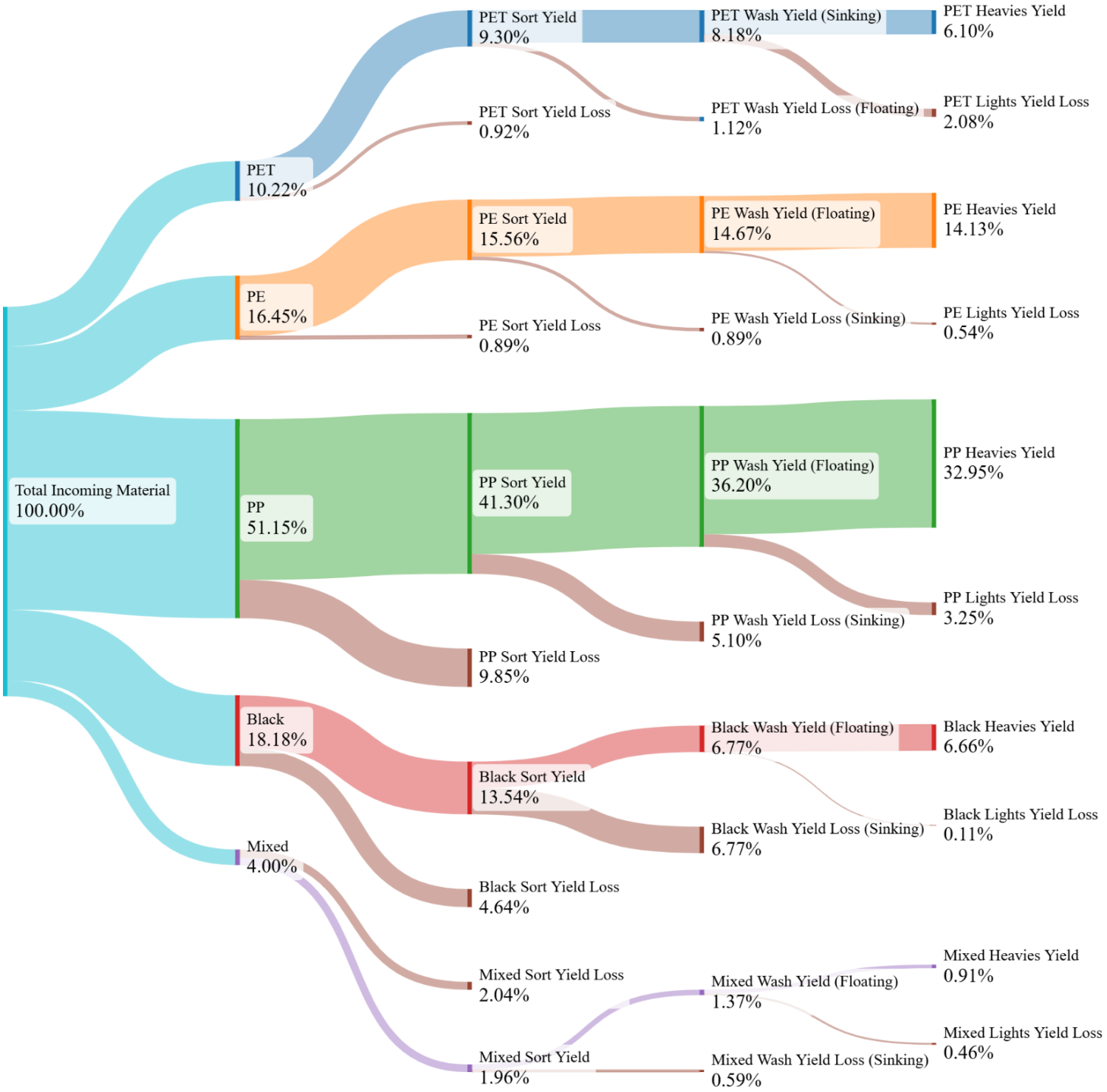
Pre-Processing and Yield

The small items evaluation examined plastic materials recovered from glass recycling streams to determine how much of the material could potentially be recovered. Before arriving at PFE, the material had already been pre-sorted using near-infrared (NIR) technology to separate it into primary resin categories, including PET, PE, PP, black plastics, and mixed materials. Once received, PFE conducted a secondary manual sorting process to further refine the streams and remove contaminants that could damage processing equipment. The materials were photographed, weighed, categorized, and inspected before unacceptable items were removed and the remaining material was advanced for processing and evaluation.

