Defining Recyclate Quality Target Specifications to Improve Plastic Packaging Circularity

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Report For

The Alliance to End Plastic Waste

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Executive Summary

Currently, there are no common recyclate specifications or consensuses in the European market to align the secondary plastics industry.

While several scientific and EU publications have emphasized the need for high quality recyclate, and standards such as the EN standards currently exist, the definition of quality remains unclear, and a framework to implement such quality in the recycling process is lacking.[1]

The current supply chain is comprised of lots of different recyclers using a variety of processes and using a high variation in bale qualities from a variety of collection and sorting approaches. The resulting recyclate specifications are therefore highly variable, being close to unique for each existing recycler. In addition, on the demand side, brands and retailers currently typically communicate their quality requirements to be as close to virgin-like material as possible. Bespoke specifications are commonly bilaterally developed between recyclers, converters and producers. This often results in converters and producers relying on a specific recycler and/or limits the number of converters or producers to which a recycler can sell their material, reducing flexibility for both. The somewhat siloed nature of the supply chain makes it difficult for each business to be effective in producing sufficient and consistent material to meet application-specific market needs.

Without consistent target specifications for quality recyclate for circular packaging, there will not be enough material to meet the recycled content demand.

The European plastics industry is not yet able to reach its recycling targets due to insufficient volumes of recycled plastic that fully meet the required quality for all key packaging applications. Furthermore, recycled content targets are expected to increase under the European Commission's proposed Packaging and Packaging Waste Regulation (PPWR).

To meet future packaging demand, recyclers may need to more strictly target specific applications or even to modify their feedstock requirements and their processes. Clarifying target specifications will make the required changes transparent and, by providing proper value for the recyclate quality, encourage tailored upstream investment for sorting and recycling operations and drive improved collection and sorting technologies. Alongside adoption of design guidelines, these investments will maximise the benefits of recycling and enable a faster transition towards a circular economy.

We urgently need to produce recyclate quality target specifications and associated bale specifications to develop the market while the market awaits the full impact of other complementary measures such as design for recycling to be realised.

The recent European Commission notification to CEN and CENELEC of a new Standardisation Request on plastics recycling and recycling plastics is a positive step. However, while this process

[1] Tonini, D. *et al.* (2022) 'Quality of recycling: Urgent and undefined', Waste Management, 146, 11-19. If accessed online: Available at: https://www.sciencedirect.com/science/article/pii/S0956053X22002057?via%3Dihub (Accessed: 8 February 2023).

is underway, there is an urgent need to accelerate a pragmatic and common definition of quality specifications for key packaging applications. This will allow industry to choose the level of quality that is appropriate for their packaging article and will enable greater volumes of plastic to be recycled and increase recycled content use. This would also provide a useful basis from which the standardisation bodies can further refine their outputs to meet market needs.

To that end, we set out to assess how specifications for fit-for-purpose quality recyclate might be produced in a more harmonised way across the supply chain – using the quality of recyclates required for three large volume applications as examples. By working with stakeholders across the value chain, we demonstrated the ability to build consensus on consistent target specifications to form a basis for further refinement by the industry.

We call upon the industry to urgently support a process to develop a suite of target specifications for a broad set of key applications and to quickly adopt them. This will facilitate the availability of recycled content for products, and starting from the applications with the largest market volume to accelerate the change required.

To further refine the target specifications produced and extract full value from existing recyclates, the proposed next steps are to undertake operational trials and develop further granularity as required. Figure 1 shows our proposed way to get there.

Figure 1: Proposed Industry Roadmap

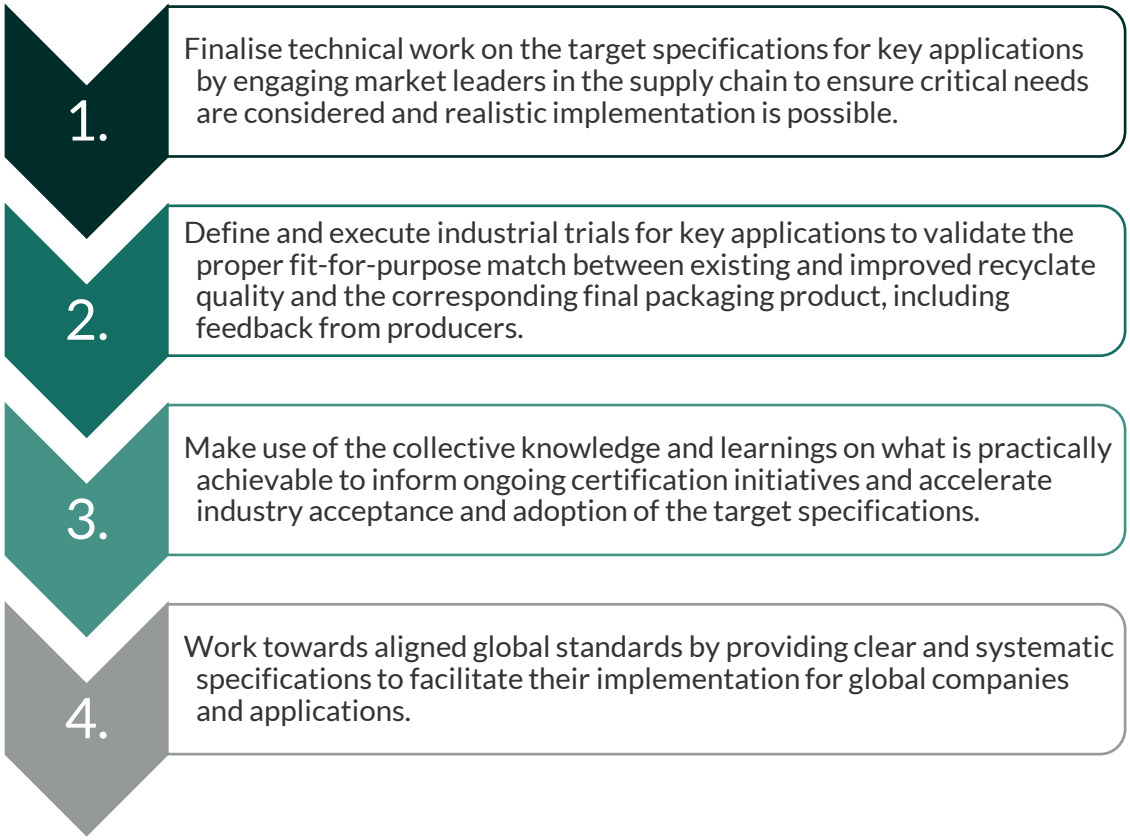

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Table of Acronyms

Acronym	Definition
C&I	Commercial and Industrial
CD	Cross direction
DIN	Deutsches Institut für Normung
DSC	Differential scanning calorimetry
EN	European Standards (from the German name Europäische Norm)
EPS	Expanded polystyrene
GC-FID	Gas chromatography – flame ionization detection
GC-MS	Gas chromatography – mass spectrometry
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
MD	Machine direction
NIR	Near-infrared
OCS	Optical Control System
PET	Polyethylene terephthalate
PET-G	Polyethylene terephthalate glycol
PO	Polyolefin
PP	Polypropylene
PRE	Plastics Recyclers Europe
PRO	Producer responsibility organisation
PUR	Polyurethane
TGA	Thermogravimetric analysis

