![POLYSECURE Preserving Resources by Innovation]

Precise and efficient sorting with SORT4CIRCLE®

The key to the Circular Economy

Jochen Moesslein, Amy Treick and Lars Watschke

1 INTRODUCTION

Circular economy with high reuse and recycling rates is considered a patent remedy against raw material scarcity, for climate protection and is the basis for a sustainable economy worldwide. However, "the demand for materials is only covered to a small extent by recycling within the stock, because the existing waste management lags behind the requirements of a circular economy" (SRU, 2020). This is clearly demonstrated by plastics, which account for a high proportion of global solid waste (Gasde, J. et al., 2021). In 2020, around 53.6 million tons of plastics were consumed in the EU27+3 (incl. UK, Norway, Switzerland), of which more than one third was required for plastic packaging. At the same time, political decision-makers and industry publish that only about 30 million t of plastic waste are collected annually (Plastics Europe, 2022). The discrepancy between the amount of plastic consumed and the amount of plastic waste collected is explained by the different lifespan of the products. In this context, it is usually assumed that the amount collected is equal to the total amount of waste. However, this is not the case, so that more critical voices assume an actual annual waste volume of ~45 million tons of plastics per year (Agora, 2021). If this figure is considered in relation to the only 4.6 million t of recyclates produced and reused in Europe, it shows on the one hand a lower recycling rate than communicated to the public (see Fig. 1). On the other hand, an urgent need for action becomes apparent, which is reinforced against the background of the European target of 10 million t of recycled plastic used in 2025 (European Commission, 2018). In this context, the difference between the amount of plastic waste sorted and actually recycled highlights **the need for a more efficient and high-quality sorting technology**.

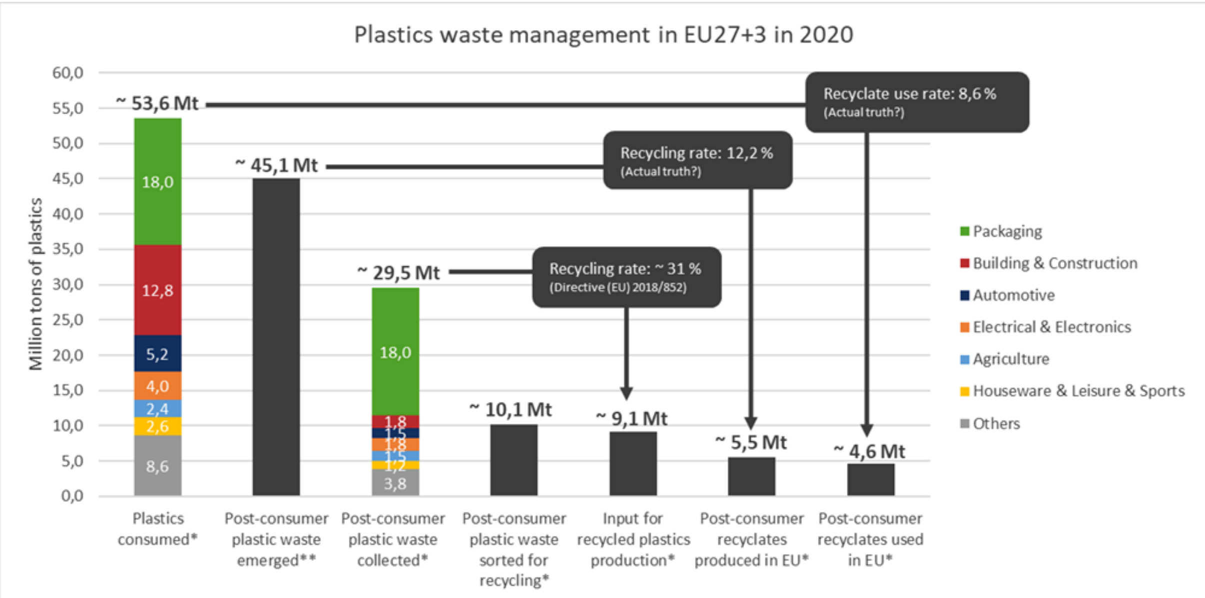

*Fig. 1: Illustration of plastics waste management in the EU27+3 (incl. UK, Norway, Switzerland) in 2020, incl. quota calculations *Plastics Europe (2022) **Agora (2021)*