The incoming stream consisted primarily of polypropylene (PP), which represented approximately 51% of the material, followed by black plastics (18%), polyethylene (PE) (16%), polyethylene terephthalate (PET) (10%), and mixed materials (4%). During PFE's secondary sorting process, contaminants such as electronics, metal components, pumps with metal springs, coffee pods, glass, fiber, ink cartridges, multi-material products, and heavily contaminated items were removed to protect downstream processing equipment and ensure a more representative assessment of recyclable material recovery.

Overall, the evaluation demonstrated that significant quantities of recyclable small-format plastics can be recovered from NIR-sorted glass stream material after additional quality control and contaminant removal. The results indicate that PE and PP offer the greatest recovery opportunities due to their combination of high volume and strong sorting yields, while mixed-material contamination remains the primary challenge to maximizing recovery and processing efficiency.

Yield Loss Flow Diagram



Yield Loss Per Stream

Processing Step	PET	PE	PP	Black	Mixed
Starting Yield	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
Sort Yield	91.00%	94.59%	80.74%	74.48%	49.00%
Sort Yield Loss	9.00%	5.41%	19.26%	25.52%	51.00%
Washing Yield	80.04%	89.18%	70.77%	37.24%	34.25%
Washing Yield Loss	10.96%	5.41%	9.97%	37.24%	14.75%
Elutriation Yield	59.69%	85.90%	64.42%	36.63%	22.75%
Elutriation Yield Loss	20.35%	3.28%	6.35%	0.61%	11.50%
Total Yield	**59.69%**	**85.90%**	**64.42%**	**36.63%**	**22.75%**
Total Yield Loss	**40.31%**	**14.10%**	**35.58%**	**63.37%**	**77.25%**

This table describes the yield loss relative to each sorted category.

Processing Results

Following the secondary sorting process, each material category (PET, PE, PP, Black, and Mixed) was processed through a series of washing, density separation, and air classification steps to evaluate its suitability for recycling. Materials were first washed to remove residual contamination and fines, then subjected to sink-float separation, where incompatible fractions were removed based on density. The washed flake was subsequently processed through elutriation (air separation) to remove lighter contaminants and isolate a heavier, more uniform material stream. At each stage, material yield and yield loss were recorded to quantify recovery efficiency and identify where losses occurred throughout the process. PET experienced the greatest losses during air separation due to the removal of light fractions, while PE, PP, and Black streams maintained relatively high yields through the washing and elutriation stages. The Mixed stream exhibited the largest overall losses, reflecting the complexity and contamination present within that fraction.

The final recovered fraction from each stream was then injection molded into test specimens to assess material quality and performance. PET was molded into plaques for color, haze, and intrinsic viscosity evaluation, while PE, PP, Black, and Mixed materials were molded into test bars for physical property testing. Key properties measured included differential scanning calorimetry (DSC), melt temperature, melt index, density, flexural modulus, tensile strength, elongation at yield and break, impact performance, and color values (L*, a*, b*). Results showed that both PE and PP produced molded parts with measurable mechanical properties and complete Izod breaks, indicating successful processing through the recovery system. PET plaques were evaluated for optical properties and intrinsic viscosity. The Black and Mixed categories were not tested for rigid properties as they did not yield enough material for testing. These results demonstrate that material recovered from the glass stream can be successfully processed through washing, density separation, air classification, and injection molding to produce usable recycled resin suitable for further evaluation and potential end-use applications.

Result Summary

Property	PET	PE	PP	Black	Mixed
Wash Sinks (%)	88.24%	6.15%	12.01%	50.27%	69.88%
Wash Floats (%)	11.76%	93.85%	87.99%	49.73%	30.12%

Property	PET	PE	PP	Black (Sinks)	Mixed (Sinks)	Black (Floats)	Mixed (Floats)
Elutriation Lights (%)	26.47%	3.41%	3.41%	3.28%	5.11%	1.31%	12.97%

