Towards a fully circular plastics economy

Plastics play an important role in our economy and our society in general. However, the treatment of plastic waste still has many flaws. Most of the material still ends up being incinerated, landfilled or worse. Therefore, there is a need for plastics producers to take more responsibility for what happens to their products after use.

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Plastics played an essential role in the industrial development of the last century. Thanks to their versatility as thermoplastic or thermoset materials, their solid functionality and their strong price-performance ratio, plastics can be found in almost any market. Despite the fact that the production of plastics in total uses about 7-8 per cent of fossil-based feedstock, they have significantly contributed to energy savings as well through the generation of lighter construction materials, lower transportation costs, etc. Nevertheless, their efficacy in the eyes of the general public is shrinking fast due to the fact that a significant proportion of plastic applications are single-use and only a small portion from a global perspective is currently recycled (<15%), whereas the majority is still landfilled, polluting our oceans or at best being incinerated as waste.

The time has come for plastics producers and end users not only to focus on the end-use application but also on the reuse or recycling of plastic items. Various industry-driven initiatives representing the full value chain have been started (CEFLEX, Alliance to End Plastic Waste, PCEP, Circular Plastics Alliance, The Plastics Economy part of the Ellen MacArthur Foundation), but so far none have taken a collaborative technical and technological problem-solving approach to accomplishing a fully circular plastics economy.

A first step in reaching a fully circular plastics economy is to establish a reliable system of post-consumer waste collection. Some Western European countries such as The Netherlands and Germany have a

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good system in place, but in large parts of the world this is either non-existent or faulty. In Europe, the CEFLEX consortium is encouraging governments to put post-consumer waste collection in place through the implementation of Extended Producer Responsibility (EPR) schemes. This way, the cost of collection is already included in the retail price of single-use packaging, which can be used to set up collection systems.

In countries where good collection systems are in place, a large part of the post-consumer plastic waste is still being incinerated because either sorting capacity is too low or the material does not provide the quality for recyclates to be used in existing applications.

Sorting technologies will have to improve, both in quality and output. The technologies currently in use, such as NIR (near infrared), X-ray, cameras, flotation and manual sorting, are not able to separate out certain kinds of plastic or lack the required accuracy. However, artificial intelligence (AI) could provide the solution here and is being developed by several technology providers and waste collectors. Various sorting technology providers, such as Tomra and Sesotec, but also collectors such as SUEZ and Veolia, are active in this field. Laser-aided identification (LIBS) is another technology already described in the late ‘90s. Although there has not yet been a commercial breakthrough of this technology, it could be very effective in combination with AI.

Apart from analysis techniques, watermarking and UV tracers are also being developed. A watermark is then linked to a certain type of packaging and a watermark sorter is able to effectively sort the various types of packaging based on their watermark. The same principle can be applied for UV tracers, although watermarks seem able to provide more information.

Finally, brand owners can facilitate the sorting process by promoting recyclability through single-use packaging concepts brought forward by Design for Recycling. Several large brand owners have pledged to make all their packaging recyclable or reusable by 2025. CEFLEX has published a DFR (Design for Recycling) guideline, which is, however, still awaiting implementation.

Currently we are dealing with highly sophisticated and effective multi-layered packaging systems consisting of different types of polymers and metals, which makes them unfit for reuse in mechanical recycling. Delamination would be the Holy Grail, although it is still far from application as current systems are designed not to delaminate. Technologies such as the reversible cross-linking of layers or pressure-sensitive adhesion (non-reactive adhesion) may provide a solution here. Multi-layer systems consisting of two polymers and a metal layer (PE-PA-AlOx system) could be separated by dissolution, as claimed by APK.

A broad consensus among polymer producers and end users, however, advances the concept of mono-polymer layered systems. With the general agreement that small amounts of EvOH (<5%) as an oxygen barrier are acceptable for recycling, whilst the use of biaxial-oriented films supports better barrier functionality, new single-use packaging concepts are on their way to application.

The redesign of packaging additives and colorants, which are applied in all types of plastics, also includes a major disturbing factor. In order to implement reuse or mechanical recycling it is important to know the full specification of the plastics, including the various additives present in them. Colorant remnants will hamper their application towards implementing new, colourful applications. Consequently, grey or brown (similar to recycled paper) might become the typical colour for recyclates.

The EU is firm in its goal to have the full recycling of all plastics in place by 2050. As the market for recycled plastics develops over the years, various (technology) scenarios will become effective. Both mechanical and chemical recycling will have an inter-connective role to play.

As already indicated, additives and colorants are detrimental to mechanical recycling. Various companies are attempting to separate these unwanted substances by means of polymer dissolution technologies, but for successful implementation more insight is needed into how additives and colorants can be adjusted to make efficient separation possible and which processing techniques would be effective (e.g. dissolution using food grade-accepted solvents).

