FIBRE-BASED PACKAGING RECYCLABILITY EVALUATION PROTOCOL

VERSION 1, JANUARY 2025

4ever green

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1. Executive summary

4evergreen strives to increase the circularity and recycling rate of fibre-based packaging to 90% by 2030. In order to support this mission, 4evergreen issues factual guidelines and technical documents alongside efforts aimed at facilitating dialogue and consensus-building among more than 100 stakeholders belonging to the fibre-based packaging value chain. A beta release of this document published in December 2022 forms the basis of the current version. The recyclability evaluation approach for standard mills (Part I) has now been upgraded. Please note that in October 2024 Cepi decided to replace the term 'Standard recycling mill' by 'Recycling mill with conventional process', which applies to the current **Fibre-Based Packaging Recyclability Evaluation Protocol.** It does not mean any change in scope but merely a change in the terminology. Evaluation schemes, i.e. scorecards for recycling mills with flotation-deinking and a specialised process for used beverage cartons (UBC) have been added to this version. This document helps to assess the recyclability of individual packaging and/or materials in a paper recycling mill with the recycling process types described later. It is based on expert opinion and consensus-building and utilises a vast amount of data from recycling tests. This data was reprocessed and calibrated to create the most up-to-date scoring for the technical recyclability of fibre-based packaging. This protocol is ready to be used by industrial stakeholders as a tool for evaluating technical recyclability within different types of paper recycling mill processes.
4evergreen has also published other tools related to design for recycling (DfR) and recycling of fibre-based packaging, namely a Circularity by design guideline and a Guidance on the improved collection and sorting for fibre-based packaging. These guides support the design of packaging in order to **achieve the best possible circularity performance.**

Future versions of this document will include an extended assessment in Part III, including a recyclability evaluation covering other specialised recycling processes for fibre-based composite packaging (FBCP).

2. Scope of the document

This document describes the assessment and score calculation procedures of the technical recyclability of fibre-based packaging items and/or materials for three different types of paper recycling mill processes:

- Part I (recycling mill with conventional process) assessment is specific to recycling mills with conventional processes, and assesses the results of the Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process.[1]
- Part II (recycling mill with flotation-deinking process) assessment is specific to recycling mills with flotation-deinking processes, and assesses the results of the test method Paper and Board – Recyclability Laboratory Test Method – Part II: Recycling mill with Flotation-Deinking process.
- Part III (specialised recycling mill) assessment is specific to recycling mills with specialised process (UBC), and assesses the results of the Paper and Board – Recyclability Laboratory Test Method – Part III: Recycling mill with Specialised process (UBC). The assessment of other specialised processes, e.g. FBCP, will follow in a further version of this document.

The Evaluation Protocol focuses on the technical recyclability of fibre-based packaging without considering collection, sorting, or the effects of recycling various packaging items together. Also the possible presence of food residues is not considered.

[1] Until this document is released, the Cepi recyclability laboratory test method applies (www.Cepi.org)

3. General introduction

Consumers are increasingly aware of environmental problems and the importance of eco-design and recycling in both the goods they purchase and the way they are packaged. Brands and retailers are under pressure to respond to these market expectations. Fibre-based packaging is both a sustainable and circular solution – closing the loop on resources to keep them in use for longer – because it is based on renewable material and has one of the highest recycling rates among all packaging types globally. Packaging needs to fulfil various functions, such as protecting the contents, communicating information about the products, and facilitating their transportation. Using fibre-based packaging to achieve these different properties may require a combination of materials offering longer shelf-life (i.e. lower food waste) and more protection against external damage.

While the Circularity by design guideline for fibre-based packaging, published by 4evergreen, provides recommendations for the design of fibre-based packaging and addresses the entire value chain – from manufacturers to retailers, brand owners, product designers, and material suppliers – this document enables the harmonised assessment of the technical recyclability that may be affected by all components of fibre-based packaging. This protocol evaluates the recyclability only by considering if a fibre-based package can be technically recycled applying dedicated repulping and recycling processes. The recyclability is assessed by applying a defined lab test procedure (Part I, II, III), as shown in Table 1.

Parts of the Evaluation Protocol	Scope	Name of test method	Released by
Part I	Recycling mill with conventional process	Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process	Cepi
Part II	Recycling mill with flotation-deinking process	Paper and Board – Recyclability Laboratory Test Method – Part II: Recycling mill with Flotation-Deinking process	4evergreen
Part III	Recycling mill with specialised process (UBC)	Paper and Board – Recyclability Laboratory Test Method – Part III: Recycling mill with Specialised process (UBC)	4evergreen

Table 1: Lab test method references of the Recyclability Evaluation Protocol

The Recyclability Evaluation Protocol can only be applied if all required output data from the corresponding lab test method is available. If it is not possible to generate the required data the Recyclability Evaluation Protocol cannot be applied.

The Protocol does not consider collection and sorting aspects. Recyclable (as defined in ISO 14021) does, however, include aspects of collection and sorting in individual markets – i.e. whether packaging is collected, sorted (where applicable), and finally recycled in a paper or board mill.

Due to the wide variety of fibre-based packaging solutions, adaptations in the recycling process may be needed to increase the rate of material recovery. Indeed, the amount and variety of fibre-based packaging on the market is continuously growing and becoming more complex. Innovative solutions across the entire value chain are therefore needed to maintain and further increase recycling rates across Europe.

This document has been developed by the 4evergreen alliance to address the technical recyclability assessment of fibre-based packaging in different types of recycling processes in paper and board recycling mills. The Recyclability Evaluation Protocol is a document with no legal binding status, consequently retains companies the freedom to decide how they utilize the document to make their own business decisions and conduct other related commercial activities. In October 2024, Cepi replaced the term 'Standard recycling mill' by 'Recycling mill with conventional process' – a change in terminology that does not alter the scope.

Packaging and sustainability experts working in companies acting across the entire fibre-based packaging supply and value chain have been involved. The primary purpose of this Evaluation Protocol is thus to help assess and compare the technical recyclability of different fibre-based packaging materials.

Data from the individual test protocols include specific parameters, such as measurements or baselines, is used for evaluation within this Evaluation Protocol. Part I uses specific thresholds and targets weighted to assess the technical recyclability of fibre-based packaging in a recycling mill with conventional process. Part II uses specific thresholds and targets weighted to assess the technical recyclability of fibre-based packaging in recycling mill with flotation-deinking process.

While Part III also uses data and specific thresholds to assess the technical recyclability of fibre-based packaging in a recycling mill with specialised processes, it is currently only considering the recycling process for recycling UBC. Other specialised processes like FBCP will follow in a next release.

There are various degrees of complex packaging materials and solutions. This Evaluation Protocol has been elaborated in such a way that there is an acceptable balance between efficiency and quality when the packaging is processed in a recycling mill. This takes the efficiency of the fibrous material recovery and quality parameters into account.

It is important to note that a negative assessment reported for one recycling process type does not exclude further testing to be performed for another recycling process type. The **Technical Recyclability Scores** derived for one type of recycling process cannot be transferred to other types. Furthermore, it is not possible to directly compare the Technical Recyclability Score for Parts I, II and III directly with the intention to state that the recyclability in one process is any better than in another one because each Part uses a slightly different set of parameters and calculations. Only the overall assessment result (technically recyclable or not) should be used to decide in which recycling process type a packaging material could be recycled.

4. Updates and future steps schedule

The Fibre-based Packaging Recyclability Evaluation Protocol described in this document was developed within the scope of 4evergreen's Workstream 1 – a standing committee set up for an indefinite duration with the objective of delivering a harmonised and publicly available protocol. Over the course of its existence, experts across the entire value chain have collaborated intensely to create a consensus-based protocol with the aim of achieving both broad acceptance and timely delivery, an agile response to the urgent calls within the market for a harmonised recyclability assessment across Europe.

This document aims to provide a solid baseline, thoroughly scrutinised by experts and thus offering immediate value for all stakeholders, and upon which further iterations can expand and improve. In December 2022, a Beta-release was published to send a clear message to users that the 4evergreen forum has the ambition to make further adaptations and improvements in the future. The Beta-release was the outcome of collaboration and a consensus-building process between more than 100 4evergreen member organisations. Since its launch, feedback has been collected from stakeholders within the fibre-based packaging value chain. Members of the alliance integrated this feedback into the current Version 1 of the Evaluation Protocol.

During the consensus-building process, several topics were identified by the experts as key questions warranting further investigation, though not fundamentally undermining the utility of this Version 1 release. The alliance worked on many of those topics. Some of the parked topics have now been addressed in the current version, such as the evaluation of dissolved and colloidal substances (DCS), and the integration of longer disintegration times. Some matters raised by some members in the value chain require further reflection before they can be implemented properly. Such open topics include how to deal with 'macrostickies', more detailed reject quality evaluation, stream-specific evaluation, etc.

4evergreen plans to keep this document up to date and relevant to realities on the ground, while simultaneously providing and considering feedback on the underlying laboratory methodologies. To support this effort, please send suggestions to 4evergreenalliance@gmail.com. All feedback is welcome and will be duly considered for future versions.

5. Methodology of the evaluation

The Recyclability Evaluation Protocol assesses the technical recyclability of fibre-based packaging products treated under different conditions by different recycling mill process types. As stated previously, three types of paper recycling mills with different processes are described: a recycling mill with conventional process (Part I), a recycling mill with flotation-deinking process (Part II), and a recycling mill with specialised process (Part III). Depending on which mill process is considered for the assessment, the test method needs to be adapted.

It is recommended to test packaging products according to where or how they are recycled.

For household collection, the 4evergreen alliance has developed a scheme (Figure 1) showing where fibre-based packaging products would typically end up being recycled.

Please note that this graphic was developed by 4evergreen Workstream 3 and published in its Guidance on the improved collection and sorting of fibre-based packaging for recycling. For this document, the corresponding part 'Technical recyclability evaluation protocol' has been added as an additional layer to this graphic and terminology for recycling mill process types has been adapted (see Chapter 3).

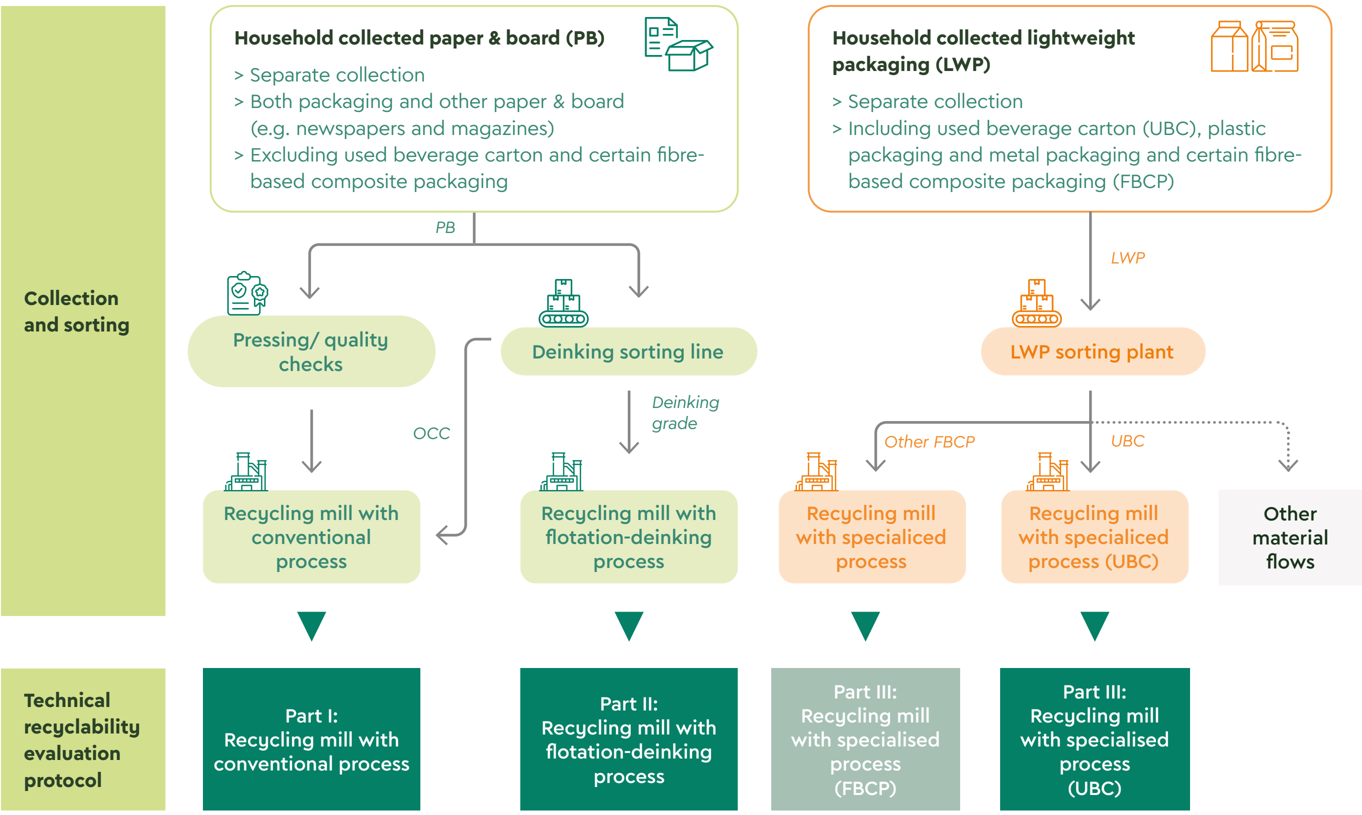


Figure 1: Recycling scheme for household collection

[2] Guidance on the improved collection and sorting of fibre-based packaging for recycling (2024) https://4evergreenforum.eu/about/guidelinesandprotocol

The production of white/bleached fibres consumes more energy and chemicals and the yield is lower compared to production of brown fibres. Therefore, it is economically and ecologically reasonable to keep white/bleached fibres as long as possible in the white fibre loop.
Locally, it is possible that paper is not collected separately but comingled (collection of paper and other recyclable material in one bin). Then paper for recycling is sorted from the comingled collection to recycling mills with conventional or flotation-deinking process.
These recommendations only apply to paper for recycling collected from households. Paper for recycling from B2B can be more specifically assigned to a recycling process. This makes it easier to evaluate and assign fibre-based packaging recyclability according to the different Parts of the Protocol.

The evaluation of a packaging product for a specific recycling process type is performed in two steps:

> **Step 1:** Laboratory testing according to the protocol for the chosen recycling process type.

> **Step 2:** The results of Step 1 are put into the corresponding Scorecard of the Evaluation Protocol and the recyclability score is calculated.

Table 1 lists the corresponding Parts of the Recyclability Evaluation Protocol and the laboratory test methods.
It is important to note that a negative assessment reported for one recycling process type does not exclude further testing to be performed for another recycling process type. Recyclability scores derived for one recycling process type cannot be transferred to other recycling process types.

For Part I and II the Technical Recyclability Scores range from +100 to -100 points, where the higher numbers indicate better technical recyclability for the individual process. The Score results are, where meaningful, also placed in several classes to clarify the interpretation of the score. A negative Technical Recyclability Score means that the assessed product is not technically recyclable in that specific recycling process type only.

For Part III, in the current version, the Technical Recyclability Score range is +100 to +50 points. Knockout criteria leading to points loss are only applied to assessment parameters other than the yield. Any activated knockout or a Technical Recyclability Score below 50 points means that the assessed product is not technically recyclable in a recycling mill with specialised process (UBC). In a later version, score deductions might be introduced on other assessment parameters and target values for these parameters should be introduced as well.

For Part I, II and III, Scores are rounded to whole numbers applying mathematical rounding rules.

It is important to be aware that the score provided by this Recyclability Evaluation Protocol is **not the same** as the score described under the EU Packaging and Packaging Waste Regulation (PPWR) used for recyclability performance grade determination. The methodology used in this document comprises various yield and quality parameters, whereas the details for the score and performance grade calculation in the PPWR are to be defined by delegated acts at a later time (see **Chapter 6** for details).

6. Regulatory background

For a detailed background on the EU regulatory framework and the future outlook, the reader is referred to the Circularity by design guideline for fibre-based packaging, Version 3.
As part of the European Green Deal and Circular Economy Action Plan, the European Commission put forward a revised Packaging and Packaging Waste Directive in November 2022, which became the Packaging and Packaging Waste Regulation, directly binding on all EU Member States with no adaption to national law necessary.

As part of this regulation four performance grades were put forward: A, B, C, and technically non-recyclable. These grades are linked to recyclability per unit (in terms of weighting) with the minimum being 70% for grade C. Various parameters determine to which performance grade a packaging is assigned, such as efficiency of sorting, ease of dismantling, presence of labels or other attachments, and availability of waste management infrastructure. The exact process for assigning grades to packaging products is yet to be determined by delegated acts (expected sometime in 2028).

This evaluation protocol is anticipated to be a useful tool to assess the suitability of fibre-based packaging products being treated in a certain recycling process type. It should be made clear that this protocol **does not offer a complete assessment** towards a grade as outlined by the PPWR. However, it is 4evergreen's intent that this protocol could be used as part of the overall evaluation by the PPWR if lab-based evaluations are needed for certain types of fibre-based packaging, thus supporting fact-based design for recycling tables.

7. PART I – Recycling mill with conventional process

MILL DESCRIPTION

Most recycling mills with conventional process utilise the EN 643 paper grades of group 1-4.
The typical process steps in a recycling mill with conventional process are shown in Figure 2.