Glossary of Terms

Term	Definition
Bale Grades	The name of the bale specification for example DSD-310 or 98-2, which relates to its composition (e.g., 98-2 will be 98% clear, 2% coloured film, typically transit packaging).
Bale Specifications	Defines the composition of the bale including the percentage of the target material and tolerances for non-target material.
Characteristic	A feature or quality belonging to a material which can be used to assess its suitability for certain applications.
Conversion Technology	A processing technology which transforms material into useful products such as packaging.
Converter	A company which uses conversion technology to create plastic products.
Producer	A company which supplies goods for sale
Recycler	A company which recycles secondary materials to create materials which can be used again.
Recyclate	Secondary raw material (e.g., flake or pellet).
Recyclate Quality Target Specifications	Defines the key characteristics and target values of the recyclate which are important for a converter to produce a product with that material.
Secondary Plastics Market	Defines the supply chain which collects, sorts and recycles plastic.
Standards	Requirements for products, processes or services to meet the requirement of fitness for a particular purpose as established by a recognised authority as, e.g., the European Standard (EN).
Target Specifications	The Recyclate Quality Target Specifications and their associated Bale Specifications

1.0

Introduction

1.1 Introduction

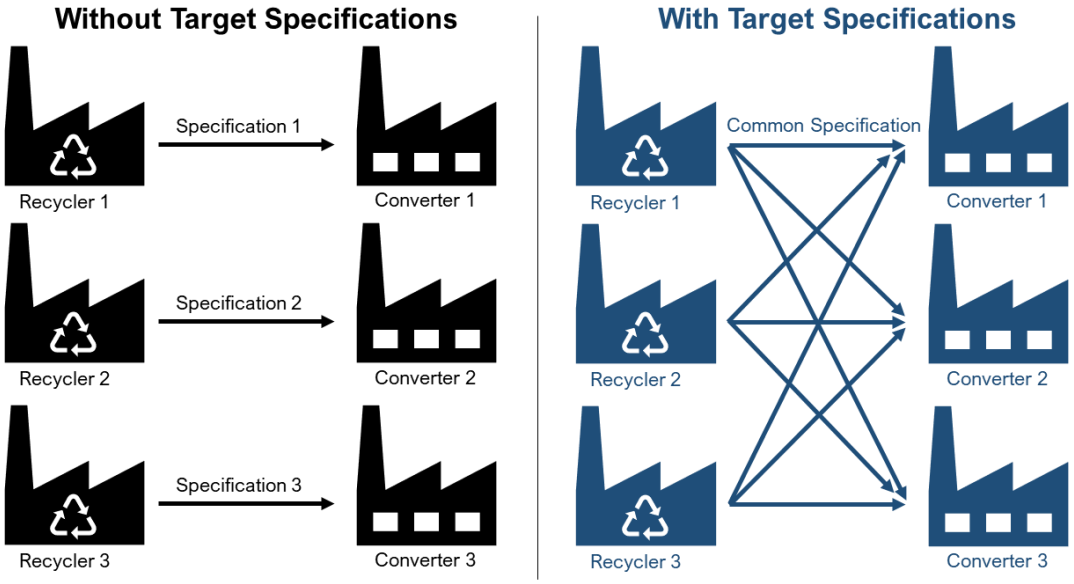
The Alliance to End Plastic Waste (AEPW) was founded in 2019 "to end plastic waste in the environment", an ambitious mission requiring the achievement of an entirely circular economy and the highest possible resource efficiency. The importance of eliminating plastic waste continues to receive extensive global attention; 250 major brands and retailers have made voluntary pledges to reduce single-use plastics and invest in new technology so that all packaging can be recycled by 2025. In addition, in November 2022, the European Commission published a proposal for a Packaging and Packaging Waste Regulation (PPWR) intended to replace the existing Packaging and Packaging Waste Directive. The draft Regulation aims to reduce the environmental impact of packaging by mandating recycled content targets in plastic packaging to be met by 2030 and 2040.

The plastics industry is far from meeting these targets. In 2019, only 5% of plastic packaging was sourced from post-consumer recycled content.[2] While several scientific and EU publications have emphasized the need for high quality recyclate, it was recently highlighted that the definition of quality remains unclear, and a framework to implement such quality in the recycling process is lacking.[3] It was suggested that the definition of quality should firstly consider whether the technical properties of the recyclate render it as sufficient for use in a particular end application, and secondly consider the extent to which the recyclate could be used to substitute primary resources in different applications within different markets. The development of clear definitions and frameworks is imperative to support waste policies that can extract the full benefits of recycling and adopt a circular economy.

Currently, there are no common recyclate specifications or consensuses in the market to align the secondary plastics industry. The current supply chain is comprised of lots of different recyclers using a variety of processes and using a high variation in bale qualities from a variety of collection and sorting approaches. The resulting recyclate specifications are therefore highly variable, being close to unique for each existing recycler. In addition, on the demand side, brands and retailers currently typically communicate their quality requirements to be as close to virgin-like material as possible. Bespoke specifications for recyclates are commonly bilaterally developed between recyclers, converters and producers. This often results in converters and producers relying on a specific recycler and/or limits the number of converters or producers to which a recycler can sell their material, reducing flexibility for both (See Figure 2). The somewhat siloed nature of the supply chain makes it difficult for each business to work effectively to produce enough consistent material to meet market needs for all key recycling applications. Overall, this hinders plastic recycling by restricting the availability or the opportunity of recyclate to be used in a more diverse set of applications, as well as limiting the availability of consistently fit-for-purpose quality recyclate.

[2] Plastics Europe (2020) *Plastics – The Facts 2020*. Available at: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2020/ (Accessed: 8 February 2023).
[3] Tonini, D. *et al.* (2022) 'Quality of recycling: Urgent and undefined', Waste Management, 146, 11-19. If accessed online: Available at: https://www.sciencedirect.com/science/article/pii/S0956053X22002057?via%3Dihub (Accessed: 8 February 2023).

Figure 2: Visual Representation of Supply and Demand Without Target Specifications (Current Position) and With Target Specifications (Proposed in this Report)



There is insufficient production of recyclate that meets packaging converter needs at present. The majority of polyolefin recyclate is used outside of packaging production. To meet future packaging demand, recyclers may need to more strictly target certain applications or even to modify their feedstock requirements and their processes. Clarifying target specifications will make the required changes transparent and enable the investment needed in sorting and recycling facilities, so that more material can be recycled in circular packaging applications.

This issue has been acknowledged through the recent European Commission notification to CEN and CENELEC of a new Standardisation Request on plastics recycling and recycling plastics to support the European Strategy for Plastics in a Circular Economy. The European Commission mandates CEN and CENELEC to revise 11 European Standards, as well as to develop around 45 new deliverables on quality grades for sorted plastic waste, characterisation of recyclates and design-for-recycling guidelines for a wide range of products used in different applications – such as packaging, construction, electronic and electrical equipment, road vehicles and agriculture. CEN and CENELEC have committed to deliver by August 2025. However, while this process is underway, there is an urgent need to accelerate a pragmatic and common definition of quality specifications for key packaging applications, to enable greater volumes of plastic to be recycled and increase recycled content use. This would also provide a useful basis from which the standardization bodies can further refine their deliverables to meet market needs.