2 STATE OF THE ART

According to the current state of the art, sensor-based optical processes are most frequently used for the automatic sorting of plastic waste. In this context, especially near-infrared (NIR) spectrometry is used e.g. for sorting lightweight packaging (LWP). For this purpose, one plastic fraction is identified in lined-up NIR sorters and pneumatically separated from the residual stream. The sorting effort therefore increases significantly with the number of desired sorting fractions. This is in discrepancy with the further fractions that a high-quality recycling management of plastics actually requires (e.g., multi-material vs. mono-material). At the same time, key limitations are also associated with the physical operating principle of NIR sorting technology. Here, the objects to be sorted are illuminated with halogen lamps and the absorption bands characteristic for the respective polymer are detected in the reflection spectrum (Neubauer, C., et al., 2021). In practice, these spectra can be masked by e.g. additives or formulation deviations, which impairs the reliability of the detection. Consequently, the NIR technique is practically limited to the detection of the main polymers (usually PE, PET, PS, PP), so that important subclasses or specifications relevant to the application are not distinguished. Accordingly, a considerable proportion of plastics remain in the low-grade mixed fraction or in the sorting residue. Furthermore, contaminants occur in the targeted plastic fractions lowering their quality and value (Wilts, H., et al. , 2016). For instance, composite materials are incorrectly assigned to only one polymer type, main plastic types with various additives are not differentiated, and use-specific sorting is not realizable (e.g., food vs. nonfood) (Woidasky, J., et al., 2018). In addition, NIR technology reaches its limits when it comes to detecting overlapping, black, dirty, wet or intensively printed objects (Schmidt, J., et al., 2021). Moreover, for economic reasons, the LWP plants are designed to meet minimum qualities and are operated at maximum throughput, which leads to shortfalls and false rejections (LAGA, 2021). Thus, further manual re-sorting processes are often required in the LWP sorting plant. Subsequently, the sorting fractions are pressed into bales and delivered to recyclers who shred, wash, re-sort and extrude the fractions into recyclates. During the re-sorting process at the recycler, a further mass loss of up to 35% of the fractions to be processed can be expected (LAGA, 2021).

Consequently, there is a clear need for action to improve the accuracy and efficiency of automatic sorting through an innovative, scalable sorting system that enables the differentiation of pure, specific fractions according to the needs of the market and the demands of a CO_2-efficient circular economy – the new sorting technology SORT4CIRLCE® from Polysecure represents a decisive solution for this.

3 INNOVATIVE SOLUTION FOR HIGH-QUALITY SORTING OF VALUABLE MATERIALS – PRECISE, RELIABLE, EFFICIENT

The sorting technology SORT4CIRCLE® developed by Polysecure comprises the three main process steps of **singulation**, **combined detection** and **target-specific sorting in several fractions** (see Fig. 2). Thus, in this new single-step process, all objects are first singulated, then fully identified once and sorted in only one step. Here, the Tracer-Based-Sorting (TBS) method developed and patented by Polysecure is provided for material identification too. It is based on the use of very small amounts of fluorescent additives (tracers) on or in objects, which glow in a specific color when suitably excited. This signal can be uniquely assigned to a tracer sorting code and the latter to a sorting fraction, allowing plastic waste to be sorted into exactly those fractions that also needs to be recycled separately in order to achieve higher sorting and recycling rates (e.g. PE non-food vs. PE food packaging).

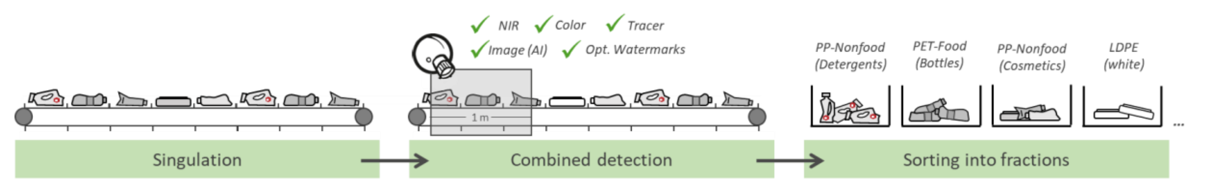

Fig. 2: Functionality of SORT4CIRCLE® with its single-step sorting and combined detection using plastic packaging

At its core, SORT4CIRCLE® combines three central innovations, that are explained below together with current technical development results.