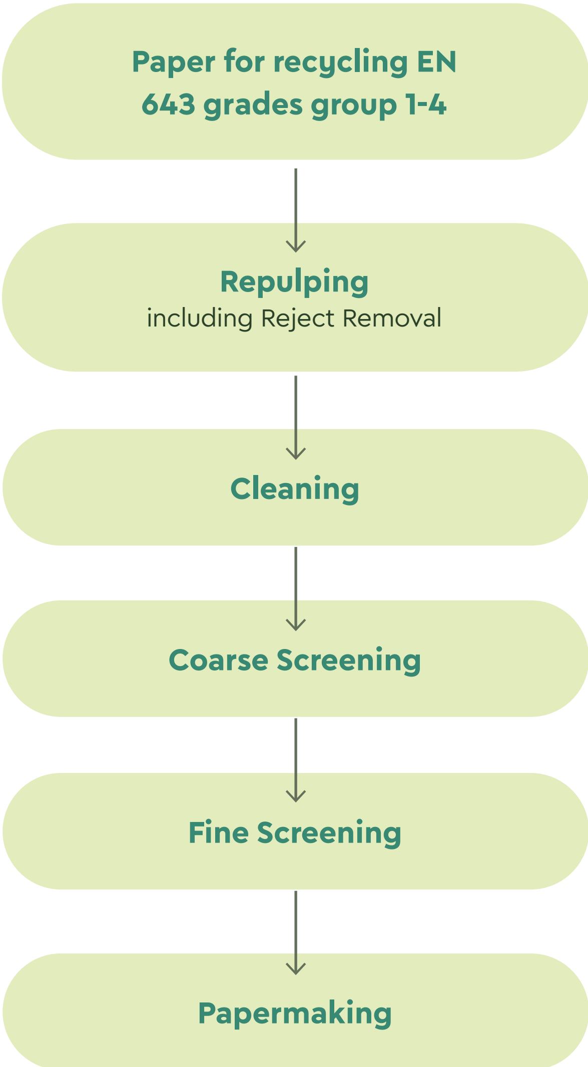


Figure 2: Scheme of a typical recycling mill with conventional process

(RE)PULPING

The purpose of repulping is to disintegrate the paper into fibres and other paper components (fillers, inks, varnishes, coatings, etc.). In this step, the paper for recycling is mixed with warm water (40°C-50°C) of pH 6-7. The conventional mills typically operate a low consistency pulper (4-5% fibre concentration) in continuous mode. Batch pulping may also be used but is less common in the industry. Average retention time in the pulper is 5-10min.

COARSE AND FINE SCREENING

Screening is a process of removing impurities from the pulp, i.e., to separate the contaminants from the fibres. It is based on particle size, shape and rigidity difference between fibre and non-fibre components or non-fully dispersed fibre flakes. It can be divided into coarse and fine screening. Coarse screening (often combined with deflaking to further disperse fibre flakes into individual fibres) is performed after the pulping step at a medium stock concentration (2.5-4.0%). The fibre suspension flows through screening holes where large contaminants are retained (typical hole diameters 2-3mm) while fibres can pass freely through. The objective of the fine screening is to remove smaller-sized particles (e.g. adhesives, smaller particles) from the pulp. Fine-screening is generally done at medium or low stock concentration (1-2.5%) through slotted baskets (typical slot size 0.15-0.4mm). Screening is often operated in cascaded systems and recycling mills may have one or more steps of coarse and fine screening in accordance with process efficiency and the target quality of recycled pulp.

CLEANING

After pulping, the fibre slurry can be fed to hydro-cyclones (so-called ‘cleaner’) to separate impurities that have different densities from fibres and water. In general, conventional mills have high-density cleaners at a stock concentration of 3-4% to separate the bigger or heavier contaminants like staples and small stones. Heavy contaminants of smaller size (e.g., sand) are taken out by low-consistency hydro-cyclones (stock concentration 0.5-1.5% and called heavyweight cleaner). In many cases the low-density debris (e.g., expanded polystyrene) are also separated in these hydro-cyclones (so-called lightweight cleaner).

PAPERMAKING

After cleaning and screening steps, the recovered pulp is mixed with additives to form a paper-making furnish which is fed to a paper machine to produce recycled paper.

LABORATORY TEST METHOD

For assessing the recyclability of fibre-based packaging in a recycling mill with conventional process, Cepi published a test method: Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process. This test method was developed with feedback from 4evergreen to improve its reproducibility and repeatability through detailed descriptions and fine-tuning of procedures. It defines a laboratory procedure emulating the most relevant process stages (repulping, coarse and fine screening, sheet formation) of a ‘paper recycling mill with conventional process’ dedicated to recycling the most common conventional grades of paper and board without deinking technology or other special features. While relevant, the hydro-cyclone cleaning step is not included in the test method due to a lack of standardised equipment that could be directly implemented in the test method. It may be addressed in future versions.

The testing method provides results relevant to recyclability performance (yield, coarse and fine reject, dissolved and colloidal substances) as well as to the quality of recycled paper (visual impurities and sheet adhesion). These results serve as a basis for Part I of the Evaluation Protocol described in this document. Analysis of macrostickies is not covered in the current version but will be included in a later one, so it is recommended that it is carried out in the meantime as an optional measurement to assemble important data ahead of its eventual addition to the Technical Recyclability Scorecard. The parameter chemical oxygen demand (COD) is also not included in the Evaluation Protocol, remaining as an optional test to assess the chemical degradation of substances in the filtrate.

TECHNICAL RECYCLABILITY SCORE

RESULTS OF THE LABORATORY TEST METHOD

In order to calculate the technical recyclability score, several output values of the lab test are considered. Table 2 shows the output values currently being considered. A detailed explanation of how these values are obtained can be found in the description of the test method. In addition to the parameters shown in Table 2, other relevant factors have been considered but not yet included in this version. Those additional parameters (shown in Table 3) may be incorporated in future versions of the Recyclability Evaluation Protocol according to release schedules.

Two-side water barrier coated samples:

All fibre-based packaging can be tested using the Part I and the recyclability assessed according to this protocol, but two-side water barrier coated samples require a more detailed evaluation to determine if it can be applied. A dedicated annex of this document provides more guidance. A suitable test procedure to identify where the method does not describe the recycling behaviour sufficiently for two-side water barrier coated materials will be developed in future.

Parameter	Acronym	Meaning
Coarse Reject	**CR**	Weight percent of packaging retained by coarse screening and dry removed components.
Fine Reject	**FR**	Weight percent of packaging retained by fine screening after coarse screening.
Total Screening Reject	**TSR**	Sum of coarse and fine reject, using a correction factor for the fine screening reject value.
Total Screening Yield	**TSY**	Total amount of packaging minus TSR expressed in percent.
Dissolved and Colloidal Substances	**DCS**	Mass of substances in the filtrate obtained following filtration of pulp and disintegration related to packaging mass in mg/g (determined as evaporation residue, ER).
Visual Impurities	**VI**	An evaluation of the optical purity of the paper. The parameter is evaluated on a hand sheet from the accept pulp after fine screening.
Sheet Adhesion	**SA**	Evaluation of the tackiness of a hand sheet from fine screening accept.
Disintegration Time	**DT**	In general, the disintegration time is 10 min. If at least 15% of total screening rejects is measured, containing a significant amount of fibres, and there is no knockout for sheet adhesion, the time can be extended to 20 min.
Reject Characterisation	**RC**	Description of the main components of the reject. Characterisation of coarse and fine reject is needed for assessing 'significant amount of fibres' (20 min disintegration option) and two-side water barrier coating.

Table 2: Part I: Parameters used for Technical Recyclability Score calculation

Parameter	Acronym	Meaning
Macrostickies Analysis	**MSA**	Quantitative assessment of tacky components in the pulp.
Chemical Oxygen Demand	**COD**	Indicative parameter for process water quality measured by the amount of oxygen needed by chemical oxidation with dichromate. High values indicate risks for deposits and risks in waste water treatment.
Biological Oxygen Demand	**BOD**	Indicative parameter for process water quality measured by the amount of oxygen needed by microorganisms to degrade organic substances.

Table 3: Part I: Additional parameters currently not used for the calculation in the scorecard – potential future parameters for the scorecard

TECHNICAL RECYCLABILITY SCORE CALCULATION

In order to translate the output values into one final Technical Recyclability Score, the results of the following parameters are added: Total Screening Yield (TSY), Dissolved and Colloidal Substances (DCS), Visual Impurities (VI), and Sheet Adhesion (SA).

Total Screening Yield score

The TSR is calculated according to Equation 1. The total screening reject measures how much solid material is removed by screening. All terms used in Equation 1 can be found in Table 2 except for α which is a correction factor used to mimic the solid material recovery in multi-stage screening processes. Residence times and mechanical shearing forces applied in the industrial process – for example in pumps – can trigger a slightly better disintegration of fibre bundles compared to lab conditions. The value of α is set to 0.9 based on expert consensus. The constant α might be changed into a variable value taking the fine reject characterisation into account in future versions.

EQUATION 1

$$TSR = CR + FR * \alpha$$

where

- TSR is the Total Screening Reject (%);
- CR is the Coarse Reject rate (%);
- FR is the Fine Reject rate (%);
- α is the correction factor.

Complementary to the Total Screening Reject (TSR) is the Total Screening Yield (TSY), which - beside the Evaporation Residue (ER) -describes the amount of material mass that can be reused in a new fibre product. The calculation is shown in Equation 2.

EQUATION 2

$$TSY = 100\% - TSR$$

where

- TSY is the Total Screening Yield;
- TSR is the Total Screening Rejects.

For a recycling mill with conventional process striving for high yield, the TSR amount must be kept to a minimum. This has clear financial, technical and environmental benefits reflected in the score level allocated. The calculation for the yield score is shown in Table 4 and is divided into five intervals or ranges. Each interval indicates an increasing reduction in score as the yield becomes lower and less material can be recovered. A value of 0 is reached at 80% yield or 20% total screening TSR. A visual representation of the score intervals as a function of yield is shown in Figure 3. As fewer points are lost when reject amounts are lower, a greater error percentage in the results in lower yield ranges ensures the scoring is still reliable.

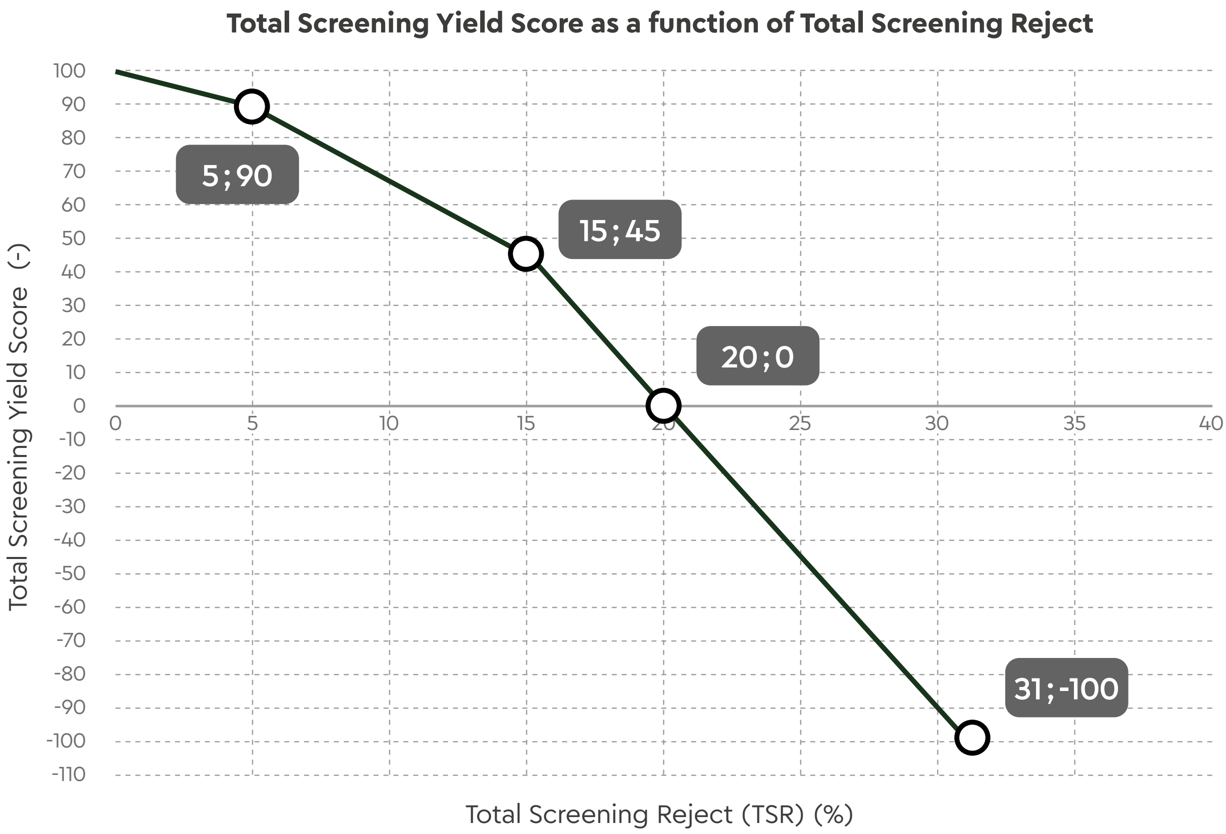


Figure 3. Part I: Visual representation of the Total Screening Yield Score as function of Total Screening Reject.

Total Screening Yield (%)	Total Screening Reject (%)	Formula	TSY Score
≥ 95	≤ 5	Score=100-TSR * 2	100…90
95… 85	5…15	Score=90-(TSR-5) * 4,5	90…45
85…80	15…20	Score=45-(TSR-15) * 9	45…0
80…69	20…31	Score=45-(TSR-15) * 9	0…-100
≤ 69	≥ 31	Score = -100	-100

Table 4: Part I: Overview of the Total Screening Yield score calculation

20 minutes disintegration and reject characterisation

The disintegration time in a lab setting is aimed to emulate the repulping behaviour of fibre-based packaging in equipment typically used in an industrial setting. Currently, the test method Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process uses a standard laboratory fibre disintegrator which is designed to defibrate dry pulp samples. It was agreed that with this setup, 10 minutes disintegration time would be the most appropriate, but the test method allows for 20 minutes disintegration time under certain conditions. The reason is that some fibre-based packaging requires only slightly longer disintegration time than 10 min to achieve good fibre recovery.

The 20 min option can be applied when the Total Screening Reject is 15% (TSR = CR + 0.9 * FR) or higher and a significant amount of fibres is present in the Coarse Rejects and/or the Fine Rejects. In addition, no other knockout criteria shall be activated such as Sheet Adhesion Level 3. The assessment of the amount of fibres and flakes found in the Coarse Reject can be supported by the Reject Characterisation decision tree (Figure 4).

Disintegration	**Not disintegrated material** Fibrous based pieces with original cut size and /or encapsulated fibres	**Partly disintegrated material** Fibrous based pieces with sharp edges, smaller than original cut size, not broken down into flakes	
Fragmentation	**Unfragmented** Original cut size pieces	**Partly fragmented** Medium pieces (size > 1 cm in one dimension), sharp edges	**Completly fragmented** Granular pieces (size ≤ 1 cm in one dimension), no sharp edges.
Amount (optional)	**Significant (S)** Extensive quantity, cannot be easily counted relevant in Part I and III	Field **S** is optional, but crucial for decisions on 20 min disintegration (Part I) and coarse reject quality levels (Part III)	

Reject absent	( )

REJECT CHARACTERISATION

Cellulose fibres and flakes		S	Polymer Barrier coating		Adhesives		Metallised film		Metal and aluminium		Mix (cellulose and non-cellulose)		S	Others	
Single fibres	( )	( )	Unfragmented	( )	Unfragmented	( )	Unfragmented	( )	Unfragmented	( )	Loose fibres	( )	( )	Other polymers	( )
Flakes	( )	( )	Partly fragmented	( )	Partly fragmented	( )	Partly fragmented	( )	Partly fragmented	( )	Attached fibres	( )	( )	Textiles	( )
Partly disintegrated sample material	( )	( )	Completly fragmented	( )	Completly fragmented	( )	Completly fragmented	( )	Completly fragmented	( )	Encapsulated fibres	( )	( )	Inks	( )
Not disintegrated sample material	( )	( )	Rolled	( )									( )	Foam	( )

Figure 4. Reject Characterisation decision tree

Additional Comments

Longer disintegration times can lead to a better fibre disintegration resulting in a reduction in the TSR and potentially increasing the yield score. To avoid samples that are disintegrated for 20 min from having an unfair advantage compared to samples that are disintegrated for 10 min with only moderate yield score, the maximum Total Screening Yield score obtainable is reduced to 45 points. This means, regardless of the result of the 20 min disintegration time, the yield score can never exceed 45. This is shown in Figure 5 and the intervals are the same as in Figure 3 with the limit of 45 points.