Property	PE	PP	Black Floats	Mixed Floats
DSC (°C)	129.53	132.07	129.10	127.81
Melt Index (g/10min)	2.839	16.116	0.203	1.620
Density (g/cc)	0.938	0.932	0.843	0.924
Flexural Modulus (psi)	141,843	172,580	NA	NA
Tensile Strength (psi)	3277	3843	NA	NA
Elongation at Yield (%)	9.75%	7.88%	NA	NA
Elongation at Break (%)	135.21%	33.08%	NA	NA
Izod Break Type	Complete	Complete	NA	NA
Part Colors L*	59.84	51.48	31.78	42.18
Part Colors a*	-4.06	-0.53	-0.03	-3.75
Part Colors b*	0.02	0.45	-0.87	-3.94

Result Summary Continued

Property	PET
MIV (dL/g)	0.697
Plaque Colors L*	67.49
Plaque Colors a*	0.26
Plaque Colors b*	20.26
Haze (%)	75.55%

Small Item Characterization Findings

To evaluate the effectiveness of APR's Small Format Packaging Guidance in predicting real-world sortation outcomes, PFE analyzed materials that had already reported to the glass stream after passing through conventional recycling system sorting equipment. Because these materials were recovered from the glass stream, they represent items that were not successfully captured by existing plastic sortation processes. However, it is important to recognize that the material received by PFE had already undergone processing and pre-sortation prior to arriving at the facility. As a result, the sample may not be representative of the complete material stream processed by the material recovery facilities (MRF), nor does it necessarily reflect the overall composition of materials entering the recycling system.

PFE does not have information regarding the total quantity of material reporting to the glass stream, the amount of material successfully recovered in other streams, or the overall yield losses associated with the facility's sorting process. Consequently, the data generated from this study should not be interpreted as a measure of total system performance, capture rate, or the effectiveness of any specific MRF. Rather, the results provide insight only into the subset of material that was observed in the glass stream and therefore represent a specific point of analysis within a much larger and more complex sorting process. The findings should be considered contextual to this study and should not be extrapolated to broader recycling system performance without additional supporting data.

The materials were manually sorted according to APR's Small Format Packaging Design Guidance criteria, which define small-format packaging as items measuring less than two inches in at least two dimensions. The analysis found that 25.0% of the PET stream, 84.8% of the PE stream, 59.0% of the PP stream, 75.9% of the Black stream, and 53.6% of the Mixed stream met APR's definition of a small-format item and would therefore be expected to report to the glass stream under the guidance. When weighted according to the relative composition of each plastic category within the overall sample, approximately 62.6% of the material recovered from the glass stream would have been expected to report to the glass stream under APR's size-based guidance, while 37.4% would not have been expected to do so.

In this analysis, “expected to report to the glass stream” refers to items that met APR’s small-format size criterion of less than two inches in at least two dimensions. Items categorized as “not expected to report to the glass stream” did not meet this size criterion and generally represented larger items. This designation relates only to the expected sorting pathway based on item size and should not be interpreted to mean that these materials were unrecyclable. Many of the larger items appeared suitable for recovery in conventional plastic recycling streams.

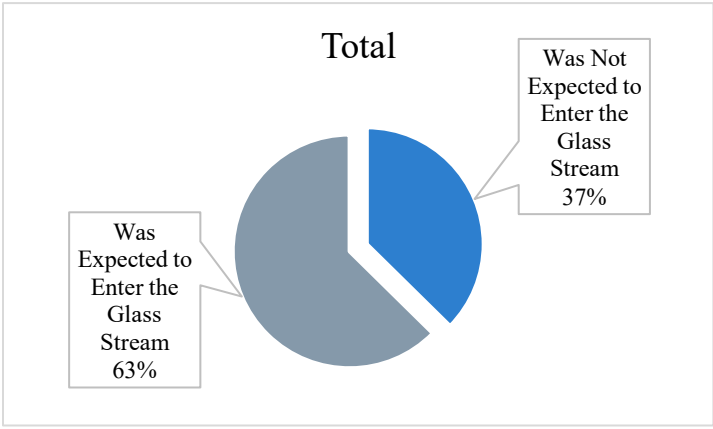
Despite meeting APR's size requirements, these items had already bypassed conventional plastic sortation systems and reported to the glass stream. Likewise, the presence of materials that fall outside the APR size criteria within the glass stream indicates that package size alone may not fully explain sortation outcomes. Factors such as package shape, rigidity, weight, material properties, equipment configuration, operating conditions, and facility-specific practices may also influence whether an item is successfully recovered. Their presence in the glass stream highlights a broader material recovery opportunity that