3.1 INNOVATION OF COMBINED DETECTION FOR FULL OPTICAL ANALYSIS

At the heart of the sorting technology is an innovative combined detector consisting of subunits for NIR, color, tracer, and image recognition (artificial intelligence, AI). On the one hand, the combination of these fast measurement techniques enables reliable identification for a large variety of objects. On the other hand, the sorting decision is no longer based on only one detection technology, so that e.g. objects without tracers can also be characterized by NIR, color, and image (AI). Consequently, the tracers are not necessary per se, but a flexible tool to define specific fractions and realize very high detection & purity rates. The combined detector thus allows a "smooth" transition from today's limited to a precise and complete sorting technique. In addition, its modular design allows it to be expandable to existing and future detection technologies, which is in line with the future-proof and flexible character of the entire sorting system concept. Consequently, e.g. a module for the detection of digital watermarks could be integrated for the packaging sector, if the usefulness of this technology is truly proven in practice. The result is a sorting process that is **technology-open** for the first time to enable the best possible detection process in today's dynamic technology landscape. Polysecure is developing the combined detector in cooperation with Carl Zeiss AG.

3.2 INNOVATION OF SINGLE-STEP SORTING AS A SCALABLE, EFFICIENT PROCESS

A central innovation of SORT4CIRCLE® is the comprehensive optical analysis and direct target-specific sorting into the respective fractions in only one step. This process of so-called single-step sorting (cf. letter and parcel sorting) clearly differs from the established cascaded sorting systems, in which only one plastic fraction is separated from the rest of the stream in several sorting steps, usually based on one measured property. As a consequence, the single-step sorting approach not only reduces the complexity of the cascaded system, but also opens up the possibility of adding or changing further target fractions in a **flexible** manner. As sketched in Fig. 3, the objects are singulated in a tray sorter, passed through the combined detector to get identified precisely and then sorted directly in the respective fraction. Compared to the usual pneumatic blow-out of a non-singulated object stream with only limited precision, e.g. in the case of overlapping objects, the handling of a singulated object stream significantly improves the targeted accuracy and reliability of the sorting procedure.