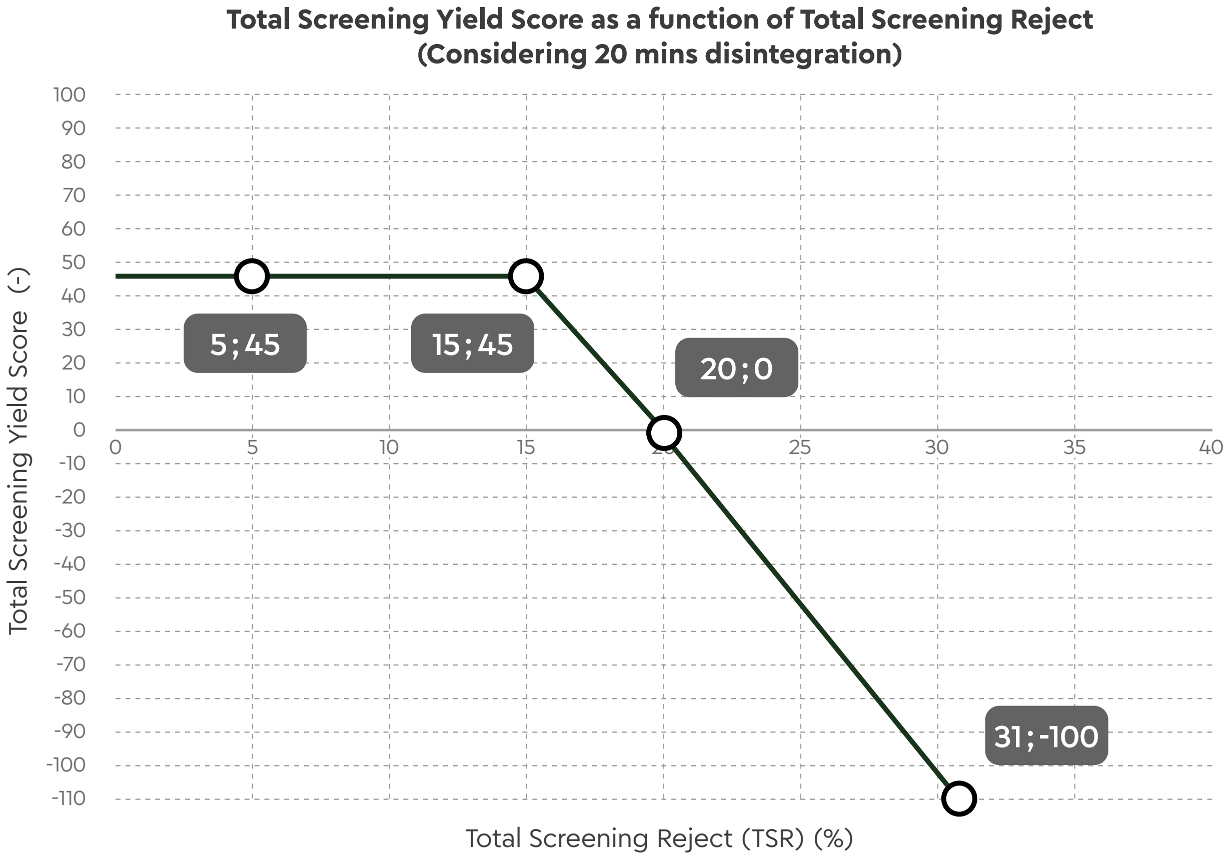


Figure 5. Part I: Total Screening Yield score as a function of Total Screening Reject for 20 min disintegration.

Total Screening Yield (%)	Total Screening Reject (%)	Formula	TSY Score
≥ 85	≤ 15	Score=45	45
85...80	15...20	Score=45-(TSR-15) * 9	45...0
80...69	20...31	Score=45-(TSR-15) * 9	0...-100
≤ 69	≥ 31	Score = -100	-100

Table 5: Part I: Overview of the Total Screening Yield score calculation

When the sample is disintegrated 20 min, the evaluation of all test parameters is done with the 20 min disintegrated sample.

Dissolved and Colloidal Substances Score

The DCS score reflects an assessment of the amount of material that would be lost in the filtrates during recycling. Although some effluents could be considered for (bio) gas production, it is considered that an excess of this type of substance would be disturbing in the recycling process.
DCS are derived directly from the Evaporation Residue in milligram solids per gram of packaging which is a direct result of the test method Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process.
The evaporation residue (ER) is obtained by filtering the pulp immediately after the disintegration and volatilising the obtained filtrate until reaching a constant mass.

The filtering is done via a paper filter so that only DCS and some very small particles like minerals remain in the filtrate, all of which are considered in the final score.
This residue is not considered as recyclable material. A value of e.g. 50 mg/g DCS indicates that 5% of the packaging ended up in the filtrate as DCS.
The DCS score is calculated directly from the ER lab result. Similar to the yield score, the DCS penalty becomes progressively more negative as DCS levels increase. Five intervals are considered based on the DCS value, as shown in Table 6.

NOTE: Mathematical rounding rules to full score points apply.

DCS (mg/g packaging)	Formula	DCS Score
≤50	Score=-DCS * 0.05	0...-3
50...150	Score=-2,5-(DCS-50) * 0,525	-3...-55
150...200	Score=-55-(DCS-150) * 0,9	-55...-100
200...311	Score=-55-(DCS-150) * 0,9	-100...-200
≥311	Score = -200	-200

Table 6: Part I: Overview of the DCS Score calculation within each interval based on the DCS value

A visual representation of the score is shown in Figure 6.

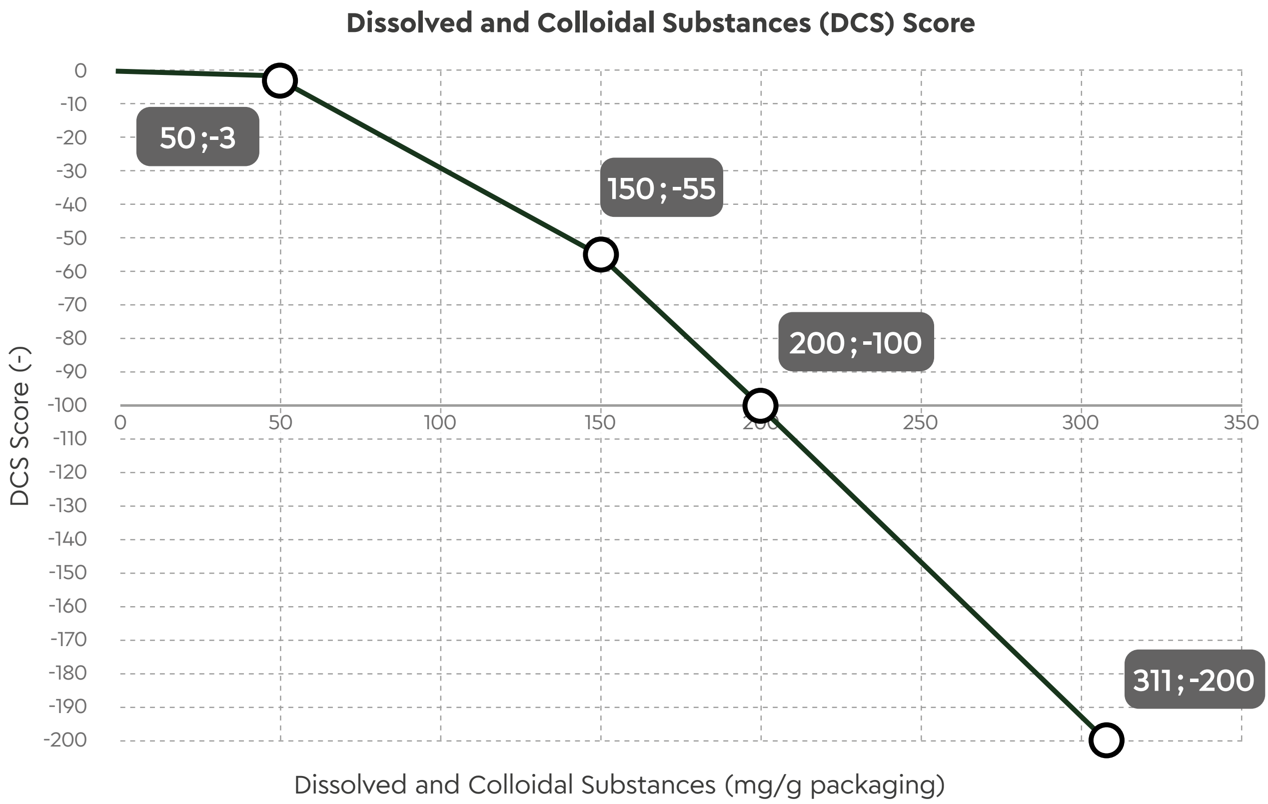


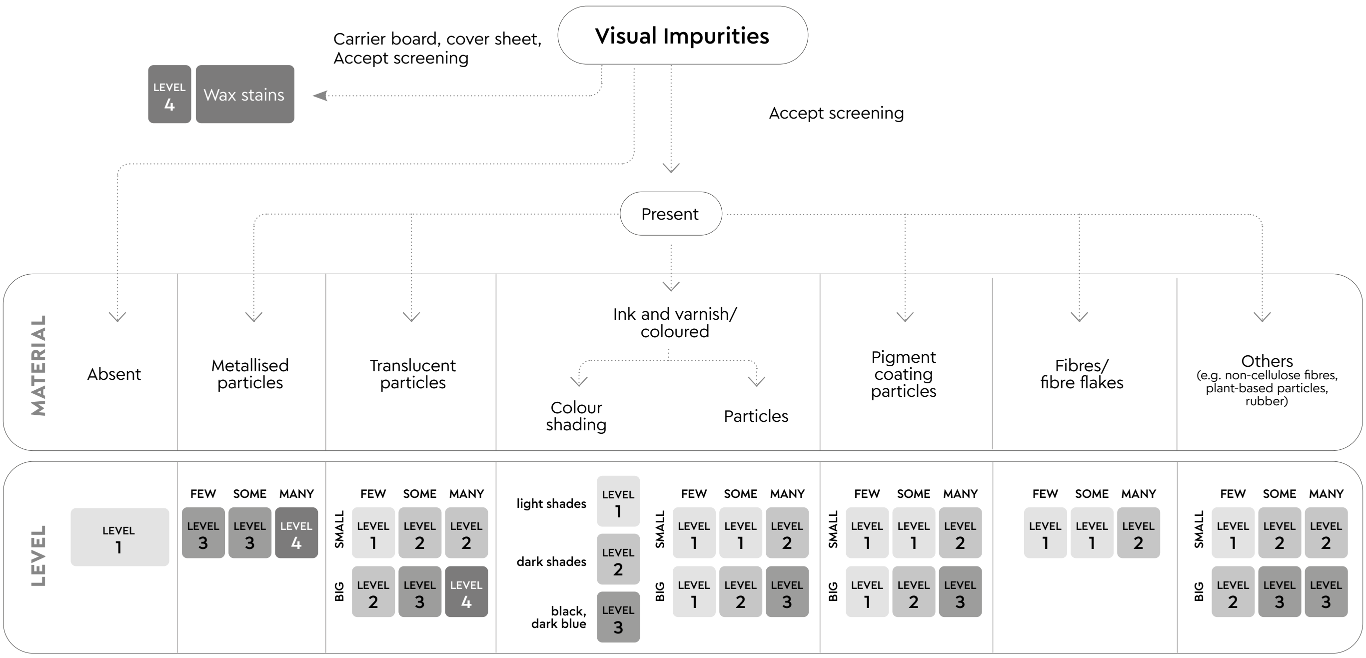
Figure 6. Visual representation of the DCS Score as function of DCS

A DCS value of 200 mg/g packaging is equivalent to having a Total Screening Reject of 20% (i.e. a loss of 20%). Lower DCS values lead to a substantially less DCS penalisation as can be seen from Figure 6. This is due to the fact that DCS values with a threshold of 50 mg have been considered not to cause significant issues during recycling and shall therefore only have a small penalty. There is a slight difference in the slope in the range below 50 mg/g compared to the screening yield score approach because recycling mills with conventional processes are designed to deal with DCS of those levels based on reference values of typical starch containing corrugated boxes. The poorest DCS score is reached at a DCS value of 311 mg/g packaging, at this value or higher, the DCS score is -200.

In this version of the evaluation protocol all types of DCS are penalised equally. In the future, the influence of the DCS characteristics (for example charge, chemical nature, biodegradability, toxicity, and residual polymer microparticles) and their impact on the filtrate properties should be studied, so that a finer gradation based on the severity of these characteristics could be applied.

Visual Impurities Score

For the visual impurities, a qualitative and quantitative evaluation is described in the test method, as shown in the decision tree (Figure 7) which converts the assessment into levels from 1 to 4. Each level defines a range of visual impurities observed in the pulp, where Level 1 is considered to have no visual quality issues and Level 4 shows significant issues impacting the optical quality of the pulp.



NOTE: All applicable columns should be evaluated. Worst case level allocation applies.

LEVEL 1 – No visual quality issues
LEVEL 2 – Minor visual quality issues
LEVEL 3 – Some visual quality issues
LEVEL 4 – Significant visual quality issues

Visual impurities per hand sheet

	Few	Some	Many
Average Amount/ Handsheet	<10	10 - 100	>100
	Small	**Big**	**Combination**
Size (1 dimension)	≤1 mm	>1 mm	Consider the worst case level

Figure 7. Decision tree to evaluate the level of the visual impurities

The four different levels are converted to a Visual Impurities Score, as outlined in Table 7. Note that points cannot be earned but can only be lost. Specific attention should be given to Level 4 as this indicates a severe deterioration in the visual quality of the pulp and results in a significant loss of points. To reflect this severity, a warning statement is given in the score interpretation of the evaluation: 'Level 4 in terms of visual impurities has been assigned to your sample'.

Visual Impurities Level	Visual Impurities Score
1	0
2	-5
3	-15
4	-30

Table 7: Part I: Conversion table for visual impurities level to visual impurities score

Indicative lab tests with a heavyweight cleaner at lab scale showed significant reduction in visual impurities for some samples (especially for some metallised particles and inks), while for other samples it had no effect. Once more data is available, this can be incorporated into a visual impurity level update.

Sheet Adhesion Score

Similarly to visual impurities, sheet adhesion is a qualitative evaluation that is assigned to three possible levels, and described in detail in the test method. Level 1 indicates no adhesion issues are observed when using the recovered material. Level 2 is assigned to material that shows sheet adhesion but only up to a degree which likely has a limited impact on the production process. Lastly, Level 3 is assigned when sheet adhesion is clearly observed and the recovered material would likely lead to production problems. Given the severity of Level 3, it is considered a knockout factor and the total score is immediately set to a negative value, making the tested product not technically recyclable in a recycling mill with conventional process. The test method provides details and examples for the level assignment. Water soluble tacky materials might not be detected with the sheet adhesion method.
In Table 8, sheet adhesion levels are given a final score. As can be seen no points are lost or gained when Level 1 and 2 are observed. It was agreed based on expert consensus, that the Level 2 is not regarded as critical to be reflected as point reduction. However, Level 2 does alert the packaging designer that there is some sticky content in the final product.

Sheet Adhesion Level	Sheet Adhesion Score	Sheet Adhesion Description
1	0	Tackiness absent: the hand sheet can be separated completely from the carrier board and cover sheet without any damage or breakage. A few single fibre pickups can be present on the carrier board and cover sheet. Visible damage to the hand sheets and fragments of paper on the carrier board and cover sheet are not permitted.
2	0	Tackiness partly present: the hand sheet can be separated completely from the carrier board and cover sheet. Fibre tears and particles occur on the carrier board, the cover sheet and the hand sheet itself.
3	Knockout	Tackiness present: the hand sheet cannot be separated from its carrier board and the cover sheet without visible damage to the hand sheet itself. A breaking of the hand sheet or holes (> 1mm [in two dimensions]) occur. **NOTE:** The rating must reflect all sheet adhesion tests conducted and provide an accurate representation of overall performance. A single occurrence of a defect may be disregarded if it is limited to an isolated hole and does not exhibit any fiber tears.

Table 8: Part I: Conversion table for sheet adhesion level to sheet adhesion score

Technical Recyclability Score for recycling mill with conventional process

The Technical Recyclability Score is the sum of the four individual scores discussed in this section and shown in Equation 3.

EQUATION 3

$$\text{Technical Recyclability Score} = \text{TSY Score} + \text{DCS Score} + \text{VI Score} + \text{SA Score}$$

where

Technical Recyclability Score range=[-100,+100]

The Technical Recyclability Score lies in the range of -100 to +100. The negative score is limited to -100. A Technical Recyclability Score below 0 indicates the packaging material tested is not technically recyclable in a recycling mill with conventional process. Negative scores are still indicated as they are useful for the packaging designer to see what is still needed to achieve a positive recyclability assessment. The only parameter adding positive values is the Total Screening Yield score; all other parameters can only lead to a lower technical recyclability score thus incentivising a designer to maximise the recyclable content while minimising any adverse impacts on the pulp quality or filtrate.

EXAMPLE A

A packaging product pulped 10 min, 4% CR, 1% FR and 50 mg ER = 50 mg/$g_{Packaging,}$ and no visual impurities or sheet adhesion.

TSR = 4% + 1% * 0,9 = 4,9%
TSY Score = 100% — TSR * 2 = 100 – 4,9% ∗ 2 = 90
DCS Score = – DCS ∗ 0,05= -50 ∗ 0,05= -3

Technical Recyclability Score = TSY Score + DCS Score + VI Score + SA Score = 90 – 3 – 0 – 0 = 87
The assessment is: ‘Technically recyclable in a recycling mill with conventional process’

EXAMPLE B

A packaging product with a 25% TSR after 10 min pulping and a high fibre content in the rejects. 20 min pulping 8% CR, 6% FR and ER = 70 mg/$g_{Packaging,}$ and no visual impurities or sheet adhesion.

TSR = 8% +6% * 0,9 = 13,4%
TSY Score = 45
DCS Score = -2,5 – (DCS — 50) ∗ 0,525= -2,5 - (70-50) ∗ 0,525 = -13

Technical Recyclability Score = TSY Score + DCS Score + VI Score + SA Score = 45 – 13 – 0 – 0 = 32 The assessment is: ‘Technically recyclable in a recycling mill with conventional process’

EXAMPLE C

A packaging product pulped 10 min, 10,4% CR, 6% FR and high fibre content in the rejects, ER = 70 mg/$g_{Packaging,}$ DCS no visual impurities and sheet adhesion Level 3. 20 min disintegration is not allowed, because of the sheet adhesion knockout

TSR = 10,4% + 6% ∗ 0,9 = 15,8%
TSY Score = 45 – (TSR – 15) ∗ 9 = 45 – (15,8 – 15) ∗ 9 = 38
DCS Score = -2,5 – (DCS – 50) * 0,525 = -2,5 – (70 – 50) * 0,525 = -13
SA Level 3 = Knock out

Technical Recyclability Score = Knockout
The assessment is: ‘Not technically recyclable in a recycling mill with conventional process. Potentially recyclable in other mill types’

Technical Recyclability Score interpretation

The 4evergreen Recyclability Evaluation Protocol provides two major statements, saying that material is either technically recyclable in a recycling mill with conventional process or not. However, it is also meant to support an eco-design process, therefore a more granular description is provided by the total score and breakdown of this total in its individual parameters, as shown in Table 9.

