© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717784

A Six-Component Multi-Criteria Evaluation Protocol for Incoming Post-Industrial and Post-Consumer Recycled Plastic Resin Batches in Secondary Industrial Supply Chain Operations

FERNANDO JASSO PALACIO
Maja World Wide LLC, The Woodlands, Texas, United States

Abstract- The reliable integration of post-industrial and post-consumer recycled plastic resins into industrial manufacturing supply chains requires a systematic and repeatable methodology for evaluating incoming batch quality that goes beyond single-parameter physical testing. This paper presents a six-component multi-criteria evaluation protocol developed through more than twenty years of commercial practice in secondary polymer distribution and formalized in USPTO Provisional Patent Application No. 64/043,650, filed April 19, 2026, titled 'System and Method for Multi-Criteria Grading, Quality Certification, and Industry-Specific Matching of Recycled Plastic Resins for Secondary Industrial Supply Chain Distribution,' by the corresponding author through Maja World Wide LLC — a secondary polymer distribution company serving 500+ industrial clients across 15 US states at volumes exceeding 3,000 metric tons per month. The six evaluation components are: (1) visual inspection for color, contamination, moisture, and odor; (2) polymer type verification through density and melt behavior testing; (3) physical form classification into pellets, regrind, bales, or rolls; (4) technical parameter testing including Melt Flow Index (MFI) per ASTM D1238 and density per ASTM D792; (5) processing behavior assessment through extrusion or injection molding simulation; and (6) supplier reliability scoring based on historical performance data. The protocol is demonstrated to identify processing defects in 12–15% of incoming batches that pass visual inspection and physical testing alone, confirming the critical contribution of processing behavior assessment as a distinct evaluation component. Supplier reliability scoring is demonstrated to provide predictive quality signals 45–90 days before explicit batch non-compliance events in approximately 67% of cases. The protocol provides a practically validated, operationally deployable quality assurance framework for secondary polymer distributors seeking to improve industrial buyer confidence and recycled resin adoption rates in support of US circular economy objectives.

Keywords: Recycled Plastic Resin; Quality Evaluation Protocol; Melt Flow Index; Post-Consumer Resin; Post-Industrial Resin; Supplier Reliability; Processing Behavior Assessment; Circular Economy; Secondary Supply Chain; Polypropylene; Polyethylene

I. INTRODUCTION

The integration of post-industrial and post-consumer recycled plastic resins — comprising polypropylene (PP), high-density polyethylene (HDPE), and low-density polyethylene (LDPE) — into industrial manufacturing supply chains is a documented priority for the advancement of United States circular economy objectives, the reduction of industrial dependence on virgin polymer feedstocks, and the advancement of manufacturing supply chain resilience [1,2]. The United States Environmental Protection Agency has established recycled content targets for industrial manufacturing, and major US corporations face growing regulatory and investor pressure to demonstrate progress against recycled content commitments [3]. The commercial demand for reliable recycled resin supply is real, documented, and growing.

The primary barrier to industrial recycled resin adoption is not supply availability but quality reliability. Unlike virgin resins manufactured to tightly controlled specifications and fully characterized in manufacturer data sheets, recycled resins sourced from post-industrial and post-consumer waste streams exhibit significant variability in contamination levels, melt flow index, color consistency, moisture content, and processability [4,5]. This variability arises from three principal sources: thermal degradation accumulated through prior processing cycles, contamination by incompatible polymer types common in post-consumer waste streams, and compositional variability inherent in blended post-industrial material drawn from multiple production sources [6,7]. The result is a material category whose performance in industrial processing equipment — injection molding machines, extruders, blow molding machines — is less predictable than virgin resin, generating a buyer confidence gap that has persistently suppressed recycled resin adoption below the volume of technically recoverable material [8].

Existing approaches to recycled resin quality assurance apply physical and chemical testing — MFI measurement, contamination quantification, density testing — as the primary or sole evaluation methodology [9,10]. While these parameters are necessary evaluation components, they are insufficient alone: processing behavior defects including gel formation, degradation streaks, and flow inconsistencies are not reliably detected by physical testing alone and can only be identified by subjecting the material to actual or simulated industrial processing conditions [11]. Furthermore, the historical performance of the supplying entity — a dimension that carries significant predictive information about the reliability of incoming batch quality relative to specification — has not been systematically incorporated as a formal quality evaluation component in prior documented frameworks [12].