To improve market conditions for secondary plastics we therefore sought to define a pathway to create recyclate quality target specifications will improve the volume and quality of recyclate available. We wanted to see if, through working closely with stakeholders across the supply chain, we could build rapid consensus towards sets of target specifications, which could then be further refined through operational testing and continued stakeholder engagement. Converters can use these target specifications as a basis to specify what they need from recyclate (their minimum quality requirements). Waste collectors, sorters and recyclers can use these target specifications to understand what recyclate to produce, and what steps they might need to take to achieve the

parameters defined by these target specifications. The production of different quality level specifications will allow industry to choose the level of quality that is appropriate for their packaging article, driving increased levels of investment in sorting and recycling technology.

> Our aim: ***to provide a basis on which the secondary plastics supply chain can drive target specification development and roll-out across multiple conversion technologies, applications and products, to enable high recycled content in products and to create a robust market for secondary plastics.***

1.2 Approach

The following steps were taken to test how the secondary plastics market might approach developing a set of target specifications. We sought to identify the most important characteristics, and their associated values and ranges, that recyclate would need to meet for a converter to achieve at least 30% recycled content in the specified packaging application in the European market. 30% recyclate incorporation was chosen as an initial target, representing a balance between achievability and challenge. Further refinement and potential proliferation of recyclate target specifications would likely be needed to achieve higher levels of incorporation.

1. *Conversion technology and application type*

We looked at three polyolefin packaging applications (Table 1) which have large market shares within the packaging industry and a corresponding high potential to contribute to increasing recycled content in the polyolefin market.

Table 1: Applications Selected for Study

Recyclate material	Conversion Technology	Application
High density polyethylene (HDPE)	Blow moulding	Bottles
Low density polyethylene (LDPE)	Extrusion	Shrink film
Polypropylene (PP)	Injection moulding	Including caps and tubs

2. *Existing standards, specifications and guidance*

Existing standards and guidance were used as a starting point from which to build the recyclate quality target specifications, looking at EN Standards, DIN Standards and PRE Recyclate Characterisation (see Appendix A 2.1). However, the existing standards do not specify target values for each given characteristic that are important for different applications.

Specifications also exist to describe the quality of outputs from sorting (bale specifications). For the European polyolefin market, Plastics Recyclers Europe (PRE) has published guidance for bales of different polymers. This guidance identifies key impurities (e.g., PVC, metal) that are challenging for product manufacturers working with post-consumer recycled material. However, the guidance does not define the limits of impurities that can be tolerated to produce the required bale quality.

On a national level there are bale specifications set by producer responsibility organisations (PROs). While these national bale specifications are useful for defining limits of key impurities and enable a degree of standardisation in the market, they are still not unified, which results in differing levels of output recyclate quality that may require further sorting to meet quality requirements of converters.

Figure 3: Stakeholder Consultation

3. Consultation

The target specifications were developed in consultation with 28 operators across the plastics recycling value chain (Figure 3), focusing on both the technical requirements of plastics converters and the quality level achievable from recyclers' perspectives.

Information provided by these stakeholders was synthesised to determine the important characteristics for each polyolefin (PO) application, the workable range of values for each of those characteristics and ultimately to create a set of target specifications. The consultations also identified further steps that may need to be taken by those in the value chain to achieve the target specifications using existing technology (see Section 2.0). The stakeholders also identified relevant test methods required to measure each of the characteristics.

4. Recyclate quality target specifications

Based on stakeholder input, a set of recyclate quality target specifications were developed to provide the physico-chemical, mechanical and aesthetic properties required for each application. The specifications developed represent a fit-for purpose level of quality which incorporate 30% recycled content for the specified application and conversion technology. However, they were not intended to meet food or skin contact-sensitive regulatory requirements.

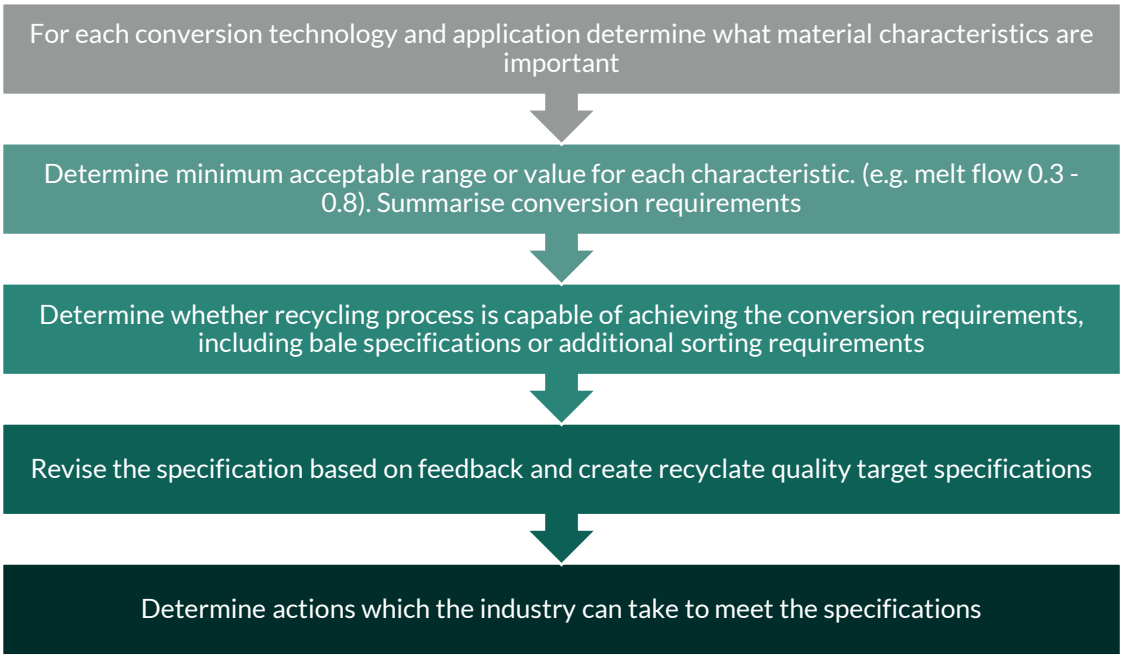
Note: The specifications are a starting point and it is anticipated that the specifications may be modified based on the field trials. Such trials will highlight different requirements from industry; some degree of compromise will be required to establish standardised specifications rather than bespoke ones. Additionally, it is possible to enhance the specifications by creating new specifications tailored to different sub-applications, catering to the distinct quality levels demanded by different end markets and/or to allow higher levels of recyclate incorporation.

5. Bale specifications

To facilitate the fulfilment of the target specifications, the input material received by recyclers from those companies and municipalities that collect and sort waste may also require improvement to support the efficient production of higher quality recyclate. To that end, examples of corresponding bale specifications were also developed.

A summary of the overall approach is provided in Figure 4.

Figure 4: Approach to Defining Quality Level



2.0

Quality Specifications for Recycled Plastic

2.1 Building Consensus on Specifications

By following the approach in Figure 4 for the three PO packaging applications, we were able to build consensus on initial target specifications across 28 stakeholders in a matter of weeks (see Section 4.0: Appendix). This work provides a theoretical starting point on which to base operational trials, to further refine and develop robust target specifications on which the market can further develop.

Recyclate Quality Target Specifications

A description of all the characteristics listed within the recyclate quality target specifications is given in Table 2.