As can be seen in Table 10, various parameters have a different impact on the Technical Recyclability Score. This classification is an outcome of an extensive consensus-building process using real test data and represents best available expert knowledge drawn from 4evergreen's members. The understanding of the value of each score component is key to efficient eco-design processes and perfecting circular fibre-based packaging.

Technical Recyclability Score for Recycling in mills with conventional process	Description
0 – 100	Technically recyclable in a recycling mill with conventional process.
< 0	Not technically recyclable in a recycling mill with conventional process. Potentially recyclable in mills with other recycling process types.*

Table 9: Part I: Interpretation of Technical Recyclability Score

*This result refers to a reference process, the individual evaluation of a recycling mill might be different, depending on available processes and stock preparation concept.

Total Screening Yield Score		Visual Impurities Score			Sheet Adhesion Score			Dissolved and Colloidal Substances Score	
Score	Score interpretation	Level	Score	Score interpretation	Level	Score	Score interpretation	Score	Score interpretation
100 - 90	The packaging creates a high screening yield in a recycling mill with conventional process and is therefore considered 'best in class'.	Level 1	0	Poses no visual quality issues	Level 1	0	Poses no adhesion issues	0 to -3	DCS expected to pose negligible issues in the process of a recycling mill with conventional process and is therefore considered 'best in class'.
		Level 2	-5	Poses minor visual quality issues	Level 2	0	Poses minor adhesion issues		
89 - 70	The packaging creates an acceptable screening yield, but the rejects could already have an impact in a recycling mill with conventional process.	Level 3	-15	Poses noticeable visual quality issues	Level 3	Knockout	Poses significant adhesion issues that can have a significant impact on a recycling mill with conventional process and is therefore not recyclable.	-3 to - 55	DCS expected to have minor issues in the process of a recycling mill with conventional process.
69 – 50	The screening yield of the packaging is high for a recycling mill with conventional process, but it is suggested that the packaging should be further optimised for recycling.	Level 4*	-30	Poses significant visual quality issues					
49 – 0	This packaging creates a significant amount of rejects which can lead to technical problems in the screening step in a recycling mill with conventional process.							-55 to -100	DCS expected to have issues in the process of a recycling mill with conventional process and suggest further optimisation.
< 0	The reject of this packaging is too high for the recycling process in a recycling mill with conventional process and should not be recycled in such a process.							< -100	DCS expected to have major issues in the process of a recycling mill with conventional process. It is recommended to test this product with part III testing in future FBCP process.

Table 10: Part I: Interpretation of individual elements

* Warning statement: Level 4 in terms of visual impurities has been assigned to your sample. In the current version of the Evaluation Protocol, Level 4 has not yet been activated as a knockout criterion. Once the representativeness of the lab-scale test and Evaluation Protocol are validated in the next version(s), Level 4 could potentially lead to an overall negative assessment of the recyclability in a recycling mill with conventional process (i.e., deemed not technically recyclable in a recycling mill with conventional process). Until then, we strongly recommend the current results be treated with special care. For example, consider reaching out to the lab running the test asking for more detailed information and observations.

FUTURE TOPICS

Not all aspects potentially affecting the recyclability of fibre-based packaging are covered in this Version 1 of the Evaluation Protocol. It is true both for technical parameters but also for the impact that collection and sorting might have on a mixed composition of paper for recycling. Therefore, this document will be reviewed and updated in accordance with user feedback and technical updates in Workstream 1 of the 4evergreen alliance. Apart from the review of the existing scoring and threshold validity, the following non-exhaustive list of aspects shall be examined in future:

- Develop methodology for linking recyclability evaluation results and DfR tables
- Impact of collection and sorting stream allocation on the potential recyclability of individual packaging items
- Implementation of macrostickies analysis
- Impact of food contamination on the recycling process and quality of produced paper
- Verification of the results via pilot testing
- Evaluation of the α factor (correction of fine reject value)
- Impact of a heavyweight cleaning step for different visual impurities
- Influence of DCS characteristics (e.g., charge, chemical nature, biodegradability, toxicity and residual polymer microparticles) and their impact on the filtrate properties

The Evaluation Protocol focuses on the technical recyclability of fibre-based packaging without considering collection, sorting, or the effects of recycling various packaging items together. Also the possible presence of food residues is not considered.

8. PART II – Recycling mill with flotation-deinking process

MILL DESCRIPTION

Recycling mills with flotation-deinking process, also referred to as deinking mills, have been designed to produce a clean white or off-white pulp which is mainly used for production of printing paper, but also copy paper, white top liners, white top cardboard, tissue products, and others. The required quality of the recycled pulp used in deinking mills differs significantly from that required for recycling mills with conventional process. In particular, sufficient brightness, a neutral white shade, and very low visual contamination are required from the deinked pulp.

Recycling mills with flotation-deinking process use mostly graphic paper grades, typically newspapers and magazines corresponding to grades 1.11.00 and other grades defined in EN 643 as intended for deinking, but also other paper products like recovered office paper, pre-consumer paper products from printing and converting, and unsold newspapers and magazines from kiosks. Many white packaging products are also suitable feedstock for recycling mills with flotation-deinking process, and have a higher value there compared to their use in recycling mills with conventional process. Once recycled in a conventional mill, fibres from white packaging grades can only be recycled again in the brown fibre loop and cannot be returned to the white paper loop.
On top of conventional processing, this type of recycling process uses flotation deinking for ink removal, a disperser for breaking down visually distracting printing ink spots (measured as dirt specks), and often bleaching process stages. For tissue products, in most cases at least one wash deinking stage is used in the first deinking loop instead of the flotation deinking stage. In additional to ink removal, the wash flotation also removes nearly all mineral ash from the pulp. In a second loop, flotation deinking is commonly used, possibly followed by a second wash flotation step which can help remove critical substances such as bisphenols, silicone or mineral oils.

Figure 8 shows a typical scheme for a recycling mill with flotation-deinking process. The green marked stages are common on a deinking line for newsprint paper products, and the yellow marked process stages are optional when higher quality is required, e.g., for the production of bright grades. A deinking line consists of 1 or 2 deinking loops with separate water circuits and counterflow water usage. In some rare cases a third loop is implemented.

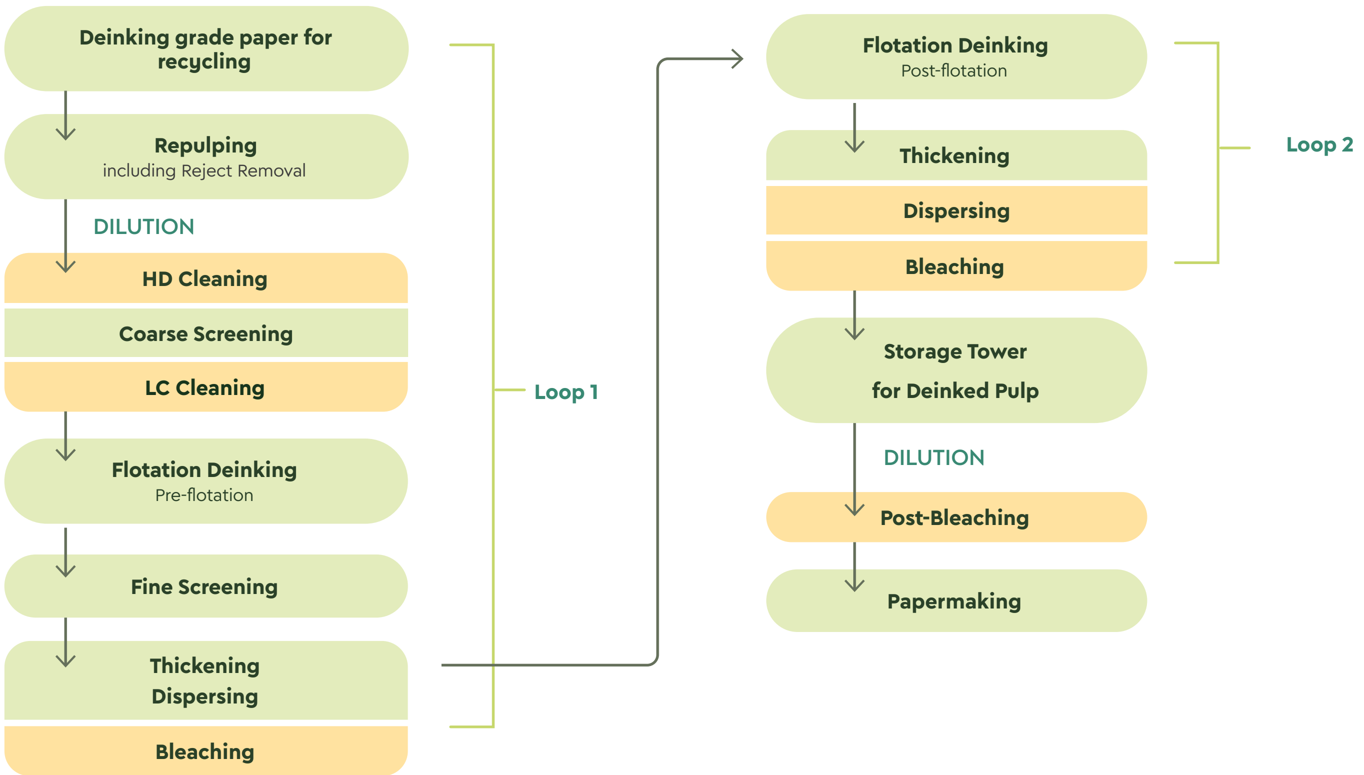


Figure 8. Scheme of a typical recycling mill with flotation-deinking process

Details about the process stages in a typical flotation deinking process are given below:

REPULPING

Horizontal drums or vertical vats equipped with a spiral rotor are used for high-consistency repulping of the paper for recycling. The objective of this stage is to break the input material into individual fibres under temperatures of usually 40-50°C and stock concentrations over 14% solids. Alkaline conditions and surfactants are used to detach the inks from the fibres. The pulped material is fed through hole screens in the drum pulper or vat, and the non-pulpable content is separated as pulper reject.

COARSE SCREENING

After dilution, the pulp is further treated mechanically. Optional high-density cleaners (large size cyclones) are used to remove large and heavy impurities like staples, glass, and stones. In the coarse screening stage, the pulp slurry is forced at medium stock concentration (2,5-4,0%) through small holes (hole diameter 2-3 mm) or slots where free fibres and mineral pigments can pass through and coarse particles like wood chips or medium-sized plastic particles are removed. Heavy contaminants of a smaller size (e.g., sand) are removed with low consistency hydrocyclones (concentration 0,5-1,5% and called heavyweight cleaner). In many cases the low-density debris (e.g., expanded polystyrene) is also separated in these hydrocyclones (so-called lightweight cleaner).

FLOTATION

Flotation stages remove printing inks from the pulp. Air is injected into the pulp in the flotation cells where the ink attaches to the small air bubbles, floats to the surface, and accumulates in the froth at top of the flotation cells. The ink is removed with the froth which results in a brighter pulp.

Flotation deinking removes a wide range of hydrophobic particles – sizes from about 10 µm to 250 µm – very efficiently with a high fibre yield. Printing inks and toners for offset, rotogravure and dry toner printing processes use hydrophobic inks, which can be floated well in general. In many cases, other types of inks such as flexographic inks, UV inks, liquid toner, and inkjet inks cannot be processed in a deinking process with the same efficiency, but depending on the individual behaviour may still be compatible with the deinking process.

Flotation stages are installed in the first process loop for removal of most of the free ink from the pulp, usually also in the second loop for the removal of any ink released from the fibres in the disperser. In some deinking lines there is only one flotation stage, while in others there may be three stages.

FINE SCREENING

In the fine screening stage, the pulp slurry is forced at low concentration (about 1% solids) through small slots (with slot width typically about 0,15 mm) where free fibres and mineral pigments can pass through them, while impurities such as stickies – mainly derived from seal and peel labels, envelopes, and tapes – are removed. This step maximises the pulp quality for maximum runnability and further minimises the amount of impurities in the pulp.

THICKENING AND DISPERSING

For water loop separation and treatment at higher concentrations, pulp is dewatered mostly with disc filters to approximately 10% solid concentration. A higher concentration is needed for pulp treatment in a disperser, therefore screw presses or wire presses may be used to increase the concentration to about 30% before dispersing. The disperser detaches ink particles that still adhere to the fibres and also breaks up any larger ink particles remaining after flotation. Smaller ink particles can then be floated out in a second loop flotation unless they are already small enough – i.e., they are no longer visually disturbing. However, this has the disadvantage that the brightness of the pulp may be reduced.

BLEACHING

In this process stage, coloured substances and lignin are bleached to convert them into lighter colours or to enhance the brightness and cleanliness of the pulp itself. In most cases, bleaching is required for manufacturing white paper grades with brightness requirements higher than newspaper. Bleaching can be done by oxidative reactions with hydrogen peroxide or by reductive reactions usually with sodium dithionite. For high brightness, oxidative and reductive bleaching is used. Oxidative bleaching stages usually have a bleaching tower after the disperser or kneader, which is then simultaneously used for intense mixing of the bleaching agents with the pulp.
A common application is a reductive post-bleaching of the deinked pulp after the storage tower.

PAPERMAKING

The final deinked pulp is placed in storage tanks and ready for use in the manufacture of new paper on the papermaking machine.

LABORATORY TEST METHOD

For assessing the recyclability of fibre-based packaging in a recycling mill with flotation-deinking process, an adapted test method for fibre-based packaging, based on the INGEDE Method 11-2 Deinlability Test - Part 2: Packaging Products, has been developed by the 4evergreen alliance. The test method will be used for the 4evergreen Recyclability Evaluation Protocol Part II and the corresponding assessment scheme.

The relevant method is called Paper and Board - Recyclability Laboratory Test Method - Part II: Recycling Mill with Flotation-Deinking process. It defines a laboratory procedure emulating the most relevant process stages (disintegration, coarse and fine screening, flotation, sheet formation) of a flotation-deinking process.

The testing method provides results relevant to process efficiency as well as to the quality of deinked pulp that serve as a basis for the Evaluation Protocol, Part II described in this document. To obtain all the results, two subsequent disintegration batches are required:

> Batch 1 corresponds to high consistency (HC) repulping with conventional chemical dosage according to INGEDE Method 11-2 followed by pulp storage. This batch is used to determine the Total Screening Yield (coarse and fine screening), Dissolved and Colloidal Substances (Evaporation Residue), Chemical Oxygen Demand, and Sheet Adhesion.

> Batch 2 is used to evaluate the flotation-deinking performance and is carried out according INGEDE Method 11-2. The amount of screenable non-paper constituents and ash content of the coarse reject is considered in the evaluation. After repulping the pH must be within a defined or specified range and can be adjusted with chemical dosages if needed. The pulp is then stored at 45°C in water bath for 60 min at 5% stock concentration followed by a laboratory flotation-deinking sequence. This deinking sequence is used to determine the quality parameters (luminosity, colour shade, dirt specks) and process parameters (filtrate darkening and luminosity gain).

TECHNICAL RECYCLABILITY SCORE FOR RECYCLING MILL WITH FLOTATION-DEINKING PROCESS

RESULTS OF THE LABORATORY TEST METHOD

The results of the laboratory test form the basis for the calculation of the Technical Recyclability Score. Table 11 and Table 12 show the test metrics currently used for the calculation of the Recyclability Scores.

Parameter	Acronym	Meaning
Coarse Reject	**CR**	Weight percent of packaging removed by coarse screening and dry removed components.
Fine Reject	**FR**	Weight percent of packaging removed by fine screening after coarse screening.
Total Screening Reject	**TSR**	Sum of coarse and fine reject, using a correction factor for the fine screening reject value.
Total Screening Yield	**TSY**	Total amount of packaging minus TSR expressed in percent.
Sheet Adhesion	**SA**	Evaluation of the tackiness of a hand sheet from the accept of fine screening.
Chemical Oxygen Demand	**COD**	Indicative parameter for process water quality measured by the amount of oxygen needed by chemical oxidation with dichromate. High values indicate risks for formation of deposits and high loads in the waste water treatment.
Dissolved and Colloidal Substances	**DCS**	Mass of substances in the filtrate obtained after filtration of pulp after disintegration related to packaging mass in mg/g. It is determined as Evaporation Residue (ER).

Table 11: Part II: Batch 1 parameters used for the technical recyclability score calculation

Parameter	Acronym	Meaning
Luminosity	**Y**	Measured as light reflectance in the wavelength of 557 nm.
Luminosity of undeinked pulp	Y_{UP}	Luminosity of undeinked pulp measured as light reflectance in the wavelength of 557 nm
Luminosity of deinked pulp	Y_{DP}	Luminosity of deinked pulp measured as light reflectance in the wavelength of 557 nm has context menu
Colour shade a*	**a***	Colour shade parameter of deinked pulp from green to red.
Dirt specks area (A50)	A_{50}	Dirt speck area for particles larger than 50 µm (circle equivalent diameter).
Dirt specks area (A250)	A_{250}	Dirt speck area for particles larger than 250 µm (circle equivalent diameter).
Luminosity gain	**YG**	Luminosity increase during flotation by removal of coloured content (printing ink).
Filtrate darkening	**ΔY**	Staining of deinking line water-loop from soluble or colloidal ink.