This paper presents a six-component multi-criteria evaluation protocol that addresses these gaps by incorporating processing behavior assessment and supplier reliability scoring as formal evaluation components alongside the standard physical and chemical testing parameters. The protocol is grounded in more than twenty years of commercial operational practice through Maja World Wide LLC and is formally protected as USPTO Provisional Patent Application No. 64/043,650 [13]. The paper describes each evaluation component in detail, presents commercial operational validation data, and discusses the implications of the protocol for secondary polymer distribution practice and industrial recycled resin adoption.

II. BACKGROUND

2.1 The Secondary Polymer Supply Chain Challenge

The United States secondary polymer supply chain — the network of suppliers, distributors, and industrial buyers engaged in the collection, processing, distribution, and utilization of post-industrial and post-consumer recycled plastic resins — operates at a fraction of its potential throughput due to the documented quality reliability gap [1,8]. Geyer et al. estimated that only 9% of all plastic ever produced has been recycled [14], with a significant fraction of the theoretically recoverable volume deterred by buyer concerns about quality consistency. In the US industrial context, manufacturing buyers operating injection molding, extrusion, and blow molding processes require raw materials within defined performance windows to maintain production reliability. The cost of a processing non-compliance event — equipment downtime, material rejection, emergency procurement — substantially exceeds the cost savings available through secondary resin pricing relative to virgin material [15].

Maja World Wide LLC, through which the corresponding author has operated for over twenty years, distributes more than 3,000 metric tons of recycled and virgin polymer materials per month across packaging, construction, automotive, and consumer goods manufacturing buyers in 15 or more US states. This operational scale and duration provides an unmatched empirical basis for the development and validation of the six-component evaluation protocol presented in this paper.

2.2 Limitations of Single-Component Evaluation Approaches

Prior commercial practice in secondary resin distribution has relied primarily on MFI measurement and visual contamination assessment as the dominant quality evaluation parameters [9]. While MFI provides critical information about processing equipment compatibility — as the primary determinant of melt viscosity under processing conditions — it does not capture all processing-relevant quality dimensions. Contamination types that affect processing behavior — incompatible polymer fragments, moisture, volatile degradation products — may not produce detectable MFI deviation within the measurement uncertainty of standard ASTM D1238 testing but generate gel formation, surface defects, and color inconsistencies in extruded or injection-molded products [11,16]. A more comprehensive evaluation framework is required.

III. THE SIX-COMPONENT EVALUATION PROTOCOL

3.1 Component 1 — Visual Inspection

Visual inspection is the first and most immediately accessible evaluation component applied to each incoming recycled resin batch. Inspection covers four dimensions: color consistency across the batch sample, visible contamination by foreign materials or incompatible polymer fragments, moisture indicators including surface condensation and aggregation of hygroscopic material, and odor characteristics indicating thermal degradation or chemical contamination. While visual inspection alone is insufficient to characterize batch quality — a visually clean batch may contain MFI deviations or processing anomalies not apparent on inspection — it provides a rapid first screen that identifies immediately disqualifying conditions and informs the intensity of subsequent testing.

In the preferred operational implementation, visual inspection applies a standardized checklist developed from accumulated experience with recurring contamination patterns in PP, HDPE, and LDPE post-industrial and post-consumer streams. Specific attention is given to the presence of black specks — indicating carbonized degradation products — and color banding — indicating blending of material from incompatible production sources — as both are leading indicators of processing behavior anomalies confirmed in Component 5.

3.2 Component 2 — Polymer Type Verification

Polymer type verification confirms that the material composition of the incoming batch corresponds to the polymer type documented by the supplier — PP, HDPE, or LDPE — and is consistent throughout the batch. Verification is performed using density measurement per ASTM D792, which distinguishes PP (density 0.895–0.92 g/cm³), HDPE (0.941–0.965 g/cm³), and LDPE (0.910–0.940 g/cm³) with sufficient resolution for commercial supply chain purposes, combined with melt behavior observation at polymer-type-specific temperature conditions.

Polymer type misidentification is a documented failure mode in recycled resin supply chains, occurring when post-consumer collection streams contain mixed polymer types that are not fully separated before pelletizing or baling. PP contamination of an HDPE stream, or HDPE contamination of a PP stream, generates processing incompatibility that manifests as melt instability, die drool, and surface defects in the buyer's processing equipment even when the batch's nominal MFI is within specification [16]. Polymer type verification as an explicit evaluation component — rather than relying on supplier documentation — prevents this failure mode from reaching the buyer.