The recyclate quality target specifications provide an outline of the physico-chemical and mechanical properties required for 30% recycled content to be incorporated into each given application. Products within the applications may require additional characteristics to be specified. For example, the HDPE blow moulded bottle category may be appropriate for generic bottles containing non-hazardous substances; however, it would require further development for the containment of hazardous substances (such as motor oil) due to safety requirements or for food or skin contact-sensitive products (such as those used in cosmetic applications). It would also require further development for customer-specific requirements regarding aesthetics and organoleptics. It should be noted that the specifications are distinct from a standard, since the target value ranges allow for negotiations between recyclers, converters and producers.

A key issue noted amongst converters was the intrinsic variability of properties of recyclate material within a given batch and across separate batches. For example, a consistent melt index is of upmost importance to allow for continuous processing and to achieve products of reliable quality. Therefore, to monitor characteristic values, the recyclate quality target specifications need to advise standardised means of testing to aid the industry in advancing towards the right quality of recyclate. In addition, sampling methodology and the frequency should also be considered to ensure representative samples of the recyclate are taken and the desired properties are met. For some of the characteristics in the specifications, a tolerance was also specified to ensure that each sample is within the tolerance needed to create a homogenous batch of recyclate.

It is recommended that testing is conducted multiple times per batch – such as at least at the start, middle and end of production – to ensure consistency of the product. While it would be beneficial to test all characteristics at this frequency, it is likely that characteristics that require more expensive testing methods will be tested at a lower frequency. Alternative methods of testing may be required where the suggested testing in the target specifications is cost prohibitive, to ensure a level of process control to account for the lower testing frequency. For example, the recyclate quality target specification developed for HDPE blow moulded bottles advised the use of gas-chromatography for characterisation of odour. Since it may be cost prohibitive to analyse odour this way, less frequent external testing may be employed to analyse odour, such as panel tests.. Irrespective of testing frequency, an approved quality standard such as ISO 9001 or equivalent

should be maintained, and the results of the quality checks documented and stored such that the quality of recyclate can be effectively monitored over time.

Table 2: Recyclate Characteristics

Characteristic	Importance
Physical Properties	
Ash Content	Indicative of the presence of inorganic compounds, such as minerals and producers
Density	Indicative of recyclate polymer type
Filtration	Enables the removal of residual particulate materials such as minerals and paper labels
Gel count	Gels impact film material both structurally (risks increase > 200 µm) and aesthetically (< 200 µm)
Melt index	A measure of the ease of flow of the melted plastic
Moisture content	Excessive moisture demonstrates the need for drying
Odour	Impacts consumer-acceptance and product formulation
Pellet colour	Impacts branding and consumer-acceptance
Polyethylene content	Impacts the melt index of PP materials and the formation of gels
Polypropylene content	Impacts the melt index of PE materials and the formation of gels
Volatile Content	Cause unpleasant odour during the conversion process and may migrate into product affecting its formulation
Mechanical properties	
Elongation at break	How much the material is stretched at the moment of break
Flexural modulus	The material's resistance to deformation
Tearing force (MD/CD)	The difficulty or ease of tearing a material
Tensile strength at break	How much tension the material can withstand before breaking
Tensile strength at yield	How much tension the material can withstand before irreversibly deforming

Bale Specifications

Focus should also be given to the role of waste collection and sorting in delivering high quality feedstocks. To ensure the properties within the recyclate quality target specifications are achievable, the input bale material must firstly be of sufficient quality and consistency to secure the recyclate output quality. As such, it would be beneficial to standardise bale grades and utilise bale specifications that align with the recyclate requirements. The bale specification characteristics developed for the three PO packaging applications are listed in Table 3. It should be noted that secondary sorting may be required to achieve the target bale specifications developed.

Table 3: Bale Specification Characteristics

Characteristic	HDPE Bale	LDPE Bale	PP Bale
Non PO content	✓	✓	✓
Other PO content	✓	✓	✓
Non plastic content	✓	✓	✓
Moisture	✓	✓	✓
Colour	✓	✓	
Impurities			✓

2.2 Achieving the Specifications

This study set out to define recyclate quality target specifications that are achievable under current market conditions with existing technologies, techniques and processes. Waste collectors, sorters and recyclers may need to adopt better available technologies and/or processes to achieve the target specifications. They may need to consider one or more of the following:

- Appropriate **collection and initial sorting** by those managing the waste to align bale quality with subsequent specifications.
- Best practice **sorting** at recycling plants or secondary sorting centres (such as plastic recycling facilities (PRFs)) would improve separation of target and non-target polymers to improve recyclate quality e.g., using Near-Infrared (NIR) technology in pre-treatment. Flake sorting should also be used.
- **Recyclate Washing** - most recyclers currently wash ≤ 40 °C. Several key factors can improve recyclate washing including increasing the washing equipment to > 60 °C to enable the removal of organic contaminants, some inks and pressure sensitive labels including laminates and adhesives labels. In addition, having a high level of turbulent flow within the washing equipment will facilitate inter-particle shearing which will improve cleaning performance.
- **Double filtration** would facilitate the removal of contaminants (such as labels and non-target materials including paper and PET).
- **Deodorisation** of recyclate is an important attribute for many applications and should be carried out on a pellet after the extrusion.
- Investment in the required equipment and resources required for increased **testing frequency** of the characteristics in the specifications with the recommended testing methods, e.g., several samples taken throughout the batch production. Investment should consider the testing of

incoming bales, the testing of feedstock following further sorting, and the recyclate product output.

By advancing sorting and recycling protocols to meet the recyclate quality target specifications, recyclate of higher quality and economic value is anticipated. Evidence for the impact of improving sorting and recycling was revealed in a recent scientific article,[4] which evaluated an improved mechanical recycling process for flexible packaging, proposed and being commercialised as ValueFlex by the industrial CEFLEX consortium. The process, named the Quality Recycling Process (QRP), described protocols akin to those described above, including additional sorting, hot-washing, additional filtration and deodorisation. Importantly, the recyclates that were assessed revealed enhanced properties compared to their conventionally sorted and recycled counterparts, and the economic value of recyclates was found to potentially increase between 5 and 38 %.

2.3 Design for Recycling

Improved design for recycling would make the proposed target specifications easier to meet, enabling higher yields and lower costs, and would also help incorporation of higher recycled content in packaging in future.

Producers currently maintain high aesthetic demands for products containing recycled content. Converters and producers working with post-consumer plastic indicated that visual imperfections and inconsistency in colour can be difficult to control due to the variation in incoming material. To overcome this challenge, brands and retailers could promote consumer acceptance associated with products containing recycled content. Consumer acceptance could be facilitated by increasing the awareness that differences in aesthetic properties, such as variations in shades of a coloured bottle, are associated with recycled content. Further design simplifications for colour of specific packaging items would also greatly enhance the ability to create critical mass of waste streams dedicated to specific applications. Innovation in packaging design to make packages less sensitive to minor colour variation could also help create improved secondary raw material streams e.g., the use of shrink sleeves over non-pigmented packaging items.

Quality specifications are anticipated to deliver better value for the recyclates, which will encourage tailored upstream investment for sorting and recycling operations and improved collection and sorting technologies. These investments will maximise the benefits of recycling and enable the transition towards a circular economy.

[4] Bashirgonbadi, A. *et al.* (2022) Quality evaluation and economic assessment of an improved mechanical recycling process for post-consumer flexible plastics', Waste Management, 153, 41-51. If accessed online: Available at: https://www.sciencedirect.com/science/article/pii/S0956053X22004275 (Accessed: 8 February 2023).