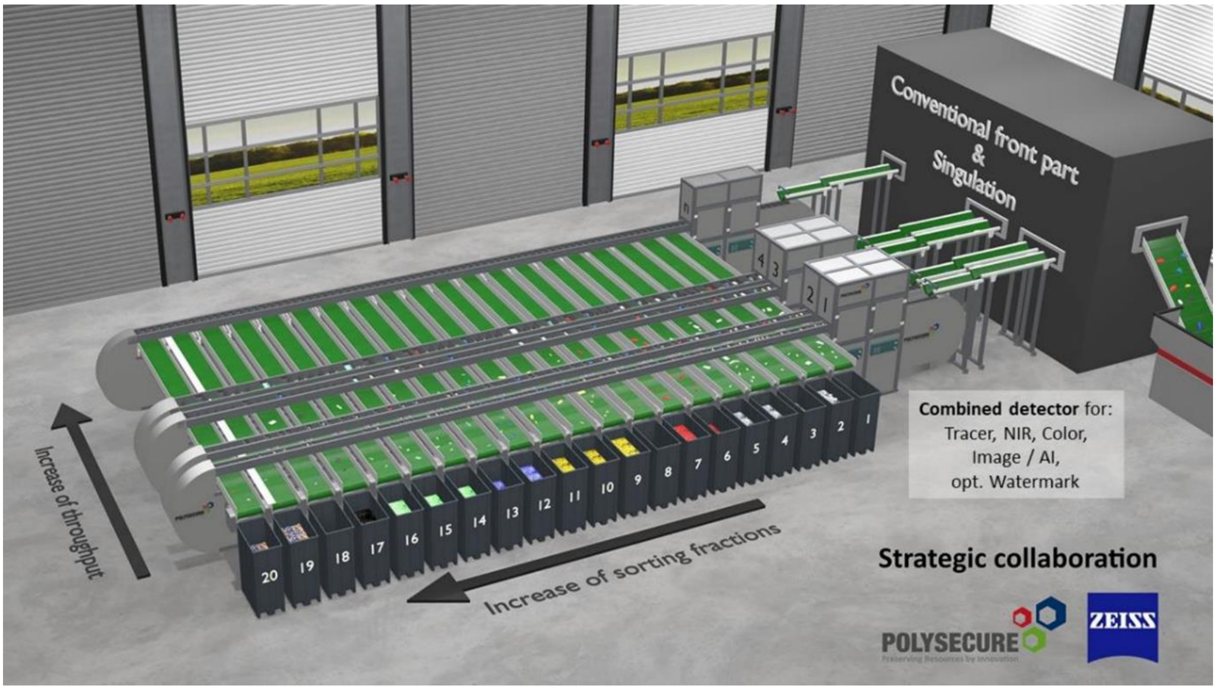

Fig. 3: Simulation of a SORT4CIRCLE® plant for single-step sorting of packages with several parallel sorting lines, incl. singulation, combined detection and deposit

3.3 INNOVATION OF THE TRACER-BASED-SORTING PROCESS FOR SORTING INTO DEFINABLE, PARTICULARLY PURE FRACTIONS

The application of Tracer-Based-Sorting (TBS) provides an innovative solution to previous sorting challenges in the plastics sector. By using fluorescent tracers developed by Polysecure, an external sorting feature independent of the material itself can be defined and identified to enable a sorting into relevant fractions according to the real circular economy needs. Thus, by enabling sorting lines to differentiate and sort highly specific target-fractions, the basis for high-quality recycling is created.

The tracer materials are rare-earth compounds produced via an innovative synthesis process that glow in a characteristic "color" under a certain excitation wavelength. This largely radially symmetrically emitted fluorescence signal is best suited for fast and reliable identification and sorting of packaging and other materials that move quickly and chaotically, are deformed and dirty, and occur in a wide variety of printed and unprinted forms (see Fig. 4). Based on the combination of various tracer materials, Polysecure has developed a sorting code system that makes packaging and other materials better recyclable because they can be sorted more precisely and **reliably**.

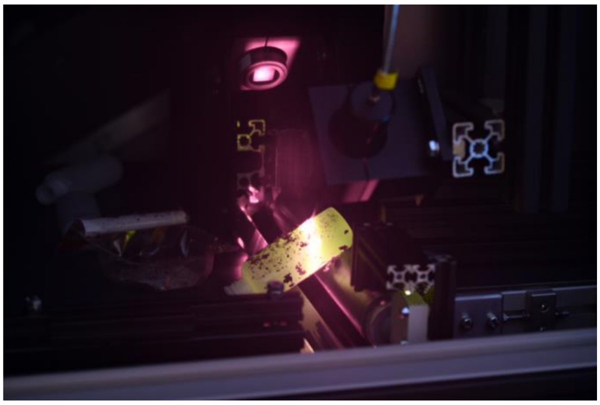

Fig. 4: Marked, dirty packages passing through the laser curtain with (left) and without (right) ambient light

Right from the start, Polysecure has developed its own tracers with a focus on maximum efficiency and biocompatibility. Consequently, great progress has already been achieved for reliable detection even at lowest tracer concentrations (e.g. 3-30 ppm in plastics). In addition, the toxicological studies and migration tests carried out to date indicate that approval for food contact applications can be expected in 2023.

In general, the tracers can be applied onto packaging e.g. via conventional printing processes or labels, and washed off or removed with the printing ink during the recycling process. Alternatively, the tracers can also be dispersed in the plastic as an additive. In this case, previous studies have shown that the tracers survive several extrusion cycles and other stresses without negatively affecting the properties of the polymer itself. As a component of the plastic, they could thus be used by producers and suppliers for quality assurance of recyclates and compounds.

3.4 HIGH PURITY IN THE SORTING OF MARKED FLEXIBLE PACKAGING WITHIN INDUSTRY-TYPICAL SORTING TESTS

In the following, the **high reliability** of tracer detection resulting in **high purity** of sorted fractions is demonstrated in the context of industry-typical sorting tests with marked flexible packaging. The tests were carried out as part of the EU-funded Horizon 2020 project "CIRCULAR FoodPack[1]" (CFP), which started with 14 partners in 2021. One of the goals of this project is the first successful demonstration of a closed recycling loop on an industrial scale for food packaging based on mono-polyethylene (PE). In order to enable a corresponding reuse as food contact material, a.o. the EU Regulation/282/2008[2], sets a purity requirement of >99% for the sorted PE food packaging fraction from the post-consumer waste stream. This criterion cannot be derived from the material properties of the packaging itself, so Polysecures' tracers are applied as an additional sorting property for specific marking and sorting.