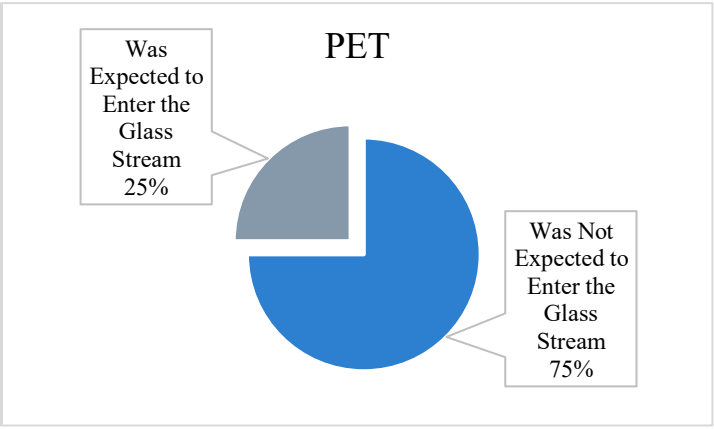
extends beyond small-format packaging and includes any recyclable plastic that bypasses primary MRF recovery.

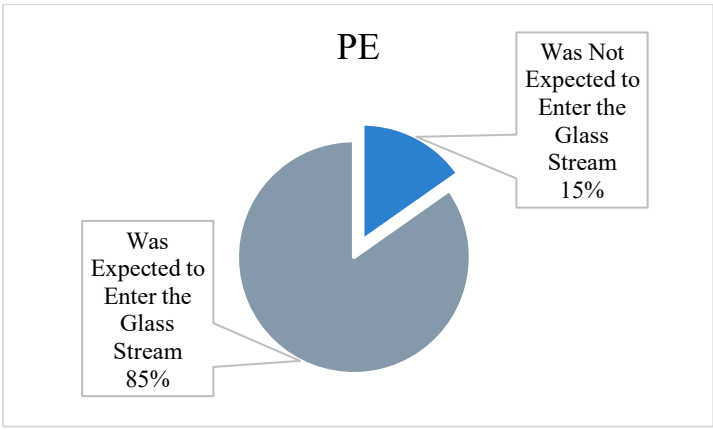
Additionally, recycling systems, package designs, and sorting technologies continue to evolve. The results presented here reflect the material composition and sorting performance observed within this specific study, using material collected at a particular point in time and from a particular sorting pathway. As such, the findings should be viewed as a study-specific assessment intended to provide context and insight into observed sortation behavior, rather than a universal representation of MRF performance or a definitive validation of APR guidance across all recycling systems.