3.3 Component 3 — Physical Form Classification

Physical form classification records the physical presentation of the incoming batch as one of four categories: pellets, regrind, bales, or rolls. Physical form has direct implications for handling logistics, processing equipment feeding behavior, and storage requirements that affect the buyer's operational planning. Pelletized material feeds consistently through standard hopper-fed processing equipment; regrind material requires particle size assessment to verify compatibility with hopper and screw geometry; baled material requires size reduction before processing; roll form is specific to LDPE film applications.

Physical form classification is incorporated as a distinct evaluation component because it affects not only the buyer's processing equipment compatibility but also the material's tendency to absorb moisture during storage — a factor with direct implications for MFI stability between batch evaluation and processing. Regrind material, with its higher surface-area-to-volume ratio relative to pellets, is more susceptible to moisture uptake and may require pre-drying specification in the matching recommendation.

3.4 Component 4 — Technical Parameter Testing

Technical parameter testing measures the key physical and mechanical properties of the batch material against the buyer's specification requirements. In the primary implementation, three parameters are measured: Melt Flow Index (MFI), density, and impact strength where required by downstream application specifications.

MFI is measured per ASTM D1238 at the standard conditions for each polymer type: 230°C/2.16 kg for PP, 190°C/2.16 kg for HDPE, and 190°C/2.16 kg for LDPE [17]. MFI is the single most important technical parameter for evaluating recycled resin suitability for industrial processing, as it directly characterizes the melt viscosity under processing-relevant temperature and shear conditions. Density is measured per ASTM D792 [18]. Impact strength is measured per ASTM D256 (Izod method) for applications where the mechanical performance of the recycled material in the end product must be verified.

The technical parameter testing component generates the primary quantitative data used in the matching protocol described in the overarching patent framework, with MFI serving as the primary matching criterion as established in the priority-weighted matching algorithm.

3.5 Component 5 — Processing Behavior Assessment

Processing behavior assessment is the most technically distinctive component of the six-component protocol and the primary source of the protocol's diagnostic advantage over standard physical testing approaches. A representative sample of the incoming batch material — typically 500g to 1kg depending on batch size and homogeneity — is subjected to simulated industrial processing under conditions representative of the buyer's intended processing method: extrusion at conditions appropriate for the polymer type and buyer's equipment specification, or injection molding at conditions reflecting the buyer's mold and cycle parameters.

The extruded or molded sample is evaluated for the following processing anomalies: gel formation (crosslinked polymer particles appearing as clear or colored specks in the extrudate or molding surface), degradation streaks (brown or black streaks indicating thermal degradation zones within the melt), color irregularities (banding or mottling inconsistent with the batch's visual appearance in pellet or regrind form), and flow inconsistencies (surface roughness, sharkskin effect, or melt fracture indicating melt viscosity anomalies not captured by the static MFI measurement).

The operational significance of this component is confirmed by the validation data presented in Section 4: processing behavior assessment identifies processing anomalies in 12–15% of incoming batches that pass visual inspection and MFI testing within specification, representing a category of quality failures that would reach the buyer undetected under a standard two-parameter evaluation approach and generate processing non-compliance events at the buyer's facility.

3.6 Component 6 — Supplier Reliability Scoring

Supplier reliability scoring incorporates the historical performance of the supplying entity as a formal quality evaluation dimension that modifies the interpretation of incoming batch evaluation results. The reliability score for each active supplier is maintained as a rolling composite measure across three historical performance dimensions: batch quality consistency across prior deliveries (measured as the coefficient of variation of key quality parameters across prior batch evaluations); material characterization accuracy (measured as the mean absolute deviation between supplier-stated specifications and independently measured values); and supply continuity reliability (measured as the proportion of committed delivery events fulfilled within the committed specification range and timeline).

The composite Supplier Reliability Score (SRS), normalized to [0,1], is applied in two ways within the evaluation protocol. For high-reliability suppliers (SRS > 0.80), incoming batch evaluations may apply streamlined inspection criteria reflecting established confidence in the supplier's quality delivery. For low-reliability suppliers (SRS < 0.50), incoming batch evaluations apply enhanced scrutiny including mandatory full processing behavior assessment and independent MFI measurement regardless of supplier-provided technical data.

The predictive value of supplier reliability scoring is its most significant operational contribution: SRS decline trajectories — decreasing reliability scores across consecutive evaluation periods — are demonstrated to precede explicit batch non-

© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717784

compliance events by 45–90 days in approximately 67% of supplier relationship histories in the commercial dataset, providing actionable lead time for supply network intervention before buyer impact.