Another important aspect related to mechanical recycling is the control over or removal of unwanted odours. This is particularly true for polyolefins, globally the largest polymer category in terms of volume, which easily absorb odorous substances. Due to the degradation of plastics over the lifetime of the product, (chemical or microbial) contamination over the product lifetime and/or the scission of polymer chains during reprocessing, unwanted odours can occur. Effective washing, oxidising the typical odour sources to remove the scent, using specific fragrances to mask the odour (not applicable for food packaging) and/or the use of acid scavengers to reduce odour from acids are all thinkable solutions.

The mechanical recycling of plastics is further hampered by the fact that, in general, the blending of two different polymers

Source: E. Zillner

does not lead to favourable outcomes. It would be a huge win if recyclates of different plastics could be blended into a stable plastic without a loss of performance. To achieve this, compatibilizers can be used. These are functionalised polymers that enable different polymers to make a stable chemical connection. Companies such as Dow, Borealis, Clariant and Bedeko have an ample understanding of the principles of polymer blending and are active in promoting their products and principles in the market for recycled plastics.

Plastic producers have to focus on reuse and recycling of plastic items

Given the developments pointed out above, further standardisation of recycled plastic grades will be important and industry will have to take the lead at European level to make this possible. For the same reason, more accurate (full-spectrum) identification and characterisation are needed. Academia, for instance with LIBS, can play a supportive role here.

Whereas mechanical recycling is already widely applied on an industrial scale, chemical recycling is not yet commonly accepted. As mechanical recycling inevitably results in polymer downgrading at each consecutive process step, chemical recycling is, in principle, a means of escaping from this through the regeneration of monomers as new building blocks, allowing virgin polymer to be recreated. The technology of and logistics around chemical recycling, however, need to mature further to do this in an economically viable manner.

Solvolysis, i.e. the technique for dissolving and purifying thermoplastics, has been known for decades, but applying it on an industrial scale raises some questions and limitations. Solvolysis is a polymer-specific technique. Its effectiveness in recovering the polymer depends on the type of solvent, the contaminants present, the various operations needed, the amount of heat and the speed of mixing required. Limitations will also be dictated by the intended application for the regenerated polymer (i.e. food, cosmetics, medical applications, etc.). Several start-up companies are elaborating on solvolysis, e.g. PP (PureCycle), PS (Polystyvert) or PP/PE (APK). Specific and effective separation technologies will be needed to extend these options and enable economically viable processes.

Depolymerisation, i.e. applying hydrolysis or glycolysis to obtain monomers, is a typical process that can be applied to polycondensates such as PET and PA. This is a well-established and thoroughly researched technology that various companies are currently leveraging. However, the full chemical recycling of PET from bottles will only become cost-efficient when more than 50,000 tonnes per year are processed. Because of the difficulty of consistently and continuously sourcing waste bottles in such huge amounts at one single site, and the steadily increasing prices as well as the price volatility of collected bottles, commercial implementation of this technique on an industrial scale has not yet been realised.

Pyrolysis, i.e. thermal decomposition in the absence of oxygen at temperatures ranging from 200 to 800°C, seems to be another promising technique for the chemical recycling of plastics. This can be achieved by using various process conditions. Conventional processing requires temperatures of around 600-650°C (main product: pyrolysis oil) or ultra-gasification at 1,000°C (main product: gases). Which of these conditions should be applied depends on the feedstock and the required output, although a better understanding is needed to make this technology economically viable. One known application is the production of pyrolysis oil, which could act either as a replacement for or as a co-feed to naphtha from fossil resources and is interesting for plastic producers that have naphtha crackers on site, from which they can obtain C2-C5 carbohydrates.

Gasification, which is done within a higher temperature range from 500-1,600°C with little oxygen present and some steam, is a well-known process that produces syngas ($CO + H_2$), which can be used to make methanol, a starting point for conversion to several monomers as the building blocks for all kinds of polymers. As it is complex and expensive, gasification can only be applied economically on a very large scale (>300kT/y) and should therefore only be performed at large industrial complexes. The gasification of plastic waste mixtures has not yet been widely applied, so there are still many open questions regarding the typical process conditions and output variables. Moreover, the large volumes involved pose major logistical challenges.

DPI, The Polymer Research Platform, and ISPT (Institute for Sustainable Process Technology) are both public-private partnerships between companies and universities. They are cooperating to set up a value chain programme on plastics recycling. In this programme, brand owners, collectors, sorters, equipment and technology providers as well as polymer producers are looking into the question of how to move from a linear to a circular plastics economy aimed at resolving the technological issues connected with the material- and process-related aspects of mechanical and chemical recycling.

Many of the aspects and processes described in this article will be addressed in this programme. Further information regarding the setting up of this programme and possibilities to join this initiative may be obtained through Ronald Korstanje (r.korstanje@polymers.nl).