2.4 Contact-Sensitive Challenges

The recyclate quality target specifications focus on physico-chemical and mechanical properties of recyclate and do not address any characteristics that are required for contact-sensitive applications. As food-contact packaging with post-consumer recycled content becomes increasingly feasible, the specifications should be considered along with other requirements such as the European Commission Regulation No 2022/1616 on recycled plastic materials and articles intended to come into contact with foods. Additional consideration should also be made for recyclate to be used in skin-contact applications, such as nappies and cosmetics, to ensure that recycled packaging provided by the industry is safe for the consumer. To ensure safety, initiatives such as CosPaTox,[5] (Cosmetics, Packaging, and Toxicology) aim to establish specific safety standards for high quality plastic recyclates used in, for example, containers for cosmetics. Incorporation of such guidance should therefore also be included in field trials to allow the recyclate quality target specifications to address possible contact-sensitive challenges.[6]

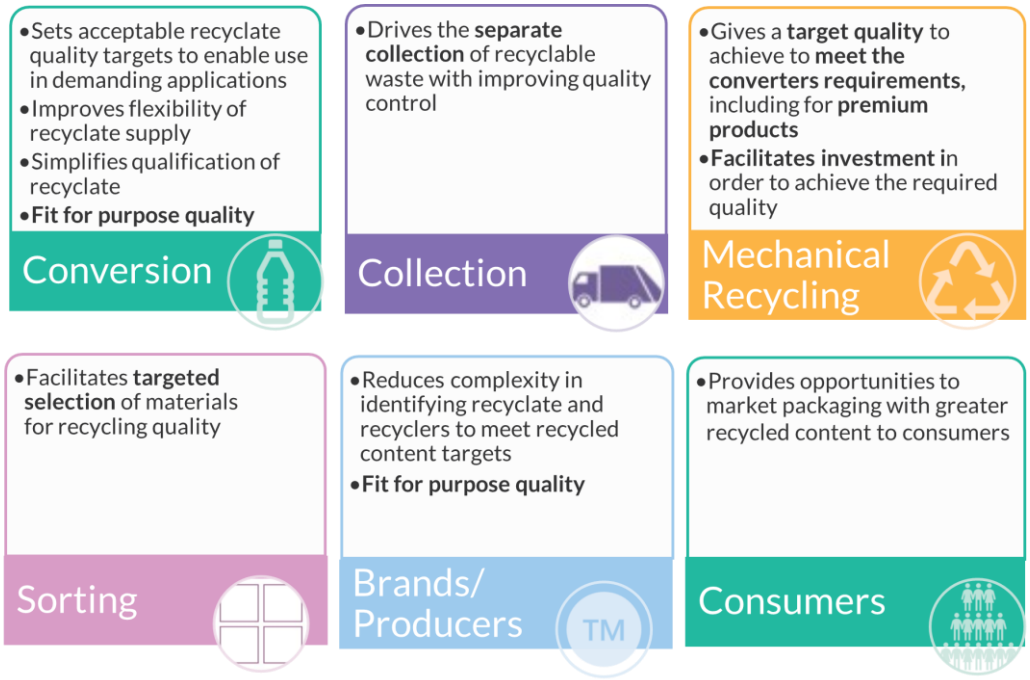
[5] Available at: https://www.bkv-gmbh.de/news-reader-4/cospatox-consortium-founded.html
[6] Regulation 2009/1223 and the Cosmetic Products Enforcement Regulations 2013: Great Britain. Available at: https://www.gov.uk/government/publications/cosmetic-products-enforcement-regulations-2013/regulation-20091223-and-the-cosmetic-products-enforcement-regulations-2013-great-britain

3.0

Action Plan: Recommended Next Steps

Through further development of recyclate quality target specifications and associated bale specifications across the secondary plastics market we can unlock benefits for all stakeholders in the value chain, as summarised in Figure 5.

Figure 5: Benefits of Target Specifications



Working with stakeholders from across the value chain, we have developed an initial set of target specifications for three PO packaging applications. To further refine these, the next steps would be to undertake operational trials and develop further granularity as required. Moving forward, we call upon the industry to urgently support the development of a suite of target specifications for a broad set of key applications. This will drive investment in the secondary plastics market and facilitate the availability of recycled content for products, starting from the applications with the largest market volume. Subject to industry engagement, the Alliance to End Plastic Waste is willing to facilitate such work.

To further develop the recyclate quality target specifications to create clarity for the industry on required investments to deliver quality, the following is recommended as an **industry roadmap**:

1. Finalise technical work on the target specifications for key applications by engaging market leaders in the supply chain to ensure critical needs are considered and realistic implementation is possible.
2. Define and execute industrial trials for key applications to validate the proper fit-for-purpose match between improved recyclate quality and the corresponding final packaging product, including feedback from producers.
3. Make use of the collective knowledge and learnings on what is practically achievable to inform ongoing certification initiatives and accelerate an industry acceptance and adoption of the target specifications.
4. Work towards aligned global standards by providing clear and systematic specifications to facilitate their implementation for global companies and applications.

4.0

Appendix: Can We Build Specification Consensus?

To test how the secondary plastics market might approach developing a set of target specifications, we undertook the following research.

A 1.0 Which Materials?

A 1.1 Polyolefin Market Size & Key Applications

Polyethylene (PE) and polypropylene (PP) together account for almost half of converter demand for polymer types in the EU28[7] and both are widely used in packaging applications. End markets for HDPE include toys, milk bottles, shampoo bottles and pipes.[8] End markets for PP include food packaging, sweet and snack wrappers, hinged caps, microwave containers, pipes and automotive parts. Of HDPE that is used for packaging, 61% is used for blow-moulded bottles. Of PP that is used for packaging, 70% is used for injection moulded pots, tubs & trays.

Recycled post-consumer plastic from rigid packaging meets only 8% of the demand for HDPE and 3% of the demand for PP.[9] This is insufficient to meet future targets as set by the proposed PPWR which specify minimum recycled content in plastic packaging per unit of packaging for 2030 and 2040. A summary of the targets is illustrated in Figure 1. It is also insufficient to meet the 30% average target for recycled content in beverage bottles by 2030 set by the Single Use Plastic Directive, which includes HDPE bottles used for juice and dairy.

Demand for flexible PE film in the EU28+2 was between 8.5 – 9 Mt in 2018.[10] Roughly 80% of PE film was used in packaging, with the largest category (32%) being used in stretch and shrink film applications.[11] The main polymers used to create flexible films are LDPE and LLDPE. Stretch film (often made with LLDPE) and shrink film (LDPE) are both produced by blown film extrusion and are typically used for the protection of goods or to bind products together.

[7] Plastics Europe (2018), *Plastics – the Facts 2018*. Available at: https://plasticseurope.org/wp-content/uploads/2021/10/2018-Plastics-the-facts.pdf (Accessed: 8 February 2023).
[8] Deloitte & PRE (2017), *Blueprint for plastics packaging waste: Quality sorting & recycling*. Available at: https://www2.deloitte.com/content/dam/Deloitte/my/Documents/risk/my-risk-blueprint-plastics-packaging-waste-2017.pdf (Accessed: 8 February 2023).
[9] Plastics Recyclers Europe (2020), *HDPE & PP Market in Europe – State of Play*. Available at: https://www.plasticsrecyclers.eu/wp-content/uploads/2022/10/hdpe-pp-market-in-europe.pdf (Accessed: 8 February 2023)
[10] Plastics Recyclers Europe (2020), *Flexible Films Market in Europe – State of Play*. Available at: https://www.plasticsrecyclers.eu/wp-content/uploads/2022/10/flexible-films-market.pdf (Accessed: 8 February 2023).
[11] Ibid.

