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Research Paper

Design for recycling

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Abstract: Design for Recycling (DfR) guidelines provide technical criteria to ensure products and packaging can be effectively collected, sorted, and processed into high-quality raw materials at their end-of-life. Core Principles of Design for Recycling
Material Selection: Prioritize mono-materials (single polymer types like PE, PP, or PET). Avoid mixing incompatible plastics or using multi-layer films that are difficult to separate.
Color Optimization: Transparent or unpigmented materials are highly preferred as they have the highest market value and versatility for reuse. Dark or carbon-black pigments should be avoided as they are often undetectable by infrared sorting machines.
Simple Disassembly: Design components like caps, lids, and labels to be easily and completely removable. Use "tear-off" facilities for plastic facings on paper-based products.
Label and Adhesive Compatibility: Use labels made of the same material as the main body or water-soluble adhesives that wash off easily during the recycling process.
Minimize Contaminants: Avoid additives that alter material density (e.g., glass fibers or heavy fillers) or non-recyclable components like PVC, vulcanized rubber, and complex electronics.

Keywords: Material, Colour Optimization, Disassembly, Contamination, Recyclability.

Abbreviations: Design for Recycling (DfR)

Introduction:

Most of the national and international guidelines and standards aimed towards increasing recyclability of plastic-containing products are focused on packaging. This is partly because a major part of the plastic used each year (around 40 percent) in Europe is used to produce packaging and partly because there

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is law-enforced extended producer responsibility for packaging and packaging waste in the EU since the early 1990s

Another explanation is also the fact that relatively clean plastic material (not including hazardous or potentially dangerous additives) is being used in packaging compared to other plastic-containing products because much of the plastic packaging comes in direct contact with food and consumer products. This makes the recycled plastic originating from plastic packaging moreappealing to use in different products compared to recycled plastic originating from for example electronics or construction products. Design for Recycling (DfR), independent of sector or material, lacks explanations and definitions. Designing a product for recycling not only needs to mirror the criteria and demands for the product functionality. There is also a need of knowledge where the discarded product will end up, what sorting it will go through, what recycling technology will be applied and what next life product is foreseen for the material as a recyclate (recycled plastic material). DfR needs also to take into consideration the recycled content during the design phase of the product. Few product manufacturers or designers have the whole picture, nor control, over the infrastructure a product will go through before its end of life. This becomes obvious when mapping existing DfR guidelines, primarily in Europe, where the vast majority concerns plastic packaging.

The large number of varieties of DfR guidelines is indicative of the fact that there is no consensus on criteria. There are many local varieties of DfR guidelines, and it is not completely clear if the varieties are based on actual existing criteria for high quality recycling or if they are based on input given from brand owners/converters of already existing packaging. DfR guidelines for packaging in Europe have been driven by the legislative demands in the Packaging and Packaging Waste Directive, that has been in force since 1994. The large number of DfR guidelines for packaging is driven by the existing Extended Producers Responsibility (EPR) demand in the legislation, and as every Member State had the freedom to implement this legislation according to their individual interpretation, the number of DfR guidelines is accordingly.

Another complexity in DfR is the question of available recycling technologies and how the infrastructure supports the new processes, dependent on availability. As it is normally unknown what path a plastic product may take, DfR needs to be technology neutral, meaning that criteria set in the guideline need to be adequate to all available technologies. Specific technologies cannot be considered if not fully available on the market, for example de-inking, hot water washing, exclusion of certain additives or material mixes.

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The knowledge on design for recycling varies significantly between different sectors as well as between companies within the same sector. A large challenge seems to be related to communication and coordination across the supply chain. In many cases customers or suppliers do not know which effect the choice of material has on the recyclability of the product at the end of a life management of the product.

Another related issue is the motivation to design for recycling, where understanding of the value created by making the products more recyclable is lacking.

This is due to the fragmented market for recycling and the unclear routes for generated plastic waste flows. Also, the consumers are often challenged when considering proper waste handling due to low recycling rates of the materials or examples when even sorted waste gets mixed by operators during waste management Using recycled plastics instead of new raw materials is also often not prioritized because of the assumption by many stakeholders that the quality of the recycled material does not fulfil the requirements as well as the new raw material can.

Furthermore, difference in price between using new and recycled plastic, recycled being more expensive, is still the dominating issue for many companies and ultimately not many are willing to compromise on this matter.

Main challenges identified

• The plastic parts contain too many additives such as pigments and plasticisers without any possible traceability of the content.

• Problems with impurity either because of polymers blended with other polymers, composite materials or for example labels composed of different materials, such as paper, that are impossible to completely remove by washing. Paper labels are often glued with adhesives that are difficult to remove. Therefore, paper fibres are often still present to some extent in the recycled material. This can cause the material to degrade quicker and thus reduce the quality of new products containing recycled plastics.

• There is no mandatory system for labelling for many components to facilitate sorting for cleaner fractions.

• When it comes to complex assembled products, such as vehicles or electronics, high costs are associated with spending time on disassembling all the parts for recycling if these are not easily removed. It is too costly compared to what the recycled plastic is worth.

• There are insufficient volumes of homogeneous material, due to vast number of different types of plastics used in the design of the products, which also limits the possibility of effective recycling.

• PVC is sometimes mixed with olefins in certain products (for example electrical cables). This means that reasonably large volumes

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of polyolefins, which could be recycled, are not recycled because of the presence of PVC as a contaminant.

• It is very challenging to obtain a post-consumer recycled plastic which is clean enough for use in a wide range of new products. Problems could arise, for example, in relation to the purity requirements for food contact and traceability.

• There is not enough demand for design for recycling, the recycled plastic is not considered a valuable material on the market which limits the profitability of the recycled material.

Increased resource efficiency in products: Design products with minimum amount of material without compromising the function of the product. Avoid unnecessary use of materials. Increase resource efficiency in the supply chain:

Design products to enable transport efficiency. For example, products that can be stackable in an efficient way to optimize transportation. High amounts of additives and lack of material traceability Reduced number of additives:

Design plastic products with a focus on reducing the use of additives such as pigments and plasticizers. This not only simplifies recycling but also minimizes the potential negative impact on human health and the environment. Increased traceability and transparency in the value chain: Implement a traceability system that provides information about the composition of plastic used in the product. For example, QR codes, watermarks, or RFID tags can be used to identify plastic types and additives, making proper recycling easier.

Difficulty in disassembly and sorting of different materials which are part of the same product User-friendly disassembly: Design products with userfriendly disassembly instructions or mechanisms to encourage consumers to separate and clean plastic components before disposal.

Visible labelling: Incorporate visible labelling and standardise codes or symbols for identification that can be used for automatic sorting at recycling facilities. High variety of plastics on the market Prioritize the use of common plastics: use common plastic materials (such as PE (HDPE, LDPE) and PP) in products to increase the volume of homogeneous material for recycling, improving profitability

Figure: 1. Showing off sustsinability

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Promote the use of recycled plastic:

Prioritize the use of recycled plastic in products to drive the demand and improve the market conditions for recycled plastic.

Advocate for regulations or industry standards that require a minimum percentage of recycled plastic in new products.

Educate the entire value chain, especially manufacturers:

Create awareness among product manufacturers about the benefits of recycled plastic and its suitability for various applications.

Consider design points such as colour: Often recycled plastic may have varying pigmentation, but this does not affect the quality of the material.

Figure: 2. Designing products and packaging with recyclability in mind involves careful consideration of materials, design complexity, and labeling. By focusing on single-material construction, minimizing complex shapes, and using clear, easily removable labels, designers can significantly improve the recyclability of the product