Table 12: Part II: Batch 2 parameters used for the technical recyclability score calculation

Table 13 shows additional parameters which might be incorporated in future versions of the Recyclability Evaluation Protocol. It is recommended to analyse these parameters, even if they are not included in the current scoring. The test method description already includes these parameters, and the data generated may help in the development of improved versions of the scorecard in the future.

Parameter	Meaning
Macrostickies Analysis	Quantitative assessment of tacky components in the pulp.
Reject Characterisation	Description of the main components of the reject.
Biological Oxygen Demand	Indicative parameter for process water quality measured by the amount of oxygen needed by microorganisms to degrade organic substances.

Table 13: Part II: Additional parameters currently not used in the scorecard – potential future parameters for the scorecard

The Macrostickies Analysis is an important parameter for rating the risk of tacky particles in recycled pulp. The method for validating macrostickies is ongoing, so it is excluded from this version of the scorecard for the time being, but with the intention of adding it in the future. It should also be pointed out that, water soluble tacky materials might not be detected with the sheet adhesion method.

More test data and research will be necessary for the creation of a scoring scheme for the reject characterisation.

TECHNICAL RECYCLABILITY SCORE CALCULATION

The Recyclability Score for this type of conventional process is calculated from the sum of the sub-score results. The aim of the batch 1 sub-score is to evaluate the yield, filtrate analysis (evaporation residue, chemical oxygen demand), and tackiness (sheet adhesion) from the test samples. The batch 2 sub-score comprises the evaluation of the optical quality of the deinked pulp and any possible interference with the deinking process. The measured parameters from batch 2 are obtained from the pulp before or after laboratory flotation.
The maximum score of each parameter is based on expert experience, indicating the relevance of the parameter for the pulp quality and economic operation in industrial deinking lines. For each parameter, individual target and threshold values are defined. Samples receiving a negative score, and therefore not passing one or more thresholds are rated as: 'Not technically recyclable in recycling mills with flotation-deinking process. Potentially recyclable in recycling mills with other processes'.

The score for each parameter (with the exception of sheet adhesion) is calculated according to Equation 4.

EQUATION 4

$$Score_P = \frac{R_P - TH_P}{T_P - TH_P} * MS_P$$

where

- Index P stands for one of the parameters TSY, COD, DCS, Y, a*, A_{50}, A_{250}, YG and ΔY
- $Score_P$ is the Score of the parameter P;
- R_P is the result of the parameter P;
- TH_P is the threshold value of the parameter P;
- T_P is the target value of the parameter P;
- MS_P is the maximum score of the parameter P.

EXAMPLE CALCULATION:

DP Luminosity is $R_{YDP} = Y_{DP} = 60$, threshold of Luminosity is $TH_Y = 53$, target value of Luminosity is $T_Y = 65$, and maximum score of luminosity is $MS_Y = 35$

$$ScoreY_{DP} = \frac{60-53}{65-53} * 35 = 20$$

The score is limited to the maximum score (MS) for each individual parameter, even if the calculation gives a higher value.

If a parameter falls below a certain minimum threshold, surpasses a maximum threshold, or falls outside of an expected range, it will receive a negative score. In such cases, the negative score is limited to the same value (but negative) as the maximum score assigned to the parameter.

The calculation of the score for sheet adhesion is described in the corresponding sub-section. Table 14 and Table 15 show all parameters considered in the calculation of the Technical Recyclability Score.

Parameter description – Batch 1	Abbreviation	Unit	Threshold	Target	Max. Batch 1 Score
Total Screening Yield	**TSY**	%	85	97	50
Chemical Oxygen Demand (COD value)	**COD**	mg/g packaging	60	25	10
Dissolved and Colloidal Substances	**DCS**	mg/g packaging	100	50	10
Sheet Adhesion	**SA**	level	2	1	30

Table 14: Part II: Parameters for score calculation batch 1

Parameter description – Batch 2	Abbreviation	Unit	Threshold	Target	Max. Batch 2 Score
UP Luminosity	Y_{UP}	%	0	0	0
DP Luminosity	Y_{DP}	%	53	65	35
Colour shade a*	**a***	-	<-3 or >2	-2 ... 1	20
Dirt Specks Area (A50)	**A50**	mm^2/m^2	2000	600	15
Dirt Specks Area (A250)	**A250**	mm^2/m^2	600	180	10
Luminosity Gain	**YG**		6	13	10
Filtrate Darkening (delta Y)	**ΔY**		18	6	10

Table 15: Part II: Parameters for score calculation batch 2

SUBSCORE CALCULATION BATCH 1

TOTAL SCREENING YIELD SCORE

The TSR is calculated according to Equation 5. The TSR measures how much material is removed by screening. To mimic the fibre recovery in multi-stage screening processes α is used as a correction factor. Residence times and mechanical shearing forces applied in an industrial process, for example in pumps, can trigger a slightly better disintegration of fibre bundles compared to lab conditions. The value of α is set to 0,9 based on expert consensus. The factor α is currently set to a constant value, however in future versions may be changed to a variable value, taking into account the fine screening reject characterisation.

EQUATION 5

$$TSR = CR + FR * \alpha$$

where

- TSR is the Total Screening Reject (%);
- CR is the Coarse Reject rate (%);
- FR is the Fine Reject rate (%);
- α is the correction factor.

Complementary to the Total Screening Reject (TSR) is the Total Screening Yield (TSY), see Part I which - beside the Evaporation Residue (ER) -describes the amount of material mass that can be reused in a new fibre product.
The calculation for Total Screening Yield is given in Equation 6.

EQUATION 6

$$TSY = 100\% - TSR$$

where

- TSY is the Total Screening Yield;
- TSR is the Total Screening Reject.

The main yield losses in a recycling mill with flotation-deinking process usually occur in the flotation-deinking stages. Nevertheless, the screening losses shall be kept to a minimum because of their financial, technical, and environmental implications.

In contrast to an industrial process, at laboratory scale, a hyper-flotation is performed to reach the highest possible quality of deinked pulp. Therefore in a laboratory flotation-deinking tests, the flotation yield is significantly lower, and flotation losses cannot be considered for the score calculation. Because of this, the laboratory flotation yield is not considered in the overall yield calculation.

Threshold	Target	Maximum Score
97%	85%	50

Table 16: Part II: Total Screening Yield parameters

The calculation of the score is following Equation 6.

SHEET ADHESION SCORE

The sheet adhesion is a qualitative evaluation that is assigned to three possible levels shown in Table 17.

Sheet Adhesion Level	Sheet Adhesion Score	Description
1	30	Tackiness absent: the hand sheet can be separated completely from the carrier board and cover sheet without any damage or breakages. A few single fibre pickups can be present on the carrier board and cover sheet. Visible damage to the hand sheets and fragments of paper on the carrier board and cover sheet are not permitted.
2	0	Tackiness partly present: the hand sheet can be separated completely from the carrier board and cover sheet. Fibre tears and particles occur on the carrier board, the cover sheet and the hand sheet itself.
3	-30	Tackiness present: the hand sheet cannot be separated from its carrier board and the cover sheet without a visible damage to the hand sheet itself. A breaking of the hand sheet or holes (> 1mm [in two dimensions]) occur. **NOTE:** The rating must reflect all sheet adhesion tests conducted and provide an accurate representation of overall performance. A single occurrence of a defect may be disregarded if it is limited to an isolated hole and does not exhibit any fiber tears.

Table 17: Part II: Sheet adhesion scores

Tacky substances are more challenging for producing lower grammage paper grades containing deinked pulp, compared to board lines, typically producing higher grammage products. Therefore Level 2 assigns a score of only 0 points.

CHEMICAL OXYGEN DEMAND SCORE

The COD is a chemical analysis test which indicates the microbiological contamination risk in the deinking line and the paper machine, as well as the required efforts to treat the effluent. Low values are preferable. The threshold and target parameters are shown in Table 18.

Threshold	Target	Maximum Score
60 $mg_{O2}/g_{packaging}$	25 $mg_{O2}/g_{packaging}$	10

Table 18: Part II: COD parameters

The calculation of the score is given in Equation 4.

DISSOLVED AND COLLOIDAL SUBSTANCES SCORE

The DCS measurement assesses the level of such substances which risk causing process disturbances as well as water-loop and waste-water contamination. Release of these substances results in lower yields (in addition to those from screening losses).

Threshold	Target	Maximum Score
100 $mg/g_{packaging}$	50 $mg/g_{packaging}$	10

Table 19: Part II: DCS parameters

The calculation of the score is following Equation 4.

SUBSCORE BATCH 1

The score points of the four parameters from batch 1 are added, and the result is reported as subscore batch 1. Maximum result is 100 points.

EQUATION 7

$$\text{Subscore Batch 1} = \text{TSY Score} + \text{COD Score} + \text{DCS Score} + \text{SA Score}$$

If one or more parameters results in a negative score, only the negative scores are considered in the calculation of the subscore for batch 1.

SUBSCORE CALCULATION BATCH 2

LUMINOSITY SCORE

Reaching sufficiently high luminosity (Y) is essential for the quality of deinked pulp, hence the Luminosity of deinked pulp (Y_{DP}) has the highest maximum score contribution of all the optical parameters.

Threshold	Target	Maximum Score
53%	65%	35

Table 20: Part II: Luminosity parameters

The calculation of the score is following Equation 4.

COLOUR VALUE a* SCORE

Most paper products using deinked pulp are produced with a neutral white shade. The paper shade is adjusted with dyes, but these reduce luminosity and should therefore be kept to a minimum – deinked pulp shall ideally have a neutral shade. While a yellowish shade often originates from the pulp (ground wood) itself, a slightly blueish shade is usually welcomed in Europe. Bright white papers are commonly coloured slightly with blue colour and optical brightener for a whiter colour perception. Most disturbing are the colours green and red. Both are on the a* axis in the CIELAB colour space (CIE: International Commission on Illumination). This is why only the colour axis a* is considered as a parameter in the Scorecard.

	Threshold	Target	Maximum Score
Lower	-3	-2	20
Upper	2	1	

Table 21: Part II: Colour shade a* parameters

The calculation of the score is following Equation 4.
If the a* value is higher than 0 (red shade), the upper thresholds and targets have to be used in Equation 4. If the a* value is lower than 0 (green shade), the lower thresholds and targets have to be used in Equation 4.

DIRT SPECK AREA SCORE

The Dirt speck area is a measure of the visually disturbing particles which are optically different enough from the average of the lab sheets of the tested pulp. It rates the area of easily visible particles larger than 250 µm circle equivalent diameter, as well as the total measured area which is larger than 50 µm circle equivalent diameter. Both parameters have separate targets and thresholds.

	Threshold	Target	Maximum Score
A_{50}	2000 mm²/m²	600 mm²/m²	15
A_{250}	600 mm²/m²	180 mm²/m²	10

Table 22: Dirt speck area parameters

The calculation of the score is following Equation 4.

LUMINOSITY GAIN YG SCORE

The aim of a flotation deinking step is to increase the luminosity of the pulp by removing the inks from the pulp. The resulting increase in luminosity is indicated by the Luminosity Gain. In the event of only small amounts of inks being present in the undeinked pulp, the luminosity cannot increase significantly. Therefore, threshold values are implemented. If the deinked pulp reaches at least the target value of the luminosity or the undeinked pulp reaches nearly the target value of the luminosity, maximum points are assigned for the parameter YG.

YG is calculated as:

EQUATION 8

$$YG = Y_{DP} - Y_{UP}$$

where
- YG is the luminosity gain;
- Y_{DP} is the luminosity of deinked pulp;
- Y_{UP} is the luminosity of undeinked pulp.

Threshold	Target	Maximum Score
6%	13%	10

Table 23: Part II: Luminosity gain parameters

The calculation of the score is following Equation 4 with the following exemptions:

The **score** for the parameter **YG** is **10 points** if

$Y_{DP} > T_Y$
or
$Y_{up} > T_Y - 3$

where
- Y_{DP} is the luminosity of deinked pulp;
- Y_{UP} is the luminosity of undeinked pulp;
- T_Y is the DP luminosity target;
- YG is the luminosity gain.

FILTRATE DARKENING SCORE

Some printing inks are water soluble or create colloidal particles which will be found in the filtrates of the pulp even after flotation. These cannot be removed by flotation and are very detrimental in the deinking process.

Threshold	Target	Maximum Score
6%	18%	10

Table 24: Part II: Filtrate darkening parameters

The calculation of the score is following Equation 4.

SUBSCORE CALCULATION BATCH 2

The batch 2 parameters are based primarily on the approach and values defined in the EPRC 'Assessment of Printed Product Recyclability – Deinkability Score'.[3]

EQUATION 9

$$\text{Subscore Batch 1} = Y_{DP}\ \text{Score} + a^*\ \text{Score} + A50\ \text{Score} + A250\ \text{Score} + YG\ \text{Score} + \Delta Y\ \text{Score}$$

If one or more parameters is negative, only the negative scores are considered in the calculation of subscore for batch 2.

TECHNICAL RECYCLABILITY SCORE FOR RECYCLING MILL WITH FLOTATION-DEINKING PROCESS

The Technical Recyclability Score is calculated as the average of subscores from batch 1 and batch 2, as given in Equation 10.

EQUATION 10

$$\begin{aligned}\text{Technical Recyclability Score} &= 0{,}5 * \text{Subscore Batch 1} + 0{,}5 * \text{Subscore Batch 2}\\ &= 0{,}5 * (\text{TSY Score} + \text{COD Score} + \text{DCS Score} + \text{SA Score}) +\\ &\quad 0{,}5 * (\text{YDP Score} + a^*\ \text{Score} + \text{A50 Score} + \text{A250 Score} +\\ &\quad \text{YG Score} + \Delta Y\ \text{Score})\end{aligned}$$

where

Technical Recyclability Score range=[-100,+100]

If one or more parameters is negative, only those scores are considered in the calculation of Technical Recyclability Score.

[3] European Paper Recycling Council (EPRC) www.paperforrecycling.eu

TECHNICAL RECYCLABILITY SCORE INTERPRETATION

The subscore batch 1 describes the expected yield in screening, impact on the wastewater and potential problems with sticky materials. A higher score indicates better performance in those parameters.

The batch 2 subscore describes the behaviour in the flotation process and the quality of pulp after flotation. A higher score indicates higher quality deinked pulp.

Table 25 provides an overview of the final rating for the Technical Recyclability Score and a description. A Technical Recyclability Score ≥ 0 indicates the material tested can be classified as 'Technically recyclable in a recycling mill with a flotation-deinking process'.

If one or more parameters is negative, the product fails the recyclability assessment and is considered 'Not technically recyclable in a recycling mill with a flotation-deinking process'. In the latter case, only the negative scores are considered and added to the calculation of the Technical Recyclability Score, indicating quantitatively the extent to which the sample failed the evaluation.

Any fibre-based packaging assessed as not technically recyclable can potentially be recyclable in another process.

Technical Recyclability Score for recycling in mills with flotation-deinking process	Score Interpretation
0 – 100	Technically recyclable in a recycling mill with a flotation-deinking process.
< 0	Not technically recyclable in a recycling mill with a flotation-deinking process. Potentially recyclable in other mills with different recycling process types.*

Table 25: Part II: Interpretation of Technical Recyclability Score

* This result refers to a process; the individual evaluation of a recycling mill might be different, depending on available processes and stock preparation.

Batch 1

Total Screening Yield Score		**Sheet Adhesion Score**			**Dissolved and Colloidal Substances Score**		**COD Score**	
Score	Interpretation	Level	Score	Interpretation	Score	Description	Score	Interpretation
40	The packaging creates a high screening yield in a recycling mill with flotation-deinking process and is therefore considered 'best in class'.	1	30	Poses no adhesion issues.	10	DCS expected not to pose any issue in a recycling mill with flotation-deinking process.	10	COD expected not to pose any impacts a recycling mill with flotation-deinking process.
21-39	The screening yield of the packaging is acceptable for a recycling mill with flotation-deinking process.	2	0	Poses minor adhesion issues.	5-9	DCS expected to have minor issues in a recycling mill with flotation-deinking process.	5-9	COD expected to have minor impact on a recycling mill with flotation-deinking process.
0-20	This packaging creates a significant amount of rejects which can lead to technical problems in the screening step in a recycling mill with flotation-deinking process.	3	-30	Poses significant adhesion issues that can have a significant impact on a recycling mill with flotation-deinking process and is therefore not recyclable.	0-4	DCS expected to have issues in a recycling mill with flotation-deinking process and suggest further optimisation.	0-4	COD expected to have adverse impact on a recycling mill with flotation-deinking process.
<0	The reject of this packaging is too high for a recycling mill with flotation-deinking process and should not be recycled in such a process.				<0	DCS expected to have major issues in a recycling mill with flotation-deinking process and is therefore not recyclable in this process.	<0	COD expected to have major adverse impact on a recycling mill with flotation-deinking process and is therefore not recyclable in this process.