Figure 6: Current Proposed PPWR Recycled Content Targets.

January 2030 Target	January 2040 Target
A. 30% for PET contact-sensitive packaging*	A. 50% for contact-sensitive packaging
B. 10% for Non-PET Contact-Sensitive Packaging*	B. 65% for single use plastic beverage bottles
C. 30% for single use plastic beverage bottles	C. 65% for packaging for others not referred to in points A & B
D. 35% for packaging for others not referred to in points A, B & C	

Three types of recyclate were selected for the development of recyclate quality target specifications based on their large shares of the polyolefin packaging market and demand for key applications - see Table 4.

Table 4: Applications Selected for Study

Recyclate material	Conversion Technology	Application
HDPE	Blow moulding	Bottles
LDPE	Extrusion	Shrink film
PP	Injection moulding	Including caps and tubs

The recyclate quality target specifications developed provide the physico-chemical, mechanical and aesthetic properties required for the highest value application in each case; they do not intend to meet food or skin contact-sensitive regulatory requirements.

Following on from the specifications given herein, the next step would likely require defining quality specifications for each key and application, as depicted in Figure 7. Further developments of the specifications are envisaged, both to extend the list of application categories, and to provide further specificity for sub-categories.

Figure 7: Building on Existing Specifications by Creating Recycle Quality Target Specifications at an Application and Conversion Technology Level

A 2.0 Existing Guidance and Standards

A 2.1 Existing Recyclate Standards & Characterisations

EN Standards

EUCertPlast is the European certification programme for companies that recycle post-consumer plastic waste. This programme references EN standards for the characterisation of plastic recyclates. The EN standards relevant to polyolefins are 'EN15344 – characterisation of PE recyclates' and 'EN 15345 – characterisation of PP recyclates.' These standards outline mandatory and optional characteristics of plastic recyclate quality and define test methods to assess these characteristics. However, the EN standards do not specify target values for each given characteristic, so recyclers must work with converters of recycled plastic to agree recyclate quality specifications for specific applications.

DIN Standards

The German national organisation for standardisation, Deutsches Institut für Normung (DIN) published guidelines for the classification of plastic recyclates, named DIN SPEC 91446, "Classification of recycled plastics by Data Quality Levels for use and (digital) trading". The standard was formed with the intention of forming a basis for international standards to be developed and includes guidelines for labelling packaging to allow recyclate type and content to be identified. According to the DIN standard, recyclates are classified into one of four data quality levels (DQLs), and depending on the DQL level, a variable number of characteristics are required to be reported (or may be optionally reported) in the technical documentation. In addition to providing a list of recyclate characteristics, the DIN standards also provide a list of corresponding testing methods that may be used. The guidance is highly useful in providing guidelines for labelling such that the compliance of recyclate may be visualised on packaging, and in highlighting the characteristic data needed to classify the quality level of recyclate. However, the guidelines lack target values for each characteristic.

PRE Recyclate Characterisation

PRE has published the PRE Recyclate Characterisation Guiding Requirements to assess the quality of the output of recyclers (see Table 5). These documents serve as a template to outline characteristics and technical properties for recyclers to use in product quality reporting. The documents also prescribe preferred testing methods to assess each technical property. These guiding requirements serve as a useful way of standardising the characteristics of recyclate for

recyclers and converters, but do not contain target values for different characteristics that are important for different applications.

The recyclate quality target specifications proposed below aim to build upon the EN Standards, the DIN Standards, and PRE Recyclate Characterisation to identify the important characteristics and their values/ranges for different conversion technologies and applications. This will facilitate a way to identify target values for recyclate characteristics.

Table 5: Summary of Plastics Recyclers Recycling Input Characterisation Guiding Requirements

	Prohibited Impurities	Limited Impurities	Grade Variation
All	Minerals, rubber, wood, sacks, hazardous waste, medical waste, glass, oxo or degradable material, food, silicones		
PET Bottle Grades	PET-G (PET with added glycol for flexibility), CPET (crystalline PET suitable for ovens)	Max 5% of PET from non-food consumer applications, metals, paper/cardboard, PVC, transparent colours, opaque colours, monolayer trays, other plastics	Clear: Max 5% light blue PET, no opaques Clear blue: Max 20% of blue PET, no opaques Light Blue: >20% light blue PET, no opaques Coloured: >80% transparent mixed colours, max 5% mixed colours
HDPE Bottles; Mixed Colour	Foams, polyurethane	Max 5% of HDPE from non-food consumer applications, metals, paper/cardboard, PP, other plastics	
PP Films	Expanded polystyrene, polyurethane	Metals, paper/cardboard, PVC, LDPE, HDPE, LLDPE, other plastics, other impurities	Variations in minimum content for PP
PE Films	Expanded polystyrene, polyurethane	Metals, paper/cardboard, PVC, PP, other plastics, other impurities	Variations in minimum content for LDPE, LLDPE, HDPE

A 2.2 Existing Bale Guidance & Specifications

Specifications exist to describe the quality of outputs from sorting (bale specifications) and recycling plants (recyclate specifications). For the European polyolefin market, Plastics Recyclers Europe (PRE) has published guidance for bales of different polymers. This guidance identifies key impurities (e.g. PVC, metal) that are challenging for product manufacturers working with post-consumer recycled material (Table 5). However, the guidance does not define the limits of impurities that can be tolerated to produce the required bale quality.

On a national level there are bale specifications set by producer responsibility organisations (PROs) such as Der Grüne Punkt (Germany), Afvalfonds Verpakkingen (The Netherlands), Ecoembes (Spain), CONAI (Italy) and Fost Plus (Belgium) (Table 6 – PE Film bales, Table 7 – PE Rigid bales, Table 8 – Other Bales). While these national bale specifications are useful for defining limits of key impurities and enable a degree of standardisation in the market, they are not unified across Europe and are not aligned with the quality that would best optimise system-wide efficiency for the production of high quality recyclates.