For the sorting trials, industrially relevant and typical conditions are chosen. For this purpose, an industry-typical NIR sorter in the sorting pilot plant of Steinert GmbH (Steinert UniSort Film EVO 5.0) is extended by a tracer-specific excitation laser, which spans a laser curtain in the image plane of the NIR camera. This allows marked packaging to be detected within the system and correspondingly blown out pneumatically from the residual flow.

As marked packaging material, flexible packaging pouches were printed with tracer-shifted ink (white) and counter-laminated. Such packaging samples were moved individually at high speed through the adapted sorting machine. Here, stochastically deformed packaging patterns were correctly detected 200 times in 200 passes. This so-called TBS-light detection method per se is thus capable of ensuring sorting fractions with >99% purity despite deformation and rapid, orientationless movement.

[1] The CIRCULAR FoodPack project is funded by the EU Horizon 2020 research and innovation program, under Grant Agreement No. 101003806.

[2] Amended by Regulation EU/2022/1616

For the sorting tests in an industry-typical waste stream, a total of ~315 kg of the marked packaging pouches were mixed with an authentic background stream of also ~315 kg of PE-based light packaging taken from the French household waste stream in Poitiers near Paris (see Fig. 5).

Fig. 5: Marked packaging pouches (left, 25 µg/cm² tracer in white ink) are mixed with household waste (center)

The sorting process is carried out in two steps, as it is usual in practice. First, the material is compacted, i.e. all marked packaging is blown out (focus: quantity), and then all non-marked objects remaining in this stream are separated during the so-called cleaning process (focus: quality). After all the packaging material had been sorted under industry-typical conditions (conveyor belt occupancy: 30%, belt speed: 4.5 m/s, throughput: 1.4 t/h), the corresponding sorting performance was evaluated.
Over the entire sorting trial, a **purity of 97.4%** of the sorted PE food packaging fraction was achieved, while a **material efficiency of 90.2%** was maintained (material efficiency indicates the percentage of packaging entering the sorting process that ultimately appears in the corresponding sorted fraction). Regarding the material analysis of the sorted fraction, it became clear that the contaminants were predominantly black films (mainly agricultural films), some of which were the size of a man (see Fig. 6). These occurred due to the incorrect ejection of overlapping objects, as well as the failure to detect carbon-black colored materials in the NIR sorter. The occurrence of these contaminations can be overcome by SORT4CIRCLE®, as object overlapping can be practically excluded by the initial singulation and the detection of black objects is made possible by the combined detector including color detection. Thus, > 99 % purity of the sorted fractions is possible with SORT4CIRCLE®.

Fig. 6: Sorted fractions (left) and analyzed impurities (right) with a high proportion of black man-sized foils

4 POSSIBLE USE OF SORT4CIRCLE® AND TRACER TECHNOLOGIES IN PRACTICE

Basically, SORT4CIRCLE® transforms conventional stepwise sorting with pneumatic NIR sorters into a single-step, technology-open sorting process with a wide range of technical and economic advantages, especially if more than just a few, single-digit fractions are to be sorted. Accordingly, SORT4CIRCLE® is a sorting technology specifically intended **for new sorting facilities or for upgrading conventional sorting facilities**.

If a sorting infrastructure already exists, SORT4CIRCLE® can be used to **re-sort pre-sorted polymer fractions** to both increase the purity of the main polymer fractions and to differentiate further fractions by color, tracer, AI, opt. watermark. Furthermore, SORT4CIRCLE® can not only be used by operators of sorting plants, but also as a pre-sorting unit at the recycler to precisely sort the input streams for their recycling processes and thus produce high-quality, specified recyclates.
In addition, to provide tracer detection for existing NIR sorters in operation, Polysecure has developed the **TBS-light** technology, which was used in the sorting trials described in Section 3.4. It involves the integration of a low-cost laser-based excitation optic (~10k euros per meter bandwidth) into existing NIR sorters enabling them to detect tracers. Cost-intensive new cameras, more computing power or strong light or excitation fields are thus not required.