Table 26: Part II: Interpretation of individual elements batch 1

Batch 2					
DP Luminosity Score		**Colour Shade a* Score**		**Dirt Speck Area A50 Score**	
Score	Interpretation	Score	Interpretation	Score	Interpretation
35	The deinked pulp has a high luminosity.	20	This packaging creates a neutral white pulp.	15	This packaging creates no or nearly no total dirt specks
20-34	The luminosity of the deinked pulp is suitable for most recycled products.	10-19	This packaging produces some colour change of the recycled product.	8-14	This packaging creates some total dirt specks.
0-20	The luminosity of the deinked pulp is acceptable for the production of products like newsprints. Production of paper or board with high luminosity requirements is not recommended.	0-9	This packaging produces a coloured pulp after flotation. A shade correction is necessary which reduces the luminosity of the recycled product.	0-4	This packaging creates a high amount of total dirt specks.
<0	This product has major luminosity issues and is not recyclable in a recycling mill with flotation-deinking process.	<0	This packaging produces a strongly coloured pulp after flotation and is not recyclable in a recycling mill with flotation-deinking process.	<0	This packaging creates a very high amount of total dirt specks and is not recyclable in a recycling mill with flotation-deinking process.

Table 27: Part II: Interpretation of individual elements batch 2 (1/2)

Batch 2					
Dirt Speck Area A250 Score		**Luminosity Gain Score**		**Filtrate Darkening Score**	
Score	Interpretation	Score	Interpretation	Score	Interpretation
10	This packaging creates no or nearly no large dirt specks.	10	The luminosity gain in the flotation process is good.	10	This packaging has (nearly) no on the colour of the water loop.
5-9	This packaging creates some large dirt specks.	5-9	The luminosity gain in the flotation process is acceptable.	5-9	This packaging slightly stains the water loop.
0-4	This packaging creates a high amount of large dirt specks.	0-4	The luminosity gain in the flotation process is low.	0-4	This packaging creates a dark water loop and has the potential to lower the luminosity of the final recycled product in industry.
<0	This packaging creates a very high amount of large dirt specks and is not recyclable in a recycling mill with flotation-deinking process.	<0	The luminosity gain in the flotation process is insufficient. This product is not recyclable in a recycling mill with flotation-deinking process.	<0	This packaging creates a very dark water loop and lowers the luminosity of the final recycled product in industry. It is not recyclable in a recycling mill with flotation-deinking process.

Table 28: Part II: Interpretation of individual elements batch 2 (2/2)

Table 29 shows three examples for the Technical Recyclability Score calculation. Threshold and target values are listed in Table 14 and Table 15.

Sample 1 passes the assessment with 97 points and is rated 'Technically recyclable in a recycling mill with flotation-deinking process' because all threshold values were reached and results were exceeding or close to target parameters.

Sample 2 failed with a Technical Recyclability Score of -5 points ('Not technically recyclable in a recycling mill with a flotation-deinking process. Potentially recyclable in other mill types') because the luminosity of deinked pulp was below the threshold (53%) and the luminosity gain was below its threshold (6%) resulting in a negative subscore for batch 2 and, consequently, an overall negative Technical Recyclability Score.

Sample 3 failed with a Technical Recyclability Score of -7 points ('Not technically recyclable in a recycling mill with a flotation-deinking process. Potentially recyclable in other mills with different recycling process types') because the Total Screening Yield was below the threshold (85%) and the DCS Score (measured as Evaporation Residue) was above the threshold (100 mg/g packaging) resulting in a negative subscore for batch 1 and, consequently, an overall negative Technical Recyclability Score.

				Sample 1		Sample 2		Sample 3	
	Input parameter	Acronym	Unit	Input value	Score (points)	Input value	Score (points)	Input value	Score (points)
Batch 1	Coarse Reject	CR	0,0 - 100,0 %	2		15		6	
	Fine Reject	FR	0,0 - 100,0 %	1		0		11	
	Total Screening Yield	TSY	0,0 - 100,0 %	97,1	50	85	0	84,1	-4
	COD value	COD	mg/g packaging	20	10	20	10	20	10
	Evaporation Residue	ER	mg/g packaging	70	6	70	6	150	-10
	Sheet adhesion	SA	1-3 [Level]	1	30	1	30	1	30
Batch 2	UP Luminosity	Y UP	%	60		48		60	
	DP Luminosity	Y DP	%	65	35	51	-6	65	35
	colour shade (a*)	a*	-	1	20	1	20	1	20
	Dirt specks area (A50)	A50	mm/m²	400	15	400	15	400	15
	Dirt specks area (A250)	A50	mm/m²	100	10	100	10	100	10
	Luminosity Gain (YG)	YG	%	5	10	3	-4	5	10
	Filtrate darkening	AY	%	10	7	10	7	10	7
	Sub-score batch 1				96		46		-14
	Sub-score batch 2				97		-10		97
	Technical Recyclability assessment			Technically recyclable in a recycling mill with Flotation-Deinking process.	97	Not technically recyclable in a recycling mill with Flotation-Deinking process. Potentially recyclable in recycling mills with other processes.	-5	Not technically recyclable in a recycling mill with Flotation-Deinking process. Potentially recyclable in recycling mills with other processes.	-7

Table 29: Part II: Examples for Technical Recyclability Score calculation

9. PART III – Recycling mill with specialised process

MILL DESCRIPTION

This dedicated paper recycling mill type typically treats a mix of special grades (group 5 of EN 643) but often combined with recycling lines for other groups (1-4 of EN 643). Each recycling mill determines the optimal mix and adds one or more pieces of dedicated equipment or applies special means, such as a horizontal high-consistency drum pulper, a separate batch pulper with longer disintegration time, high screening and cleaning capacity (multiple stages), separate reject cleaning stages, deinking stages, low-consistency cleaners, hot dispersion, usage of repulping aids and/or special process and wastewater treatment systems. These specialised recycling mills can treat paper-based packaging coated with water-insoluble products (i.e. plastic layers, aluminium, polyester or wax, or treated with wet-strength agents), which is entering the recycling process in homogeneous lots. As in recycling mills with a conventional process, the result of specialised processes is also very high-quality (virgin) fibrous material, suspended in water and ready for papermaking.

The development of the testing method and respective Recyclability Evaluation Protocol for a recycling mill with specialised process makes it clear that there is not one 'typical' process/setup for specialised mills, as production processes highly depend on the incoming raw material and target quality of recycled fibre pulp. This presents a challenge in defining the test method, and after extensive discussions a compromise was reached by focusing in the first release on the recycling process designed for used beverage carton (UBC) recycling.

Mills for recycling UBCs are widespread over Europe and often utilise similar process flows. Therefore, adjusting the laboratory testing method should cover a significant share of these 'specialised' recycling mills in Europe. UBC recycling processes are designed to handle moderate wet-strength paper and materials that, due to double-sided barrier coating, need more energy/time to disintegrate. UBCs are collected and sorted in Europe in dedicated waste streams and therefore the input quality for a specialised mill is rather homogeneous (EN643 grade 5.03.00). As UBC-like packaging (similar material composition) can also be reprocessed in a specialised mill process, the test method is open for these 'equivalent' packaging types (provided they are produced with the same type of laminations and barriers), such as cup stock, ice-cream cups, boxes for powder content, laminated paper trays, etc. However, being reprocessable in a recycling mill with specialised process (UBC) does not mean that the packaging is recycled (at scale). It only describes the disintegration behaviour of such packaging in a specialised process. Collection and sorting schemes are not part of this test and evaluation methodology.

Typical for these types of recycling mills is the option to recycle the pulping rejects (well defined because of the collection and sorting schemes and the composition of UBC) in dedicated reprocessing plants for polyAl. Because of the defined reject material quality, which consists mainly of a limited group of polymers and sometimes aluminium barrier foil, this is called polyAl (polymers and aluminium). PolyAl reprocessing plants are meanwhile widespread throughout Europe with an increasing reprocessing capacity. PolyAl fraction assessment and a general compliance test with the Design for Recycling Guideline, is an essential part of the methodology.
Other types of recycling mills with specialised process (i.e. other than a UBC recycling mill), referred to as recycling mills with specialised process (FBCP), might operate under different conditions during recycling. These types of recycling processes will be addressed at a later time due to the complexity in creating a harmonised protocol for lab testing and evaluation.

LABORATORY TEST METHOD

INTRODUCTION

The laboratory test method Paper and Board – Recyclability Laboratory Test Method – Part III: Recycling mill with Specialised process (UBC)/'Harmonised European laboratory test method to generate parameters enabling the assessment of the recyclability of paper and board products in recycling mills with specialised process (UBC)' applies to Part III of the Evaluation Protocol.*

As mentioned above there is no typical specialised mill setup nor is there a specification for the product output quality defined for these mills. Nevertheless, a few characteristic features may be attributed to recycling mills with specialised process. They often run with extended disintegration times, consume more energy during pulping and usually require extra (waste) water treatment efforts than recycling mills with conventional process. Therefore, they usually focus on packaging for recycling with a high proportion of virgin fibres as raw material and on a defined reject quality, which is important especially in UBC recycling. 'Reject quality' refers to the ability to properly separate the polymer-(aluminium) coating and barriers as 'reject' in the paper recycling process and its reprocessing potential in the second step polyAl recycling. Therefore, the testing method and Recyclability Evaluation Protocol shall represent these distinctive features. The complexity of the initial testing method setup and the Evaluation Protocol is shown in Figure 9.

Repulping behaviour

WHY?
- Define repulping conditions / set up for technical recyclability

WHAT?
- UBC recycling process (collection and sorting infrastructure available today)
- additional process parameters pH, temperature (future FBCP recycling process)

Pulp quality

WHY?
- Additional effort for processing and reject handling need to be rewarded by high quality recyclate.

WHAT?
- ash content
- mechanical properties

Reject quality

WHY?
- Increase recycling rate; reject recycling needs defined quality

WHAT?
- quality (polymer)
- size distribution / fragmentation (reject stream)
- fibre content

Figure 9. High-level considerations taken in the developing a test method and recyclability assessment protocol for recycling mills with specialised process (UBC)

* The test method is scheduled to be available by 2025. Prior to this, readers are directed to the detailed work description for Part III.

TEST METHODOLOGY

The test methodology was developed by 4evergreen members to improve the reproducibility and repeatability of the method through detailed descriptions and fine-tuning of the procedures. It defines a laboratory procedure emulating the most relevant process stages (repulping, coarse-, and fine-screening) and quality parameters (reject characterisation, visual characterisation, and mechanical properties) of a paper recycling mill with specialised process (UBC) dedicated to recycling the most common paper and board for recycling grades of group 5.03.00 according to EN643 – typically without deinking technology.
The testing method provides results relevant to 'process efficiency' (fibre yield, reject characterisation and pulp quality properties) as well as to recycled paper quality (e.g. visual characterisation, sheet adhesion, mechanical and compositional properties). These results serve as a basis for assessments under Part III of the Evaluation Protocol described in this document.

BLACK AND WHITE BOX APPROACH

The default methodology for scoring is based on a black-box approach, which means no additional information regarding the sample composition is provided to the test laboratory by the applicant. However, when more detailed information is available, e.g. a data sheet is provided to the laboratory or an additional analysis is done, this information can be used to extract relevant insights. In such a case a so-called white-box (informative) option would then be available in the scorecard. Figure 10 shows a flow chart describing when and how to use both approaches.

POLYAL

PolyAl (sometimes referred to as PE-AL or ALPE) is the material left over (by-product) after the paper (re)pulping process in the recycling mills with specialised process (UBC). This material, coming from both fresh or aseptic packaging, contains a mixture of plastics (and plastics with aluminium) used as functional barrier materials, caps, and closures in the beverage cartons. These typical recycling mills with a specialised process for UBC have a dedicated 'next step' for recycling this by-product material. Therefore, this material can be considered in the Technical Recyclability Score calculation.

DESIGN FOR RECYCLING GUIDELINES

The method and scoring approach provide the opportunity to account for the polyAl share of the packaging in the Technical Recyclability Score, since at industrial scale almost all recycling mills with specialised process (UBC) have a process in place for recycling the polyAl. The polyAl share can only be counted in the Technical Recyclability Score when there is a known quality of the polymers and the polyAl fraction/composition. The polymers must be assessed as 'fully' or 'conditionally compatible' according to the DfR criteria in the 4evergreen's Circularity by design guideline for fibre-based packaging. Only if the polymers in the packaging fulfil these compliance obligations, the polyAl share can be considered in the Technical Recyclability Score calculation.
If compatible with the guideline, the polyAl share can be considered in either black- or white-box approaches.
In the white-box approach, the amount of polyAl will be based on input from the data sheet provided by the sample provider or distributor, specifically the information on the theoretical amount of recyclable rejects, referred to as RR.
In the black-box approach, the amount of PolyAl will be related to the coarse reject (CR) amount including deductions based on the coarse reject quality (CRQ) parameter. The polyAl composition used in the packaging must be proven by relevant analytical methods, such as FT-IR or Raman analysis.

TECHNICAL RECYCLABILITY SCORE FOR RECYCLING MILL WITH SPECIALISED PROCESS (UBC)

OUTPUT VALUES OF THE LABORATORY TEST METHOD

In order to calculate the Technical Recyclability Score, several output values from the lab tests are considered, see Table 30. A detailed explanation of how these values are obtained can be found in the description of the laboratory test method.

In addition to the parameters shown in Table 30 other relevant factors have been considered but are not (yet) included in this recyclability evaluation. Additional parameters (shown in Table 31) might be incorporated in future versions of the recyclability evaluation protocol.

Besides the paper share, the repulping rejects (coarse rejects) for specialised mills (UBC) are utilised in a dedicated 'next-step' recycling process, thus these rejects have a material value for the mills and should be included in the Technical Recyclability Score.

Parameter	Acronym	Meaning
Coarse Rejects	CR	Weight percent of packaging retained by coarse screening and dry removed components.
Fine Rejects	FR	Weight percent of packaging retained by fine screening after coarse screening.
Total Screening Reject	TSR	Sum of coarse and fine reject, using a correction factor for the fine screening reject value.
Total Screening Yield	TSY	Total amount of packaging minus TSR expressed in percent.
Recyclable (theoretical) Reject	RR	The amount of theoretically expected total recyclable rejects as a weight percentage according to the data sheet or analysis.
Coarse Reject Quality	CRQ	Evaluation of the PolyAl barrier pieces in the coarse reject based on the presence of fibres, since fibres are not recyclable in PolyAl stream (i.e. a score interpretation).
Visual Impurities	VI	An evaluation of the optical purity of the paper. The parameter is evaluated on a handsheet from the 'accept' proportion after fine screening.
Sheet Adhesion	SA	An evaluation of the tackiness of a handsheet from the 'accept' of fine screening.
Ash Content	ASH	Ash content is a measure of the inorganic content of the paper/board, such as filler or coating pigments including calcium carbonate, clay, titanium dioxide, etc. Measured on a filter cake at 525°C according to the ISO 1762/ISO 2144 in [%].
Tensile Index	TI	Tensile strength measures how resistant the paper is to a web break. Measured in Newton meter per grammage [Nm/g] according to the DIN EN ISO 1924-2:2009-05
Reject Characterisation	RC	Description of the main components of the reject. Characterisation of coarse and fine rejects is needed for assessing the coarse reject quality.

Table 30: Part III: Parameters used for Technical Recyclability Score calculation

Parameter	Acronym	Meaning
Dissolved and Colloidal Substances	DCS	Mass of solid materials in the filtrate related to packaging mass [mg/g packaging]. It is determined as Evaporation Residue.
Chemical Oxygen Demand	COD	Indicative parameter for process water quality measured as the amount of oxygen needed for chemical oxidation with dichromate. High values indicate risks for deposits and risks in waste water treatment.
Disintegration Time	DT	Indicates the disintegration time using the test method for recycling mills with specialised process (UBC).

Table 31: Part III: Additional parameters used in the detailed work description but not in the scorecard (i.e. potential future parameters for the scorecard)

TECHNICAL RECYCLABILITY SCORE CALCULATION

In order to translate the output values into the Technical Recyclability Score, the sum of all individual points scored is considered: total screening yield score, coarse reject quality score, and pulp quality scores.

The total screening yield score assesses the amount of fibrous material recovered from the fibre-based composite packaging using the 10-minute disintegration time.
The scoring principle is based on determining the recyclable amount of material (yield) – the recovered fibrous material from the process with ideal optical quality and mechanical and compositional properties – expressed in weight percentages. The recovered amount of 'good-quality fibre equals the yield TSY in [%]. No penalties are applied, no bonus points can be gained.

Visual impurities, tensile index and ash content are evaluated with a knockout criterion. For the TI and ASH, there is currently no 'in-between target and threshold' score due to insufficient test results data. By creating a database over time, an adapted scoring might be introduced in future versions of the score calculation.

The Equations 11 and 12 show how the technical recyclability score calculation is perfomed in the black box and white box approaches respectively.

EQUATION 11

$$\text{Technical Recyclability Score}_{\text{Blackbox}} = TSY + CR + CRQ$$

where

- TSY Total Screening Yield Score;
- CR Coarse Reject Score;
- CRQ Coarse Reject Quality Score;

The outcome in [%] is in the score card converted into points.

EQUATION 12

$$\text{Technical Recyclability Score}_{\text{Whitebox}} = TSY + RR$$

where

- TSY Total Screening Yield Score;
- RR Recyclable Reject score coming from recyclable non paper content provided in data sheet;

The outcome in [%] is in the score card converted into points.

TOTAL SCREENING YIELD SCORE

The total screening reject (TSR) is calculated according to Equation 13 which is then used to determine the total amount of recovered fibres (total screening yield, TSY) according to Equation 14. The total recovered fibres is used to define a yield in weight percent [%], i.e. fibres that can be recovered in the recycling mills with specialised process (UBC).

All terms used in Equation 13 can be found in Table 30 except for α which is a correction factor used to mimic the fibre recovery in multi-stage screening processes. Processing times and mechanical shearing forces applied in the industrial process (e.g. in pumps) can prompt slightly better disintegration of fibre bundles compared to lab conditions. The value of α is set to 0.9 based on expert consensus.