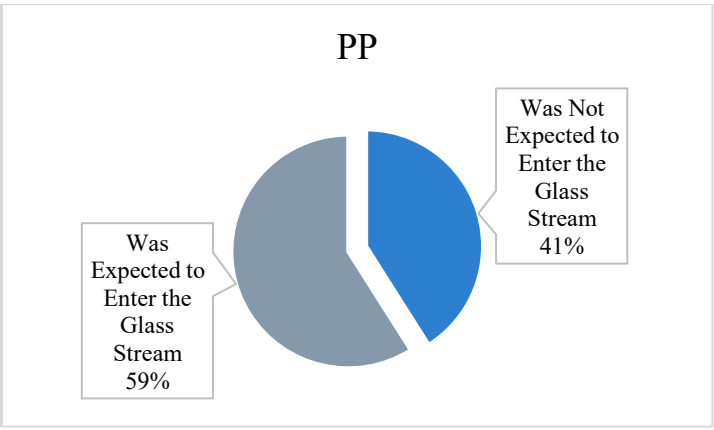
Small Item Characterization Results

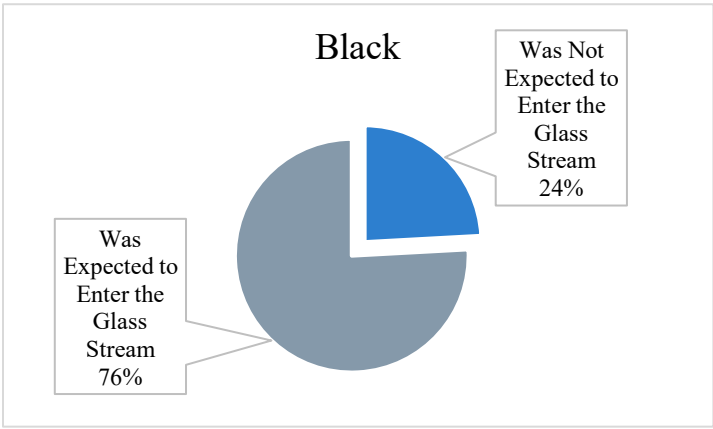
These charts show the percentage of material within each sorted resin category that did and did not meet APR's small-format size criterion. Material labeled "expected to enter the glass stream" met the small-format criterion, while material labeled "not expected to enter the glass stream" consisted of larger items that would generally be expected to follow another sorting pathway. The "not expected" designation does not indicate that the material was unrecyclable.

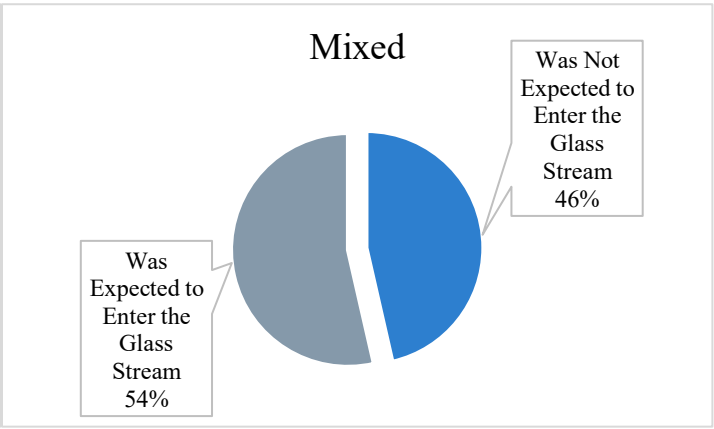












APPENDIX

PET

Incoming Article	Ground Article
	

Washed Flake	Floatables
	

Heavies	Lights
	

HDPE

Incoming Article	Ground Article
	

Washed Flake	Sinkables
	

Heavies	Lights
	

PP

Incoming Article	Ground Article
	

Washed Flake	Sinkables
	

Heavies	Lights
	

Black Plastics

Incoming Article	Ground Article
	

Washed Flake	Sinkables
	

Heavies	Lights
	

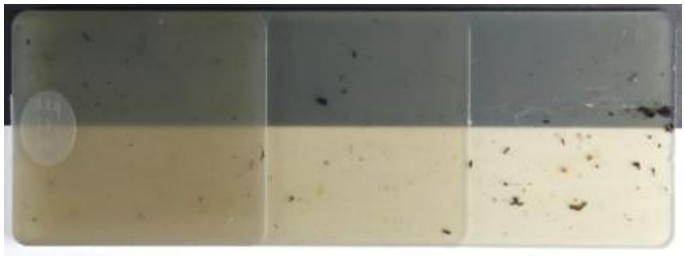
Mixed Plastics

Incoming Article	Ground Article
	

Washed Flake	Sinkables
	

Heavies	Lights
	

Injection Molded Parts

PET	HDPE
	
PP	**Black Plastics**
	
Mixed Plastics	
	

Report Statements

ANAB
ANSI National Accreditation Board
ACCREDITED
ISO/IEC 17025
TESTING LABORATORY
Certificate Number: AT-3210

Conclusions Statements

Experienced staff members do any interpretations of data with a good knowledge of the materials used during testing. All interpretations or conclusions about data can be found in the conclusions section of the report unless noted. Opinions, interpretations, or statements of conformity included are based on results for which accreditation is held. Opinions, interpretations, or statements of conformity outside the scope of accreditation but based on those results for which accreditation is identified as such by a disclaimer. PFE prides itself on being able to help the clientele understand failures with over 40 years of experience in recycling plastics. PFE does not employ its own decision rules nor set the acceptance criteria. All outliers are determined through an interquartile range and are marked with yellow highlighting. Uncertainty values are available upon request.

Report Authorizations

Report Written by	Report Written on	Report Finalized by	Report Finalized on	Report Approved by	Report Approved on
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