New Technologies are Needed to Improve the Recycling/Upcycling of Waste Plastics

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Modern society has become critically dependent on high-performance/low-cost plastics that support our lifestyles. These plastics are ubiquitous in everyday items, such as bags, plates, food packaging, state-of-the-art electronics, transportation, construction and many others. Over the past decades, increasing scientific data has emerged on challenges related to the fate of plastic components at the end of their useful lives.[1,2,3,4] Along with the leakage of plastic components into eco-systems, the presence of micro-plastic particles in ocean and terrestrial food systems has heightened public concern. The widespread of plastic particles waste was originally documented in the western Sargasso Sea back to 1972.[5] News and documentaries , such as "Plastic Paradise: The Great Pacific Garbage Patch" and "Researcher discovers microplastics in Bay of Fundy clams | CBC News", have driven public demand for solutions to these problems.[6] It has been estimated that if current global plastic disposal practices continue, by 2050 there will be more plastics than fish (by weight) in the ocean.[7] Moreover, "The New Plastics Economy Catalysing Action", published by the Ellen Macarthur Foundation (2017), states that plastic packaging represents 26% of all plastics generated, but that despite 40 years of concerted recycling efforts, only 14% of this material is currently recycled.[8] Furthermore, in the US only, approximately around 8% of plastics are currently recycled.[9] In China, 80.9 million tons of all plastics are currently consumed, and only 30% of which are recycled.[10] In 2016, 27.1 Mt post-consumer plastics waste was collected in Europe, with 27.3% ended up in landfill, 41.6% to energy recovery, and 31.1% to recycling (63% inside EU and 37% outside EU).[11]

There are several reasons for low plastic recycling rates; a primary reason is the lack of technologies that can efficiently recycle plastic materials of diverse compositions. This diversity of composition is due to plastics' diverse chemical structures, which means that necessitating different strategies for recycling process for each type of plastic. Polyethylene terephthalate (PET; denoted with the recycle No. 1 code) is the most commonly recycled plastic (e.g., 20% and 58% of PET in the US and EU is recycled), and this is typically done by mechanical means: PET is ground into flakes, cleaned, and re-extruded to make recycled PET (r-PET) flakes or pellets for resale. As the molecular weight of r-PET is decreased by this grinding and re-extrusion process, often r-PET must be blended with virgin PET to afford a product that has suitable properties for a desired end-use. Moreover, although the mechanical recycling of PET works well for bottles made of PET, it does not work well for PET used in clam shell packaging or in clothing fiber. High-density polyethylene (HDPE; denoted with recycle No. 2 code) is the second most commonly recycled plastic (e.g., 10% and 10-15% of HDPE in the US and EU is recycled). The mechanical recycling of HDPE is similar to PET recycling, but it requires more rigorous devolatilization of food odors and other contaminants. However, only a small quantity of food-grade r-HDPE is currently marketed.

Alternatively, several companies burn waste plastics to generate heat and electricity, which recovers energy but does not constitute recycling. Other companies down-cycle mixed plastic streams into construction materials or asphalt, and claim that this is “recycling.” However, true plastic recycling enables an end-user to use a recycled plastic in the same application as the virgin plastics. Currently, there is no technology capable of recycling/upcycling plastic films into virgin plastic pellets. Furthermore, low-density polyethylene (LDPE, #4), polyvinyl chloride (PVC; #3), polypropylene (PP, #5), polystyrene (PS, #6), and multi-layer plastic materials (#7) are not recycled, because the technology to recycle them does not exist, or is too expensive. Other commonly available plastics found in waste streams include nylon, polycarbonate, and polylactic acid.

Another critical challenge to the recycling/upcycling of plastics is the removal of contaminants/ additives acquired during plastic processing (e.g., colorants, antioxidants, plasticizers, foils, and paper) or from plastic packaging contents, such as those introduced by consumers (e.g., sugars and other foods). Dealing with plastic waste is a dirty business! In addition, plastics have a very low density, thus are difficult to collect and sort. Although efforts are underway to re-engineer packaging materials to mitigate some of these problems, even the most optimistic estimates predict that at least 50% of plastic waste streams will not be economically viable for recycling.

The problem described above show that society must develop economic approaches for the recycling/upcycling of multiple plastic materials to the proliferation of plastic wastes. This special issue highlights recent advances in the field of waste-plastic upcycling, and explores the evolution of this field from a niche research area to a burgeoning mainstream research topic within the concept of the Circular Economy. The processing of waste plastic resource calls for a multidisciplinary approach involving innovative depolymerization chemistry, advances in catalyst science, novel biotechnology and, analytical characterization capabilities, new approaches to separation science and waste management, and full economic analyses, and lifecycle assessments. All of these topics will be featured in this special issue.

In closing, the guest editors would like to acknowledge all the authors, reviewers, and the editorial team of ChemSusChem, whose timely efforts made it possible to produce this special issue. We

hope these advances will seed further developments toward the upcycling and valorization of plastic waste.

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