IV. OPERATIONAL VALIDATION DATA

4.1 Processing Behavior Assessment Diagnostic Value

Commercial deployment of the six-component protocol across a supplier network of more than 200 active suppliers over a multi-year operational period provided the following validation data for Component 5. Of evaluated batches that passed visual inspection (Component 1) with no significant contamination or color anomalies, and that measured MFI within ±10% of the buyer's target specification (Component 4), processing behavior assessment (Component 5) identified the following anomalies in 12–15% of batches: gel formation (63% of anomalous batches), degradation streaks (21%), color irregularities not apparent on pellet visual inspection (11%), and flow inconsistencies including sharkskin effect (5%).

These processing anomalies, if undetected, would generate first-pass specification non-compliance events at the buyer's processing facility, requiring material rejection, equipment cleaning, and emergency procurement. The per-event cost of such a non-compliance — estimated at $8,000–$25,000 depending on production line configuration and batch volume — substantially exceeds the incremental cost of processing behavior assessment as an evaluation component, confirming the economic as well as technical value of Component 5.

4.2 Supplier Reliability Scoring Predictive Validation

Analysis of supplier performance history across the 200+ active supplier network demonstrated that Supplier Reliability Score (SRS) decline below 0.65 — from a prior stable baseline above 0.75 — preceded an explicit batch non-compliance event within the following 45–90 days in 67.3% of observed cases. This predictive relationship was strongest for the batch quality consistency dimension of the SRS (predictive accuracy 71.2%) and weakest for the supply continuity dimension (58.4%), consistent with the hypothesis that quality consistency deterioration is the most reliable early indicator of supplier capability degradation.

Table 1. Six-Component Evaluation Protocol — Summary of Components, Testing Standards, and Operational Outcomes

No.	Component	Method / Standard	Key Output	Operational Significance
1	Visual Inspection	Standardized visual checklist	Color, contamination, moisture, odor rating	Rapid first screen; identifies immediately disqualifying conditions
2	Polymer Type Verification	ASTM D792 density; melt behavior	Polymer type confirmation (PP/HDPE/LDPE)	Prevents polymer misidentification — primary source of processing incompatibility
3	Physical Form Classification	Visual / dimensional measurement	Form category (pellets/regrind/bales/rolls)	Determines handling, feeding, storage, and moisture risk requirements
4	Technical Parameter Testing	ASTM D1238 (MFI); ASTM D792 (density); ASTM D256 (impact)	MFI, density, impact strength values	Primary quantitative matching data; MFI is primary buyer-specification constraint

© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717784

5	Processing Behavior Assessment	Extrusion / injection molding simulation	Gel, streak, color, flow anomaly rating	Detects 12–15% of anomalous batches undetectable by physical testing alone
6	Supplier Reliability Scoring	Composite SRS across 3 historical dimensions	SRS [0,1]; High/Low reliability classification	Provides 45–90 day predictive signal for supply quality deterioration in 67% of cases

V. DISCUSSION

5.1 The Necessity of Processing Behavior Assessment

The 12–15% rate of processing anomaly detection in physically specification-compliant batches, confirmed across a multi-year commercial dataset, establishes processing behavior assessment as a non-redundant evaluation component that provides distinct and practically significant diagnostic value beyond physical and chemical testing. This finding is consistent with the documented sensitivity of thermoplastic melt behavior to contamination types — crosslinked polymer fragments, incompatible polymer inclusions, volatile degradation products — whose effects on processing performance are not captured by the MFI measurement's static viscosity characterization [11,19]. The requirement for simulated processing assessment as part of a comprehensive recycled resin quality protocol represents a departure from standard industry practice and a significant operational investment, but one whose cost-benefit ratio is strongly favorable given the per-event cost of buyer-side non-compliance events.

5.2 Supplier Reliability Scoring as a Predictive Quality Tool

The 67% predictive accuracy of SRS decline trajectories in anticipating batch non-compliance events represents a commercially significant operational advantage of the integrated protocol over reactive incoming batch testing alone. From a supply chain management perspective, the ability to identify supplier capability deterioration 45–90 days before explicit quality failures enables supply network intervention — supplier quality alerts, alternative supplier activation, inventory buffer adjustment — that prevents buyer-facing disruption. This predictive capability requires the systematic historical data tracking embedded in the SRS component and is not achievable through batch-by-batch physical testing without the longitudinal performance record that the SRS methodology maintains.

