SUSTAINABLE PACKAGING
IN A CIRCULAR ECONOMY

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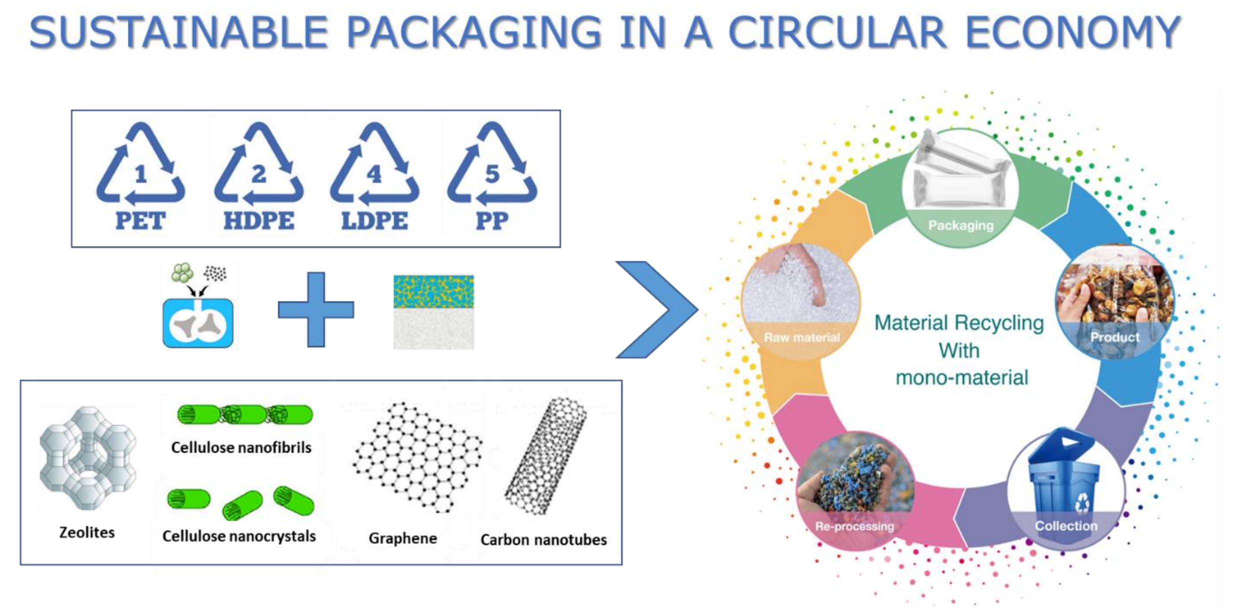
Nowadays, almost 40% of the entire polymer production is destined for the packaging sector, with around 60% of polymeric packaging being used for food and beverage. The dominant market share in the packaging sector, growing year by year, is held by commodity fossil-based thermoplastic polymers, mainly polyolefins. Polyethylene (PE) is a polyolefin that stands as the most employed polymer in packaging applications (about 50% of the total packaging polymeric production), notably in the form of flexible films for food packaging. PE, according to the different structure, can be classified in high density polyethylene (HDPE), low density polyethylene (LDPE), and linear low-density polyethylene (LLDPE). HDPE exhibits higher crystallinity, greatly improved barrier properties and chemical resistance, a higher melting point, and greater tensile strength when compared to LDPE. On the other hand, LDPE is softer, more flexible, and stretchable, featuring good clarity and heat sealability properties. LLDPE offers similar clarity and heat sealability as LDPE, combined with the strength and toughness characteristic of HDPE. Polypropylene (PP) is the second most used polymer for packaging. It is a less flexible polyolefin with lower density than PE, with remarkable resistance to high temperatures, strong chemical inertness, very high barrier properties, and good impact resistance. PP finds wide applications in flexible packaging for food products such as baked goods, as well as in the cosmetic industry. Polyethylene terephthalate (PET) is a thermoplastic polyester condensation polymer, unlike polyolefins. PET is the third most used polymer in the packaging sector, primarily to produce bottles for beverages. It can be semi-rigid to rigid, mechanically resistant to impacts, stretchable during processing, highly inert, and exhibits excellent oxygen barrier properties with a relatively low moisture barrier compared to LPDE and PP.

It is worth noting that around 50% of total polymeric waste is accountable to packaging applications: this is due to the short lifetime of these commodity products. Furthermore, petroleum-based/non-biodegradable packaging polymers (such as PE and PP), due to their extensive usage, can lead to environmental concerns when their end-of-life comes. As of 2020, 46% of post-consumer polymer packaging waste in the EU27+3 was recycled (in Italy, 49% was recycled). Polymer waste recycling can be mechanical or chemical. However, the latter generally provides, for the main packaging polymers, low yields at high costs. Mechanical recycling does not have these same limits. Potentially, most packaging polymers can be conveniently mechanically recycled to obtain new products. However, in the recycling chain, a crucial issue is the sufficient purity (>80%) of a target polymer to be separated in its specific flux, as the purity/quality of the polymer recycled from this flux may not be high enough to grant performances comparable to those of virgin material. Efficient detectors, washing operation, and flotation separation are important steps in the waste management chain to minimize contaminants; however, the packaging design plays a key role. For example, multi-material aseptic packages made of paper, PE, and aluminum are highly difficult to recycle. In this perspective, the development of recyclable packaging materials based on a ‘mono-material’ concept represents, therefore, a sustainable choice.

Starting from neat polymers, it is a common route to enhance their technological properties and functionalize them. The two different ways to modify polymers are: adding fillers/additives to the bulk neat matrix; adding a properly functionalized nanocomposite coating to the polymer substrate. Glass or clay fillers, plasticizers, flame retardants, antioxidants, stabilizers, pigments are commonly used nowadays, but the research is moving on innovative solutions. These include zeolites (also cation-exchanged), nanocarbon derivatives (such as graphene, graphene oxide, and carbon nanotubes), and (nano-)cellulose, which can provide outstanding properties such as antimicrobial activity, better mechanical and thermal performances, enhanced gas barrier properties, thermal conductibility. In terms of sustainability and circularity, interesting solutions may also be provided by wastes from vegetal or animal biomasses and wastes deriving from textiles or wood industries (which strongly contribute to Italian GDP).

However, concerning waste recycling management, functional coatings may in some cases alter the correct reading of the preliminary IR detectors, thus not allowing recognition of the target materials on which they are applied. Also, high concentrations of fillers/additives may not be correctly separated from the chopped polymer and may significantly vary the polymer density during flotation separation. Therefore, there is a need to examine the proper methods and formulations of useful and convenient fillers/additives to achieve certain technological enhancements over a neat recyclable polymer. Then, this research aims to study recyclable smart, functionalized, nanostructured, and sustainable multi-graded ‘mono-material’ packaging solutions, with proper barrier properties and efficient sealing, by further understanding the functional-structural-processing relationships.



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