EQUATION 13: TOTAL SCREENING REJECTS

$$TSR = CR + FR * \alpha$$

where

- TSR is the Total Screening Reject (%);
- CR is the Coarse Reject rate (%);
- FR is the Fine Reject rate (%);
- α is the correction factor.

Complementary to TSR is the Total Screening Yield (TSY). The calculation is shown in Equation 14.

EQUATION 14: YIELD CALCULATION

$$TSY = 100\% - TSR$$

where

- TSY is the Total Screening Yield as mass percentage of material that can be reused (%);
- TSR is the Total Screening Reject (%).

For a recycling mill with specialised process (UBC) striving to recover virgin fibres, TSR amounts need to be kept low. This has clear financial, technical and ecological benefits as well. Because the preferred feedstock for these mills is defined as used beverage cartons, typically with higher non-fibre amounts, there is no gliding scale used in this calculation (contrary to recycling mills with conventional process). Lower reject amounts will automatically lead to a higher TSY.

The constant α might be changed into a variable taking the fine reject characterisation into account in future versions of the Evaluation Protocol.
The Total Screening Yield score is the outcome of the disintegration test after 10 minutes disintegration time in the Standard Lab Disintegrator.

When using the data sheet information, the Technical Recyclability Score and thus the assessment will be 'Not technically recyclable in a recycling mill with specialised process (UBC)' when the content of fibrous material is below 50%. In the event there is no data sheet available, the score assessment is 'Not technically recyclable in a recycling mill with specialised process (UBC)' when the Total Screening Yield is below 50%.

A packaging is considered 'technically recyclable in a recycling mill with specialised process (UBC)' once the score is higher or equal to 50 (fifty), without knockout scores.

COARSE REJECT QUALITY (CRQ) SCORE

PolyAl recyclers require feedstock from recycling mills with a high purity of recyclable polyAl material. However, in the black-box approach, this amount is unknown. The coarse reject is only an indication of the order of magnitude of recyclable polyAl materials, however may contain attached fibres or other components deleterious to polyAl recycling. These attached fibres represent a material loss for the paper recycler and an undesired feedstock component for the polyAl recyclers[4]. A high amount of attached fibres in the coarse reject material will be penalised, represented by the CRQ factor – lost fibres are scored in proportion to the amount of coarse reject.

Higher amounts of fibre in the coarse reject will lead to a higher penalty, i.e. a lower score. The coarse reject quality level depends on the recyclable polyAl and the presence of fibres, attached fibre flakes and/or encapsulated within the pieces of barrier coating found in the coarse reject.

The reject characterisation tree provides a structured approach for this assessment. Coarse reject quality is rated using Table 33 and Equation 16, as given below.

The coarse reject quality score is equal to the amount of coarse rejects (CR) multiplied by the gamma-factor (ɣ-factor). The gamma factor is a correction factor for the scoring used to define the losses in fibre amount and to penalise the fibres into the polyAl reject. Based on expert consensus, this correction factor is set to the value of 0,3.

Coarse reject characterisation is performed after the 10 minutes repulping time of the test. For the reject characterisation, two criteria are considered:

1. **The level description for the reject quality characterisation**

Leading to an expert-based score (optical contaminations) with polyAl recycling in mind.

EQUATION 16:

$$CRQ_{score} = \frac{(CRQ_{Level} - 1)}{2} \cdot CR \cdot \gamma$$

where

CRQ_{score}	Coarse reject quality score
CRQ_{Level}	Coarse Reject Quality Level
CR	Coarse Reject Rate (%)
ɣ	ɣ-factor, correction factor for the scoring

The outcome in [%] is in the score card transformed into points.

CRQ level (fibre related)	Description	Score/Formula
1	Loose fibres and flakes easy to wash away. Encapsulated fibres in sealed seams are allowed.	0
2	Single fibres layers and flakes attached to polymers.	- 0,5 * ɣ * CR = - 15% * CR
3	Sample material only partly disintegrated, significant amount of fibres and flakes still attached to polymers.	- 1 * ɣ * CR = - 30% * CR
4	Not disintegrated sample material.	Knockout

Table 33: Part III: Conversion table for the coarse reject characterisation (fibre content related) for specialised process (UBC)

For more information on the reject characterisation terms used in the table above and pictures of the described levels please refer to the annexes for Reject Characterisation and Coarse Reject Quality levels.

Figure 10 shows a flow chart describing when and how the PolyAl recycling is considered in the calculation of the total screening yield.

Example A: Black-box approach with polyAl recycling

A sample measures a Coarse Reject of 22,4% and has a calculated fibre yield of 75%. No data sheet is available, but polyAl is proven to be partly or fully compliant with the DfR Guideline. The coarse reject quality characterisation (CRQ_{level}) score is Level 2.

The point deduction in case of a situation with polyAl recycling is: 0,5 * 22,4% * 0,3 = 3,4% (rounded).
Technical Recyclability Score is: 75% + 22,4 % - 3,4% = **94%.**
The assessment is: **'Technically recyclable in a recycling mill with specialised process (UBC)'.**

Example B: Approach without polyAl recycling
As sample above. In this case there is no polyAl recycling (but a process for UBC): the Technical Recyclability Score is **75%.** In the event of no polyAl recycling, the coarse reject quality characterisation (fibre based) is not applicable for the score (no double deduction).
The assessment is: **'Not technically recyclable in a recycling mill with specialised process (UBC). Potentially recyclable in a recycling mill with specialised process (FBCP)'.**

Example C: White-box approach with polyAl recycling
A sample measures a Coarse Reject of 22,4% and has a calculated fibre yield of 75%. A data sheet is available and the total theoretical reject shows 20,6 %. Theoretical rejects prevail and point deduction in this case is not applicable. Technical Recyclability Score will be: 75% + 20,6%= **96%.**
The assessment is: **'Technically recyclable in a recycling mill with specialised process (UBC)'.**

2. The polymers and aluminium used for packaging production

As described by the manufacturer's technical data sheet. These polymers and aluminium must be assessed by using the 4evergreen Circularity by design guideline for fibre-based packaging. When all polymers are compatible according to the DfR tables for polyAl recycling process (i.e. fully or conditionally compatible), the packaging as a whole can add the theoretical recyclable rejects (in %) to the Technical Recyclability Score. If no data sheet is available, the polyAl composition must be tested with an appropriate alternative analysis (such as FT-IR or Raman spectroscopy). Otherwise the sample will be assessed as 'Not technically recyclable in a recycling mill with specialised process (UBC).

Example D: PolyAl not compliant with DfR guidelines
Paper and board packaging with 70% fibre yield contains a 7% PET lamination layer. According to the DfR tables this packaging is not compatible with the UBC recycling process because PET > 5% is contaminating the polyAl recycling stream. The assessment is: **'Not technically recyclable in a recycling mill with specialised process (UBC). Potentially recyclable in a recycling mill with specialised process (FBCP)'.**

Remark: The scores do not reflect the recyclability rate of this packaging in a country or region. For that, collection and sorting schemes need to be in place as well. The Technical Recyclability Score reflects only the technical reprocessability of packaging, and if industrial scale recycling processes are available. Some samples will therefore score lower in a recyclability rate assessment, because there is no collection or sorting scheme yet for this type of FBCP; strictly they should not end up in a recycling mill with specialised process (UBC).

Preparing for recycling mills with specialised process (FBCP)

To be ready for using this scoring methodology also for recycling mills with specialised process (FBCP), assessing the quality of the rejects is a variable based on the desired type of recycling route to be assessed. However, in this Evaluation Protocol release, the focus is on recycling mills using a specialised process for UBCs, hence this option is fixed and not shown to the user of the scorecard.

VISUAL IMPURITIES SCORE

For the visual impurities, a qualitative and quantitative evaluation is described in the test method Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process. The method uses a decision tree (Figure 7) to convert this assessment into a level ranging from 1 to 4. The scoring is according to Table 34. Each level defines a range of visual impurities observed in the pulp, where Level 1 is considered to have no visual quality issues and Level 4 shows significant issues impacting the optical quality of the pulp leading to the assessment, 'Not technically recyclable in a recycling mill with specialised process (UBC)'.
Based on feedback from recyclers operating recycling mills with specialised process (UBC), this criterion is less critical for UBC recycling, therefore only the knockout criterion is used for the threshold level and no point reduction for in-between values.

Visual Impurity level	Score
1, 2, 3	0
4	Knockout

Table 34: Part III: Conversion table for the visual impurities

SHEET ADHESION SCORE

Similarly to visual impurities, sheet adhesion is a qualitative evaluation assigned to three possible levels. Level 1 indicates no adhesion issues are observed when using the recovered material. Level 2 is assigned to material that shows some indication of sheet adhesion but likely has a limited impact on the production process. Lastly, Level 3 is assigned when sheet adhesion is clearly observed and the recovered material would likely lead to production problems. Given the severity of Level 3, it is considered a knockout factor and the total score is immediately set to a knockout score, rendering the tested packaging 'Not technically recyclable in a recycling mill with specialised process (UBC)'. The test method Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process provides details and examples for the level assignment. Water soluble tacky materials might not be detected with the sheet adhesion method.

In Table 35, sheet adhesion levels are given a final score. As can be seen, no points are lost or gained when Level 1 and 2 are observed. Given the difficulties of differentiating between Level 1 and 2 using the lab-test method, both are set to a score of zero (0). However, Level 2 does alert the packaging designer that there is some sticky content in the final product and that more strict rules in future editions of this Evaluation Protocol Part III could lead to a lower score or a knockout.

Sheet Adhesion Level	Sheet Adhesion Score	Description
1	0	Tackiness absent: The handsheet can be separated completely from the carrier board and cover sheet without any damage or breakages. A few single fibre pickups can be present on the carrier board and cover sheet. Visible damage to the handsheets and fragments of paper on the carrier board and cover sheet are not permitted.
2	0	Tackiness partly present: The handsheet can be separated completely from the carrier board and cover sheet. Fibre tears and particles occur on the carrier board, the cover sheet and the handsheet itself.
3	knockout	Tackiness present: The handsheet cannot be separated from its carrier board and the cover sheet without a visible damage to the handsheet itself. A breaking of the handsheet or holes (> 1mm [in two dimensions]) occur. **NOTE:** The rating must reflect all sheet adhesion tests conducted and provide an accurate representation of overall performance. A single occurrence of a defect may be disregarded if it is limited to an isolated hole and does not exhibit any fiber tears.

Table 35: Part III: Conversion table for sheet adhesion level to sheet adhesion score

PULP QUALITY SCORE

The parameters tensile index and ash content determine the quality of the pulp for the paper-making process. Recycling mills with specialised process (UBC) are targeting top-quality (virgin) fibres with high mechanical and compositional properties.

Because beverage cartons are the primary source material, the targets and thresholds for the scoring of a packaging entering these mills are based on all available test-result data for beverage cartons within the 4evergreen sample list (tested either by 4evergreen WS1-WG3 or obtained from data donations). The values obtained from these beverage cartons lead to an average value for tensile index and ash content. Because a large test database is still lacking, only threshold values are used. Targets are not yet provided in the scorecard but might be added in a later version once more data become available. While lower strength in recycled fibre may be due to poor packaging design, it may also come from packaging containing a higher share of mechanical pulp; fibres which are perfectly suitable for other recycled paper applications.

Based on statistical rules and expert consensus, the threshold value for ash content (ASH) will equal the average value (AVG) measured in the test database increased by twice the standard deviation (STDEV). For the tensile index threshold, the value is calculated based on a tolerance interval of 90%, leading to a fixed value. Targets are not defined in this release and therefore not used in the scoring tables. These thresholds, as included in the scorecard, are subject to periodical update, where more information will lead to a more refined value.

For now, available data is limited so the scoring is less strict to begin with (i.e. materials falling within the thresholds will not receive negative scores). Values outside these thresholds are regarded as 'knockout' conditions leading to an overall assessment that the material is 'Not technically recyclable in a recycling mill with specialised process (UBC)'. Table 36 shows the targets and thresholds for tensile index and ash content

Parameter	Acronym	Target	Threshold
Ash Content [%]	ASH	Not defined[5]	<11,7
Tensile Index [Nm/g]	TI	Not defined[6]	>25,8

Table 36: Part III: : Rounded thresholds for tensile index and ash content of pulp recovered in specialised mills (UBC)

If data is available for ash content and tensile index obtained with 20 minutes of disintegration time, it can be used in the Evaluation Protocol. However, there is no need to repeat the tests after the 10-minute mark in the disintegration phase.[7]

TECHNICAL RECYCLABILITY SCORE FOR RECYCLING MILL WITH SPECIALISED PROCESS (UBC)

The Technical Recyclability Score for a recycling mill with specialised process (UBC) equals the sum of the scores according to Equation 11 and 12. To keep as aligned as possible with the scoring principles of the other parts, this percentage is translated into a point-based score. Other parameters described above do not currently affect the score calculation, but any parameter resulting in a knockout will immediately lead to the assessment: 'Not technically recyclable in a recycling mill with specialised process (UBC)'. A full overview of the scoring options are listed in Table 38 and Figure 10, and can also be found in the scorecard Excel File.

Technical Recyclability Score for Recycling in mills with specialised process	Description
50 - 100 and no KO	Technically recyclable in a recycling mill with specialised process (UBC).
KO(s)	Not technically recyclable in a recycling mill with specialised process (UBC). Potentially recyclable in other mills with different recycling process types.

Table 37: Part III: Interpretation of Technical Recyclability Score
* This result refers to a reference process, the individual evaluation of a recycling mill might be different, depending on available processes and stock preparation concept.

[5] Target values might be defined in a later version once more data is available.
[6] Target values might be defined in a later version once more data is available.
[7] Annex Detailed work description: Recyclability Laboratory Test Method – Part III: Recycling mill with Specialised process.

Coarse Reject Quality			Visual Impurities			Sheet adhesion			Properties (compositional, mechanical)		
Level	Score	Interpretation	Level	Score	Interpretation	Level	Score	Interpretation	Level	Score	Interpretation
Level 1	0	Packaging expected not to pose any repulping issue in a recycling mill with specialised process (UBC) and is therefore considered Best in Class.	Level 1	0	Poses no visual quality issues.	Level 1	0	Poses no adhesion issues	Ash content below and tensile index above target	0	Properties expected to fulfil high pulp quality demands of a recycling mill with specialised process (UBC) and is therefore considered Best in Class.
Level 2	-15% *CR	Packaging has minor repulping issues that slightly lowers the quality of the polyAl as more efforts are needed to separate the attached fibres in the polyAl recycling process.	Level 2	0	Poses minor visual quality issues that are considered acceptable in a recycling mill with specialised process (UBC).						
Level 3	-30% *CR	Packaging has repulping issues that lowers the fibre yield for the mill. It also reduces the quality of the polyAl as more efforts are needed to separate the attached fibres in the polyAl recycling process.	Level 3	0	Poses visual quality issues that are currently still considered acceptable in a recycling mill with specialised process (UBC).	Level 2	0	Poses minor adhesion issues	Ash content and/or tensile index in between target and threshold	0	Properties expected not to pose significant issue in the recycling process of the specialised mill (UBC) and is therefore considered acceptable. Once more data are available a score deduction can be considered.
Level 4	KO	Packaging has major repulping issues and is considered not to be suitable for recycling in a recycling mill with speciallised process (UBC).	Level 4	KO	Poses significant visual quality issues that are considered not suitable in a recycling mill with specialised process (UBC).	Level 3	KO	Poses significant adhesion issues that can have a significant impact on the process in a recycling mill with specialised process (UBC)	Ash content and/or tensile index outside threshold	KO	Properties expected not to fulfil high pulp quality demands of a recycling mill with specialised process (UBC) and is therefore considered not suitable for recycling in a recycling mill with specialised process (UBC).

Table 38: Part III: Overview of the score interpretation for recycling mills with specialised process (UBC)

DATA SHEET AVAILABLE (WHITE BOX APPROACH)

As described earlier, when a data sheet is available, the fibrous material recovery yield can be calculated using this formula: recovered fibrous material according to the yield calculation divided by the theoretical available fibrous material (to be calculated by the laboratory).

EQUATION 15 (13):

$$\text{fibre recovery} = \frac{TSY}{(100\text{-}RR)}$$

where

TSY Total Screening Yield [%];

RR Recyclable Rejects [%].

This value gives additional information of the pulping quality of the packaging in recycling mills with specialised recycling process. This information can be used by the applicant of a recyclability assessment as additional guidance and, where appropriate, to improve the packaging design for better future recycling (explained in more in detail later in the Part III description).

If a data sheet is available, the theoretical and empirical reject amounts can be compared.

To minimise losses and associated costs in the recycling process, the fibrous material content recovered should exceed 90% of the total theoretical content in the fibre-based composite packaging (based on the producer's data sheet). This threshold helps to avoid issues such as excess wet-strength material entering UBC mills or significant losses in fibrous content due to packaging shape and structure. This assessment is only possible with a technical data sheet.

Data analysis and expert opinions concluded that a fibrous material recovery rate above 90% would be considered as best in class.

Example: When a packaging has 80% fibrous content according to the data sheet and the recovered fibrous content is 60% after the lab test, the recovery of fibrous material is 75%.

Calculation	Interpretation
TSY/(100-RR) ≥ 90%	Packaging expected not to pose any repulping issue in the specialised mill (UBC) and is therefore considered 'best in class'.
TSY/(100-RR) < 90%	Packaging has repulping issues that lowers a) the fibrous material yield of the recycling mill, and/or b) the quality of the polyAl as more efforts are needed to separate the attached fibres in the polyAl recycling process.

Table 39: : Part III: White box interpretation table

[4] PolyAl recyclers have a dedicated process to remove the attached fibres from the paper rejects from the recycling mill.