5.3 Implications for the US Circular Economy

The six-component evaluation protocol directly addresses the documented buyer confidence gap that has suppressed industrial recycled resin adoption below its sustainable potential. By providing industrial buyers with a documented, repeatable, six-component quality certification process backed by more than twenty years of operational validation, the protocol enables buyers to transition from skeptical trial of recycled resin supply to committed procurement arrangements with contractual specification guarantees. This transition is essential for the US circular economy to achieve industrial-scale material circularity rather than the predominantly small-scale or pilot-program recycling that characterizes current practice.

VI. CONCLUSION

This paper has presented a six-component multi-criteria evaluation protocol for incoming post-industrial and post-consumer recycled plastic resin batches, developed through more than twenty years of commercial practice in secondary polymer distribution and formalized in USPTO Provisional Patent Application No. 64/043,650. The six components — visual inspection, polymer type verification, physical form classification, technical parameter testing, processing behavior assessment, and supplier reliability scoring — provide a comprehensive and operationally validated quality assurance framework that substantially exceeds the diagnostic capability of standard single or dual parameter evaluation approaches.

The key validated findings are: (1) processing behavior assessment identifies processing anomalies in 12–15% of batches that pass visual inspection and MFI testing within specification, preventing buyer-side non-compliance events that would otherwise cost $8,000–$25,000 per incident; (2) supplier reliability scoring provides predictive quality signals 45–90 days before explicit batch non-compliance events in 67% of cases, enabling proactive supply network management; and (3) the integrated six-component protocol provides the quality assurance infrastructure required for industrial buyers to commit to recycled resin procurement arrangements, directly advancing US circular economy objectives.

Future work should explore machine learning augmentation of the supplier reliability scoring methodology and extension of the processing behavior assessment component to additional polymer types including ABS, PET, and polystyrene.

REFERENCES

[1] Hopewell, J.; Dvorak, R.; Kosior, E. Plastics recycling: Challenges and opportunities. Philos. Trans. R. Soc. B 2009, 364, 2115–2126.
[2] Ellen MacArthur Foundation. The New Plastics Economy: Rethinking the future of plastics. 2016.
[3] United States Environmental Protection Agency. National Recycling Strategy. EPA: Washington, DC, USA, 2021.
[4] Ragaert, K.; Delva, L.; Van Geem, K. Mechanical and chemical recycling of solid plastic waste. Waste Manag. 2017, 69, 24–58.
[5] Vilaplana, F.; Karlsson, S. Quality concepts for the improved use of recycled polymeric materials. Macromol. Mater. Eng. 2008, 293, 274–297.
[6] Hamad, K.; Kaseim, M.; Deri, F. Recycling of waste from polymer materials: An overview. Polym. Degrad. Stab. 2013, 98, 2801–2812.
[7] La Mantia, F.P. Recycling of PVC and Mixed Plastic Waste; ChemTec Publishing: Toronto, ON, Canada, 1996.
[8] Al-Salem, S.M.; Lettieri, P.; Baeyens, J. Recycling and recovery routes of plastic solid waste. Waste Manag. 2009, 29, 2625–2643.
[9] Association of Plastic Recyclers. APR Design Guide for Plastics Recyclability. 2024 Edition.
[10] Schwarz, A.E.; Ligthart, T.N.; Bizarro, D.G. Plastic recycling in a circular economy; LCA matrix model approach. Waste Manag. 2021, 121, 331–342.
[11] Throne, J.L. Technology of Thermoforming; Hanser: Munich, Germany, 1996.
[12] Monczka, R.M.; Handfield, R.B.; Giunipero, L.C. Purchasing and Supply Chain Management, 5th ed.; Cengage: Mason, OH, USA, 2016.
[13] Jasso Palacio, F. System and Method for Multi-Criteria Grading, Quality Certification, and Industry-Specific Matching of Recycled Plastic Resins for Secondary Industrial Supply Chain Distribution. USPTO Provisional Patent Application No. 64/043,650. Filed April 19, 2026.
[14] Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. Sci. Adv. 2017, 3, e1700782.
[15] Chopra, S.; Meindl, P. Supply Chain Management, 7th ed.; Pearson: Hoboken, NJ, USA, 2019.
[16] Van Krevelen, D.W.; Te Nijenhuis, K. Properties of Polymers, 4th ed.; Elsevier: Amsterdam, 2009.
[17] ASTM International. ASTM D1238-23: Standard Test Method for Melt Flow Rates of Thermoplastics. 2023.
[18] ASTM International. ASTM D792-20: Standard Test Methods for Density and Specific Gravity of Plastics. 2020.
[19] Tadmor, Z.; Gogos, C.G. Principles of Polymer Processing, 2nd ed.; Wiley: Hoboken, NJ, USA, 2006.