5 SUMMARY AND OUTLOOK

The aim of the new sorting process SORT4CIRCLE® from Polysecure is to raise the sorting of plastics and other materials to a new level of precision, purity and efficiency. This is a central building-block to better exploit the previously untapped recycling potential of plastics in particular. With the single-step sorting and combined detection (NIR, color, tracer, image (AI), opt. further detection technologies (e.g. digital watermarks)) envisaged in this process, both the quantity and quality of the sorted fractions can be optimized. This means:

- Through singulation, combined detection, tracer technology and single-step sorting, much **more waste can be sorted more purely (e.g., for packaging: 80% of plastics instead of 40% today with >99% purity of sorted fractions instead of ~90% on average today) into those fractions that the circular economy really needs to realize CO_2-efficiently higher recycling rates**: e.g., food, cosmetic and detergent packaging can be differentiated, packaging films can be sorted, and impurities can be separated. In this way, pure, specified input streams can be generated for subsequent mechanical, solvent-based or chemical recycling. At the same time, current calculations show that SORT4CIRCLE® is economical compared to existing multi-step NIR sorting systems, in addition to its higher sorting quality and functionality.
- The simultaneous use of different detection technologies creates, for the first time, a **technology-open sorting system** into which new sorting features can be introduced without having to laboriously establish a new technology standard. Furthermore, operators of sorting plants can make future-proof decisions. As a result, the innovation backlog can be eliminated more quickly.
- With SORT4CIRCLE® and tracers, **packaging from individual brands** and **"problematic" objects** such as the increasing amount of paper-based packaging or fiber-reinforced polymers in industry can be separated and sorted in a targeted and reliable manner.
- SORT4CIRCLE® is **scalable** and **economical**, especially for multiple fractions. In a stepwise sorting process, a new sorting stage must be set up for each additional fraction. On the other hand, with SORT4CIRCLE® additional fractions can be flexibly added at low additional cost. This modularity combined with the technology-openness underlines the adaptability of the SORT4CIRLCE® plant principle to corresponding market and technology dynamics, which results in the future proofness of the plant investment.

As a result, SORT4CIRCLE® is a sorting process that can meet the requirements of a true circular economy and can be established as a standard application in the high-quality sorting of recyclable materials of all kinds.

REFERENCES

Agora. (2021). Europe's missing plastics. https://static.agora-energiewende.de/fileadmin/Partnerpublikationen/2021/Material_Economics_Europes_Missing_Plastics/Material_Economics_Europes_Missing_Plastics.pdf

European Commission. (2018). A European Strategy for Plastics in a Circular Economy.

Gasde, J. et al. (2021). Plastics Recycling with Tracer-Based-Sorting: Challenges of a Potential Radical Technology. Sustainability, 13(1), 258.

LAGA. (2021). Kennzeichnung / Identifizierung von Kunststoffen. https://www.laga-online.de/documents/kik_bericht_18_1591617236.-v_06022020f.pdf

Neubauer, C., et al. (2021). Sortierung und Recycling von Kunststoffabfällen in Österreich: Status 2019. https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0744_hauptteil.pdf

Plastics Europe. (2022). The Circular Economy for Plastics. https://plasticseurope.org/wp-content/uploads/2022/06/PlasticsEurope-CircularityReport-2022_2804-Light.pdf

Schmidt, J., et al. (2021). Challenges and Solutions for Plastic Packaging in a Circular Economy. Chemie Ingenieure Technik, 93(11), pp. 1751-1762.

SRU. (2020). Für eine entschlossene Umweltpolitik in Deutschland und Europa. https://www.umweltrat.de/SharedDocs/Downloads/DE/01_Umweltgutachten/2016_2020/2020_Umweltgutachten_Kurzfassung.pdf?__blob=publicationFile&v=2

Wilts, H., et al. . (2016). Entwicklung von Instrumenten und Maßnahmen zur Steigerung des Einsatzes von Sekundärrohstoffen. https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/texte_65_2016_steigerung_einsatz_sekundaerrohstoffe.pdf

Woidasky, J., et al. (2018). Tracer Based Sorting - Innovative Sorting Options for Post Consumer Products. Recycling & Waste Processing, pp. 105-110.