TECHNICAL RECYCLABILITY SCORE INTERPRETATION

Packaging that requires specialised recycling processes (as per the flow chart described in the 4evergreen Guidance on collection and sorting) has the option of obtaining a technical recyclability score with or without polyAl recycling. Figure 10 shows the options presented in the Evaluation Protocol Part III. An analysis of coarse reject composition can be carried out by a laboratory, either using the data sheet or by doing an analysis like FT-IR or Raman spectroscopy.

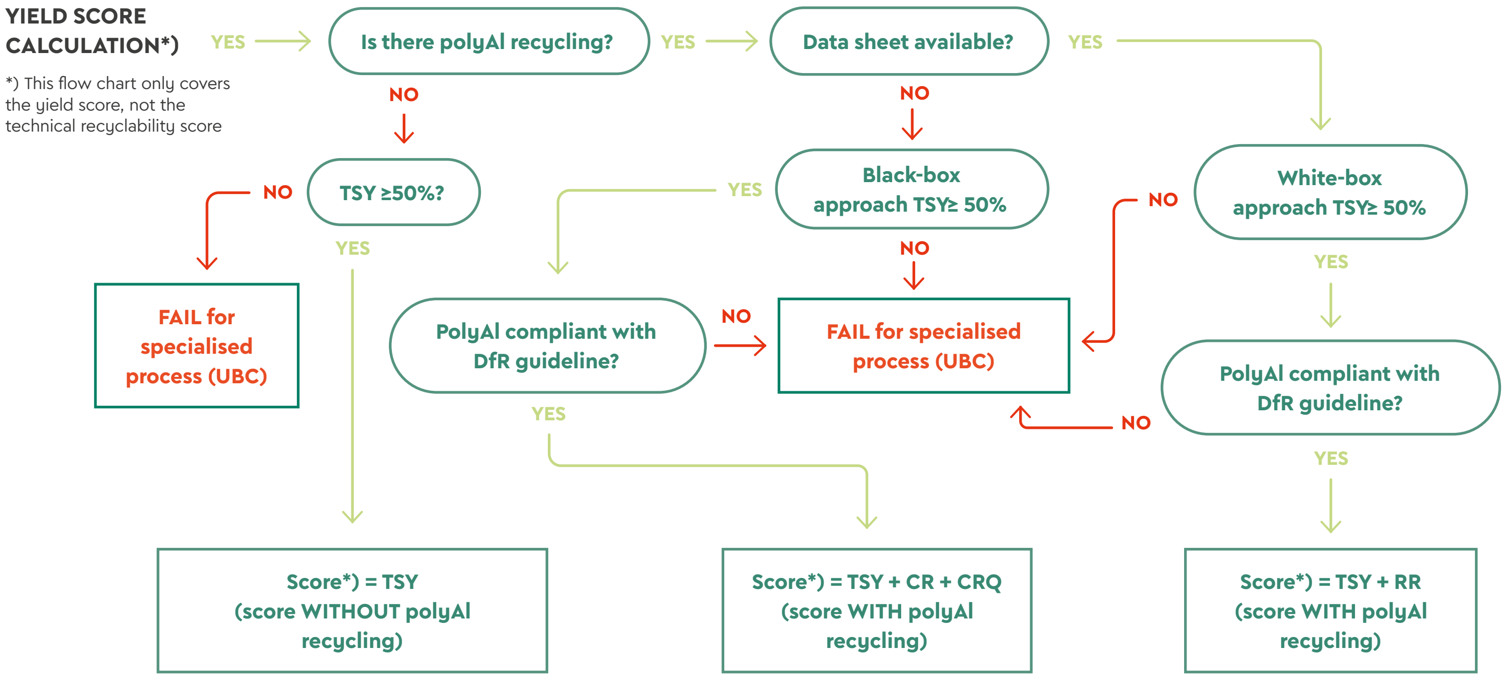


Figure 10. Flow chart for calculating the yield score and when to use the WITH and WITHOUT polyAl recycling options for specialised process (UBC)

<u>The 4evergreen recyclability evaluation protocol Part III provides the following statement if:</u>

1. packaging material is either technically recyclable or not in a recycling mill with specialised process (UBC),
2. packaging material is compatible or not compatible with polyAl recycling.

FUTURE TOPICS

DISINTEGRATION CURVE APPROACH

During the development of this test methodology a decision was made to introduce a Standard Lab Disintegrator as the equipment to be used. Because the initial methodology proposed included three disintegration times to test the disintegration behaviour of packaging, a mathematical simulation was made to describe this disintegration curve, by using a calculated factor (curve deviation), or k-factor [k_f]. Based on this disintegration curve, R-infinity (R∞) can be calculated as the total amount of expected reject material after a long (infinite) disintegration time.

The potential advantages of the disintegration curve approach are:

- Enhanced understanding of the pulping behaviour of different materials
- Demonstrated pulping differences in the scorecard by means of the k-factor
- Using k-factor to reflect variations in temperature and chemistry needed for FBCP evaluation

Although several tests using the disintegration curve approach were carried out and the results were promising, 4evergreen experts decided to postpone its inclusion in the Evaluation Protocol, allowing more time to generate more robust and reproducible data. However, the lab procedure needed to calculate disintegration curve is already described in the detailed work description, and can be performed as an optional test.

This work and the integration of specialised mills (FBCP) will be further investigated as a priority in the next edition of the Protocol.»

In this version of the Evaluation Protocol the disintegration time has been set to 10 minutes. For the time being, the 20-minute disintegration time can only be used as information in the scorecard. In future releases an increased disintegration time of 20 minutes for reject and yield characterisation might be considered to reduce method variability and potentially address typical attributes of mills with special equipment.

To underline the importance of this work and the prediction of the pulping behaviour, there is an option built into this Evaluation Protocol (data sheet) that describes pulpability in terms of the packaging composition. In this case, the theoretical percentage of coarse reject (polyAl) can be used in the calculation of the score and which corresponds to R∞. This option relates to the 'White-box approach', which is further outlined in this document.

DATABASE

This Evaluation Protocol was created thanks to extensive testing performed by various specialised laboratories and secondary 'data donations' from the industry. These tests provided the working group significant data to help create this Evaluation Protocol, but more robust datasets are needed to expand the range and impact of the tools contained within it. Therefore, in the next release, more data will be generated and gathered through 4evergreen testing and additional external data contributions in order to investigate and refine the robustness of the method. The disintegration curve work indicates reduced variation with increased pulping time. Further work will focus on refining methods and investigating increased pulping time as a mean to reduce variation and mimic the special attributes and conditions (i.e. high consistency pulping within mills with specialised equipment). Options to further refine the evaluation scorecard will also be investigated. Target and threshold values might also be revised and adjusted in future versions.

10. Appendix

EXTERNAL STAKEHOLDER CONSULTATION

4evergreen has shared the previous Beta-release of this Recyclability Evaluation Protocol with a select group of industry stakeholders and associations to gather their inputs and feedback. 4evergreen is committed to fostering a fruitful dialogue with partners across the fibre-based packaging industry and other sectors, and their contributions to 4evergreen's work are highly valued.

Feedback received on the previous version of this publication has been incorporated into the current document. It concerns:

- The Version 1 now includes the assessment of technical recyclability in recycling mills with flotation-deinking process and recycling mills with specialised process (UBC)
- Wording and definitions and procedures have been described
- The sheet adhesion test procedure and levels have been described in more detail with additional guidance (pictures and video) provided
- Adhesive manufacturers have been actively involved in the work to improve the sheet adhesion procedure via technical focus groups
- The visual impurities decision tree has been improved in order to provide clear guidance

Stakeholders from across all industries and sectors involved in fibre-based packaging are invited to share this document among their own networks and 4evegreen would be pleased to receive further feedback or comments on its implementation. Please contact the 4evergreen secretariat (4evergreenalliance@gmail.com, subject: 4EG / EXTERNAL CONSULTATION / WS1) to receive further information about how to get involved in the consultation process.

AVAILABLE DOCUMENTS

To support the application of laboratory test methods relevant for Part I, II and III and the Recyclability Evaluation Protocol several annexes are available:

- Detailed work description: Paper and Board – Recyclability Laboratory Test Method – Part I: Recycling mill with Conventional process
- Detailed work description: Paper and Board – Recyclability Laboratory Test Method – Part II: Recycling mill with Flotation-Deinking process
- Detailed work description: Paper and Board – Recyclability Laboratory Test Method – Part III: Recycling mill with Specialised process (UBC)
- Detailed work description Sample preparation
- Recyclability Evaluation Scorecard
- Annex Visual impurities
- Annex Reject characterisation
- Annex Coarse reject quality
- Annex Sheet adhesion test (incl. video)
- Annex 2-side barrier coated samples
- Annex Flowcharts for Laboratory test methods Part I, II, and III

GLOSSARY

Board/Paperboard
Generic term applied to certain types of paper frequently characterised by their relative high rigidity. The primary distinction between paper and board is normally based upon thickness or grammage, though in some instances the distinction will be based on the characteristics and/or end-use. For example, some materials of lower grammage, such as certain grades of folding boxboard and corrugated raw materials, are generally referred to as 'board', while other materials of higher grammage, such as certain grades of blotting paper, felt paper and drawing paper, are generally referred to as 'paper'.

Collection
Separate or co-mingled transport of separate or co-mingled paper and paper products from industrial and commercial, from households and offices for recovery. Collection includes transport to the sorting or recycling plant/paper mill. Collection = utilisation plus exports minus imports of paper for recycling. The difference between collection and utilisation of paper for recycling can be explained by trade, stock variations and some volumes destined to other material uses.

Converting
Manufacture of products by processes or operations applied after the normal paper or board manufacturing process. The operation of treating, modifying, or otherwise manipulating the finished paper and paperboard so that it can be made into end-user products, such as special coating, waxing, printing, and gumming, and envelope, bag, and container manufacturing.

EN 643 – European List of Standard Grades of Paper and Board for Recycling
The European List of Standard Grades of Paper and Board for Recycling gives a general description of the standard grades by defining what they are allowed and not allowed to contain.

Fibre-based composite packaging
Packaging composed of paper and a considerable share of non-paper elements that by design are not separated after use.

Fibre-based packaging
A product, based on paper and/or cardboard, suitable to pack filling goods. The design aspects and properties of fibre-based packaging are typically specific for the respective filling goods.

Fibre-based packaging material
The sum of paper-making fibres, fillers added in the wet-end, pigments used in print receptive coating, binders used as a minor fraction in pigment print receptive coating, starch and other dry strength agents, other functional and process chemicals used in the wet-end of the paper machine (printing inks, overprint varnish) as well as adhesives used to bind two layers of paper (or paper and plastic film) together, polymeric barrier layers, and any additional/auxiliary items (closure, tape, label).

Paper
Generic term for a range of materials in the form of a coherent sheet or web, excluding sheets or laps of pulp as commonly understood for paper making or dissolving purposes and non-woven products, made by deposition of vegetable, mineral, animal or synthetic fibres, or their mixtures, from a fluid suspension onto a suitable forming device, with or without the addition of other substances. Papers may be coated, impregnated or otherwise converted, during or after their manufacture, without necessarily losing their identity as paper. In conventional papermaking process, the fluid is water; new developments, however, include the use of air and other fluids.

PolyAl
PolyAl (sometimes referred to as PE-AL or ALPE) is the residual material after the paper (re)pulping process in the recycling mills with specialised process (UBC). This material contains a mixture of the plastics and aluminium used as functional barrier materials, caps and closures in the beverage cartons. Typical recycling mills with specialised process (UBC) have a dedicated 'next-step' recycling for this by-product. Therefore, this material can be added to the total packaging score.

Pulp
Fibrous material, generally of vegetable origin, obtained through various processes from raw materials in different forms and made ready for use in further manufacturing processes. Examples of raw materials are wood, wood chips, plants, paper and board for recycling, textiles, etc.

Pulping
The act of processing wood (or other plant) and slushing paper and board for recycling to obtain the raw material for making paper and board. The fibres are separated from one another into a mass of individual fibres (see Pulp). At laboratory scale the process is referred to as disintegration.

Recyclability

Recyclability of paper-based packaging is the individual suitability of a paper-based package for its factual reprocessing in the post-use phase into new products and board. Factual reprocessing means that collection, sorting (if relevant), and at scale recycling takes place. Recyclability criteria of materials are described in ISO 14021 (guidelines for self-declared environmental claims). Where relevant and followed by sorting) into EN 643 grades and final recycling takes place at an industrial scale.

Recycling rate

The ratio between the recycling of used paper, including net trade of paper for recycling, and paper and board consumption. It is calculated as 'paper for recycling utilisation + net trade' divided by 'paper and board consumption', on base paper level.

Recycling mills with specialised process

These mills treat a mix of special grades (group 5 of EN 643) and grades from other groups (1-4 from EN 643). Each recycling mill determines the optimal mix and adds one or more piece of dedicated equipment, such as a horizontal high consistency drum pulper, a separate batch pulper with longer pulping time, deinking, fine cleaners, hot dispersion, and special process and waste-water systems. These specialised recycling mills can treat fibre-based packaging that has been coated with non-water soluble products such as wax, plastic film or other layers (e.g. aluminium, polyester, polyethylene) entering the recycling process in homogeneous lots. In order to optimise the recycling process, fibre-based composite packaging, which cannot be handled in a conventional process, should be delivered to specialised paper mills in EN 643 identified flows. As in recycling mills using conventional processes, the result of the process is also very high quality fibrous material suspended in water and ready for paper-making.

Stock concentration

Ratio of the oven-dry mass of material that can be filtered from a stock sample to the mass of unfiltered sample. Note: The term consistency is widely used for the stock concentration range at process stages, e.g. HC pulping, LC cleaning. Different process stages might use different stock concentration ranges respectively.

Technical recyclability at recycling mill with conventional process

Technical recyclability considers if a fibre-based packaging can be recycled applying dedicated recycling process and conditions which is assessed typically by applying a defined referenced lab test procedure (Part I). The assessment of technical recyclability can differ between Part I, II and III. It does not consider the aspects of collection and sorting and if the packaging is finally recycled at industrial scale. Besides the technical recyclability, the recycling at scale furthermore includes aspects of collecting and sorting in individual markets, i.e. whether packaging is collected, sorted (if applicable) and finally recycled in a paper or board mill. There are also economic aspects influencing the recycling of individual packaging.

LIST OF ABBREVIATIONS

Abbreviation	Meaning
α (alpha)	Correction factor for fine rejects at the lab scale
A	Dirt speck area
a*	Colour shade parameter from green to red
A250	Dirt speck area for particles larger than 250 μm (circle equivalent diameter)
A50	Dirt speck area for particles larger than 50 μm (circle equivalent diameter
ASH	Ash content
AVG	Average value
BOD	Biological Oxygen Demand
Cepi	Confederation of European Paper Industries
CIE	Commission Internationale de l'Eclairage
COD	Chemical Oxygen Demand
CR	Coarse Reject (Coarse Screening Rejects)
CRQ	Coarse Reject Quality
ΔY	Filtrate Darkening
DCS	Dissolved and Colloidal Substances
DfR	Design for Recycling
DT	Disintegration Time
DWD	Detailed Work Description
EN 643	European List of Standard Grades of Paper and Board for Recycling
EPRC	European Paper Recycling Council
ER	Evaporation Residue
EU	European Union
FBCP	Fibre-Based Composite Packaging
FL	Fibre Length measured after the accept screening
FR	Fine Reject (Fine Screening Rejects)
FT-IR	Fourier Transform Infrared
ɣ (gamma)	Correction factor in scoring the reject quality characterisation
HC	High Consistency
INGEDE	International Association of the Paper Recycling Industry
ISO	International Organisation for Standardisation
k_f	k-factor, used for disintegration simulation in Part III to describe the disintegration behaviour
KO	Knockout
LC	Low Consistency
MS	Maximum Score

LIST OF ABBREVIATIONS

MSA	Macrostickies Analysis
M_{SP}	Maximum Score of the parameter P
OCC	Old Corrugated Containers
PE	Polyethylene
PE-AL or AL-PE	Polyethylene-Aluminium
pH	Potential of Hydrogen (acidity)
PolyAl	Polymers and Aluminium (Reject stream)
PPWD	Packaging and Packaging Waste Directive
PPWR	Packaging and Packaging Waste Regulation
R_{∞}	R-infinity, amount of rejects after infinite pulping time
RC	Reject Characterisation
R_P	Result of the parameter P
RQ	Reject Quality
RR	Recyclable Rejects
SA	Sheet Adhesion
$Score_P$	Score of the parameter P
STDEV	Standard deviation
TH_P	Threshold value of the parameter P
TI	Tensile Index
T_p	Target value of the parameter P
TSR	Total Screening Reject
TSY	Total Screening Yield
TY	Target Value of the Parameter Luminosity
UBC	Used Beverage Cartons
VI	Visual Impurities
WG	Working Group within 4evergreen alliance
WS	Workstream within 4evergreen alliance
Y	Luminosity
Y_{DP}	Luminosity of Deinked Pulp
YG	Luminosity Gain
Y_{UP}	Luminosity of Undeinked Pulp

ABOUT 4EVERGREEN

4evergreen is a cross-industry alliance perfecting the circularity of fibre-based packaging to contribute to a climate-neutral and sustainable society. Our goal is to raise the overall recycling rate of fibre-based packaging to 90% by 2030. We bring a particular focus on packaging with a lower circularity performance today, namely the types used for household, out-of-home and on-the-go consumption.

The alliance brings together industry representatives from across the fibre-based packaging value-chain, from pulp, paper and board manufacturers and recyclers to packaging producers and converters, including brand owners, retailers and waste management companies. It also comprises non-fibre material suppliers (e.g., adhesives, inks, coatings), technology providers (e.g., machinery, collection, and recycling solutions), and leading research institutes.

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