Table 6: Comparison of PE Film Bale Grades

Country	Organisation	Reference	Primary Material Focus	Targeted Description	Non-Targeted Description
Germany	VerpakG & Der Grune Punkt	DSD-DKR 310	LDPE	At least 92% in accordance with the Specification/Description. Description: Used, completely emptied, system-compatible articles made of plastic film, surface > A4, e.g., bags, carrier bags and shrink-wrapping film, incl. packaging parts such as labels etc	Max. total amount of impurities 8% Metallic and mineral impurities with an item weight of > 100 g are not permitted. Other metal articles: < 0.5% Other plastic articles: < 4% Other residual materials: < 4%
Netherlands	AFVALFONDS VERPAKKINGEN / Nedvang				
Spain	Ecoembes	LLDPE	LLDPE	Flexible film packaging (bags and packaging film, including stretchable film and shrinkable film) from selective collection ≥82% (including labels that are part of the packaging after compaction).	Improper materials <18.00% with maximum limits for the various fractions as follows: PET <1.00%; Metals <1.50%; Paper/cardboard, beverage cartons <2.50%; Other impurities <9.00%; Moisture <5.00%
Italy	CONAI SYSTEM	24610	PE	Colour: transparent, opaque, coloured Flexible packaging in the < A3 format: 20% max Other manufactured articles, other materials, polymers and contaminated containers: 2% max Contaminations: only minimal contamination from remains and external fouling allowed	Other manufactured articles, other materials, polymers and contaminated containers: 2% max Contaminations: only minimal contamination from remains and external fouling allowed

Country	Organisation	Reference	Primary Material Focus	Targeted Description	Non-Targeted Description
		24611	PE	Colour: transparent, opaque, coloured Other products and plastics packaging, materials (excluding metals and inert: 6% max Metals and inert materials: 2.5% max Contaminations: Accepted only minimal contaminations from residue and external origins	Other products and plastics packaging, materials (excluding metals and inert: 6% max Metals and inert materials: 2.5% max Contaminations: Accepted only minimal contaminations from residue and external origins

Table 7: Comparison of PE Rigid Bale Grades

Country	Organisation	Reference	Primary Material Focus	Targeted Description	Non-Targeted Description
Germany	VerpakG & Der Grune Punkt	DSD-DKR 329	PE	At least 94% in accordance with the Specification/Description. Description: Used, completely emptied, rigid, system-compatible articles made of polyethene, volume < 5 litres, e.g bottles, dishes and tubes ncl. Packaging parts such as caps, lids, labels etc	Max. total amount of impurities 6% • Metallic and mineral impurities with an item weight of > 100 g and cartridges for sealants are not permitted. • Other metal articles < 0.5% • Dimensionally stable PP articles < 3% • Foamed plastics including EPS articles < 0.5% • Plastic films < 5% • Other residual materials < 3%
Netherlands	AFVALFONDS VERPAKKINGEN / Nedvang				
Italy	CONAI SYSTEM	24010	PE	Container volume 0.5 min - 5 max Colour: mixed colours Containers of PET 1% max; Containers of PVC: 1% max; Containers of PP: 10% max Other manufactured articles, other materials, polymers and contaminated containers: 1.5% max Contaminations: only minimal contamination from remains and external fouling allowed	

Country	Organisation	Reference	Primary Material Focus	Targeted Description	Non-Targeted Description
Spain	Ecoembes	HDPE Bottles	HDPE	HDPE bottles and jugs obtained from selective collection ≥90% (including labels and caps that form part of the package after compaction). This percentage includes moisture.	Non-targeted materials <10% with maximum limits for the various fractions as follows: • rubber, silicone, polystyrene and polyurethane foam <0.05% • packages of other polyolefins and other plastic materials (except rubbers, silicones, polystyrene foams and polyurethane) <7% • metals <0.50% • paper/cardboard, beverage cartons and other impurities <2%
Belgium	Fosplus	HDPE	HDPE	All components that form part of selectively collected and sorted HDPE bottles and flasks, like caps and labels, are not regarded as pollution under the categories listed above	• Moisture content: < 10% • *Pollution due to non-plastic materials:* glass, stone ≤ 0.05%; metals (ferrous and non-ferrous) ≤ 0.20%; paper, cardboard (excl. bottle labels) ≤ 0.20%; drink cartons ≤ 0.20% • *Pollution due to plastic material:* non-polyolefin bottles and flasks (PET, PVC, PS, PC etc.) ≤1%; film/ foil ≤ 0.10%; plastic packaging or items other than bottles and flasks; ≤ 0.50%; HDPE recipients for food oil or liquid better ≤3%. • HDPE packaging that may hinder recycling and that as a result may not normally be present or may only be present in extremely limited quantities. Others: ≤ 0.05%

Table 8: Comparison of other bale grades

Country	Organisation	Reference	Primary Material Focus	Targeted Description	Non-Targeted Description
Germany	Der Grune Punkt	DSD-DKR 350	Mixed	Used, completely emptied, rigid, system-compatible articles made of plastics that are typical for packaging (PE, PP, PS, PET) incl. packaging parts such as caps, lids, labels etc.	Max. total amount of impurities 10 mass % • Metallic and mineral impurities with an item weight of > 100 g are not permitted. • Paper, cardboard < 5% • Other metal articles < 2% • PET bottles, transparent < 4% • PVC articles other than packaging < 0.5%
Netherlands	AFVALFONDS VERPAKKINGEN / Nedvang				
Germany	VerkpakG & Der Grune Punkt	DSD-DKR 324	PP	Rigid, system-compatible plastic articles made from PP, ≤ 5l in volume, like bottles, trays and cups, including ancillary components such as closures, labels, etc.	Max. total amount of impurities 6 mass % • Metallic and mineral impurities with an item weight of > 100 g and cartridges for sealants are not permitted! • Other metal articles < 0.5% • Rigid PE articles < 1% • Expanded plastics incl. EPS articles < 0.5% • Plastic films < 2% • Other residual materials < 3%

Country	Organisation	Reference	Primary Material Focus	Targeted Description	Non-Targeted Description
	VerkpakG	DSD-DKR 322	Mixed	Rigid, system-compatible plastic articles, like bottles > 5l in volume, and buckets, canisters and bulk packs ≤ 200l in volume, including ancillary components such as closures, labels, etc.	Sealant cartridges are disqualified
		DSD-DKR 323	PO	System-compatible plastic articles made from polypropylene (PP) and polyethylene (PE), like bottles, cups, trays, films, as well as household and plastic articles composed of the same material, including ancillary components such as labels, etc.	Sealant cartridges are disqualified
		DSD-DKR 351	PO & PS	Rigid, system-compatible articles made from polypropylene, polyethylene or polystyrene, like cups, bottles and trays, including ancillary components such as closures, labels, etc.	Foamed plastics, including EPS articles, are disqualified

A 3.0 Recyclate Quality Target Specifications

A list of characteristics, their proposed measurement method options and range of values are presented as follows:

- Table 9: HDPE - Blow Moulding (Bottles)
- Table 10: LDPE - Extrusion (Film)
- Table 11: PP - Injection Moulding

The range of values associated with each characteristic were determined based on feedback from all stakeholders.

A summary of the stakeholder feedback associated with each characteristic, value range and testing method is given in Table 12.

A 4.0 Target Bale Specifications

To ensure the properties within the recyclate quality target specifications are achievable, the input bale material must firstly be of sufficient quality. As such, it would be beneficial to standardise bale grades and utilise bale specifications that align with the recyclate requirements. As part of the research conducted, examples of three target bale specifications that align with the three recyclate quality target specifications were developed and are presented as follows:

- Table 13: HDPE Bale Specification
- Table 14: LDPE Bale Specification
- Table 15: PP Bale Specification

The target bale specifications provide a list of characteristics that require analysis and the corresponding recommended target values. For comparison, the typical recommended target values provided by existing bale specifications has also been included in each table. It should be noted that secondary sorting may be required to achieve the target bale specifications developed.

Table 9: HDPE - Blow Moulding (Bottles)

Characteristic	Measurement Method Options	Value	Unit
Physico-chemical Properties of Extruded Pellet			
Ash Content	EN 1SO 3451-1	< 1.0	%
Density	EN 1SO 1183-1 Method A	950 - 970 with variance of ± 0.5	kg/ m^3
Filtration	Mesh Size	≤ 100	µm
Melt Index	EN ISO-1133-1 Condition D	0.3 – 0.8 with variance throughout the batch of less than ± 0.2	g/ 10 min
Moisture	Moisture Analyser	< 0.2	%
Odour	GC-MS or GC-FID (ASTM D6420-18)	Limonene < 10	ppm
Polypropylene Content	DSC (EN ISO 11357-1, EN ISO 11357-2, EN ISO 11357-3)	≤ 2.0	%
Pellet Colour	Yellowness Index (ISO 17223) or L*a*b* Colour Space (ISO 11664-4)	Ultimate colour to be determined by customer. Delta E < 2	n/a
Volatile Content	GC-MS or GC-FID (ASTM D6420-18)	< 20	ppm
Mechanical Properties of Product			
Flexural Modulus	EN ISO 178, EN ISO 527-1, EN ISO 527-2	> 1000	MPa

Table 10: LDPE - Extrusion (Film)

Characteristic	Measurement Method Options	Value	Unit
Physico-chemical Properties of Extruded Pellet			
Ash Content	EN 1SO 3451-1	< 2.0	%
Density	EN 1SO 1183-1 Method A	920 - 950 with variance of ± 0.5	kg/ m^3
Filtration	Mesh Size	≤ 100	µm
Melt Index	EN ISO-1133-1 Condition D	0.3 – 0.8 with variance throughout the batch of less than ± 0.2	g/ 10 min
Moisture	Moisture Analyser	< 0.1	%
Polypropylene Content	DSC (EN ISO 11357-1, EN ISO 11357-2, EN ISO 11357-3)	≤ 2.0	%
Volatile Content	GC-MS or GC-FID (ASTM D6420-18)	< 20	ppm
Mechanical Properties of Product			
Elongation at Break	EN ISO 527-1, EN ISO 527-2	> 800	%
Gel Count	Visual Inspection	Max 250 gels >200 µm per m^2	Number
Tearing Force (MD/CD)*	EN ISO 6383	MD<1200; CD<5500	mN
Tensile Strength at Break[12]	EN ISO 527-1, EN ISO 527-2	14 – 15	MPa

*Machine direction/ cross direction

Table 11: PP - Injection Moulding

Characteristic	Measurement Method Options	Value	Unit
Physico-chemical Properties of Extruded Pellet			
Ash Content	EN 1SO 3451-1	< 1.0	%
Density	EN 1SO 1183-1 Method A	910 - 920 with variance of ± 0.5	kg/ m^3
Filtration	Mesh Size	≤ 100	µm
Melt Index	EN ISO-1133-1 Condition M	> 15	g/ 10 min
Moisture	Moisture Analyser	< 0.2	%
Odour	VDA 270	Odour rating < 3.5	Number
Pellet Colour	Yellowness Index (ISO 17223) or L*a*b* Colour Space (ISO 11664-4)	Ultimate colour to be determined by customer. Delta E < 2	n/a
Polyethylene Content	DSC (EN ISO 11357-1, EN ISO 11357-2, EN ISO 11357-3)	≤ 5.0	%
Volatile Content	GC-MS or GC-FID (ASTM D6420-18)	Negligible	ppm
Mechanical Properties of Product			
Flexural Modulus	EN ISO 178, EN ISO 527-1, EN ISO 527-2	1000 - 1600	MPa
Tensile Strength at Yield	EN ISO 527-1	> 20	MPa

Table 12: Summary of stakeholder feedback on test methods and challenges in reaching the characteristic limit set

Characteristic	Stakeholder Feedback
Physical Properties	
Ash Content	Ash was noted as being colour dependant, owing to its visibility in white and natural products. For coloured HDPE material in particular <2 % may be acceptable.
Density	No variance in the density specification is anticipated.
Filtration	No variance in the filtration specification is anticipated
Gel count	Gel count has been noted as being highly important across numerous converters for LDPE shrink film. While gels > 200 µm can cause structural issues, gels < 200 µm affect aesthetics. Achievement of a lower gel count may be attained through the use of additional filtration. A key issue with gel count is that it remains challenging to measure in a standardised way. Two approaches are commonly used: • Visual inspection: In this approach, a sample may be subjectively compared to a reference sample, rather than the number of gels being exactly counted. • Optical Control System (OCS): The OCS method provides an automated method of gel counting, however remains challenging to standardise as different conditions and parameters can skew results. While larger recycling companies tend to rely on the more expensive OCS approach, smaller companies continue to rely on visual inspection. In both cases, the preparation of a thin sample is required which is currently non-standardised.
Melt index	No variance in the melt index specification is anticipated.
Moisture content	No variance in the moisture content specification is anticipated. The moisture content is on delivery of the recyclate at the converter.

Odour	For HDPE bottles and LDPE shrink film, limonene is a good proxy for odour since it is present in many detergents employed during washing. However, limonene is not the only compound that may be tested for. Details of other compounds are typically proprietary information and producer-dependant. In addition, due to the high cost associated with the gas-chromatography based measurement process, odour may be assessed qualitatively rather than quantitatively making it challenging to set a target value range. For PP, there is no current standardised way of measuring odour, however the VDA 270 method employed by the automotive industry was suggested by several companies.
Pellet colour	Colour is customer-dependant and tested using various methods in industry. While the acceptable variation is colour dependant, a value of Delta E < 2 was selected as a general starting point. Currently, colour consistency remains challenging in the market for aesthetic reasons
Polyethylene content	No variance in the polyethylene content specification is anticipated.
Polypropylene content	No variance in the polypropylene content specification is anticipated.
Volatile Content	The identification of specific volatiles is typically proprietary information, and therefore variance is anticipated in the value range given. Due to the high cost associated with the gas-chromatography based measurement process, volatiles are often only measured once annually, if at all.
Mechanical properties	
Tensile strength at break	No variance in the tensile strength at break specification is anticipated.
Tensile strength at yield	No variance in the tensile strength at yield specification is anticipated.
Flexural modulus	No variance in the flexural modulus specification is anticipated.
Elongation at break	No variance in the elongation at break specification is anticipated.
Tearing force (MD/CD)	No variance in the tearing force specification is anticipated.

Table 13: HDPE Bale Specification

Characteristics	Unit	Target Bale Specification Recommended Value	Existing Range of Recommended Values
Non PO content	%	< 2	<0.05 to < 1
Other PO content	%	< 4	< 7 or not specified
Non plastic content	%	< 2	<0.2 to < 2
Moisture	%	< 10	< 10 or not specified
Colour	n/a	Separate natural and coloured	Not specified

Table 14: LDPE Bale Specification

Characteristics	Unit	Target Bale Specification Recommended Value	Existing Range of Recommended Values
Non PO content	%	< 2	< 4
Other PO content	%	< 4	< 4
Non plastic content	%	< 2	< 4 (and below 100 g of metal/ mineral content)
Moisture	%	< 10	Not specified
Colour	n/a	Separate clear and coloured	Not specified

Table 15: PP Bale Specification

Characteristics	Unit	Target Bale Specification Recommended Value	Existing Range of Recommended Values
Total impurities	%	< 4	< 6
Non-PO content	%	< 1	< 0.5 (for “expanded plastics”)
Other PO content	%	< 0.5	< 1 to < 2
Non plastic content	%	<2	< 4 (and below 100 g of metal/ mineral content)
Moisture	%	< 10	Not specified