Challenges and opportunities in the chemical recycling processes of plastic waste

Emelin J. Luna Barrios[1,2], Steven De Meester [1], Haritz Sardon[2]

[1]Department of Green Chemistry and Technology, Ghent University, Graaf Karel De Goedelaan 5, Kortrijk, 8500, Belgium

[2] Department of Polymers and Advanced Materials: Physics, Chemistry and Technology, University of the Basque Country UPV/EHU, Paseo Manuel de Lardizabal 3, Donostia-San Sebastián, 20018, Spain
Keywords: Recycling, Depolymerization, Waste, Process intensification, Glycolysis, purification
Presenting author email: Emelinyhoany.lunabarrios@UGent.be

The commercial success of the different varieties of plastic material available in the market has derived in the exponential increase of the amount of plastic waste generated worldwide, from which up to 359 million tons were reported by 2018 (Eurostat, 2021). Among the recycling strategies proposed as sustainable solutions to handle this global plastic challenge, the chemical depolymerization is especially attractive when waste streams can not be recycled by mechanical methods due to economic, technical or environmental constrains (Thiounn & Smith, 2020). Moreover, through this approach the original monomers can be recovered with virgin-like properties or new, high-quality products can be synthesized (upcycling); avoiding material downcycling, preserving waste material market value and implementing the circular economy concept into the material life cycle (Jehanno et al., 2019; Payne & Jones, 2021). However, the industrial scaling up of the most relevant chemical recycling pathways named glycolysis, hydrolysis (acid, alkaline, neutral, enzymatic), methanolysis, aminolysis and ammonolysis is strongly affected by factors like physical properties and composition of the waste stream, logistics (collection and transportation costs) as well as the final use of the material before disposal. In addition, operational drawbacks such as the use of organometallic catalysts, the generation of corrosive or toxic waste streams, low energetic efficiency, long batch cycle times as well as high product purification cost limit the commercial implementation of these recycling processes (Glavič et al., 2021). Although these problems are challenging, the implementation of process intensification principles as well as the use of chemical process design tools (e.g., modeling and simulation software, techno-economic analysis, sustainability analysis, etc.), contribute to the development of more efficient and competitive chemical recycling processes and in the improvement of the existing ones (Figure 1).

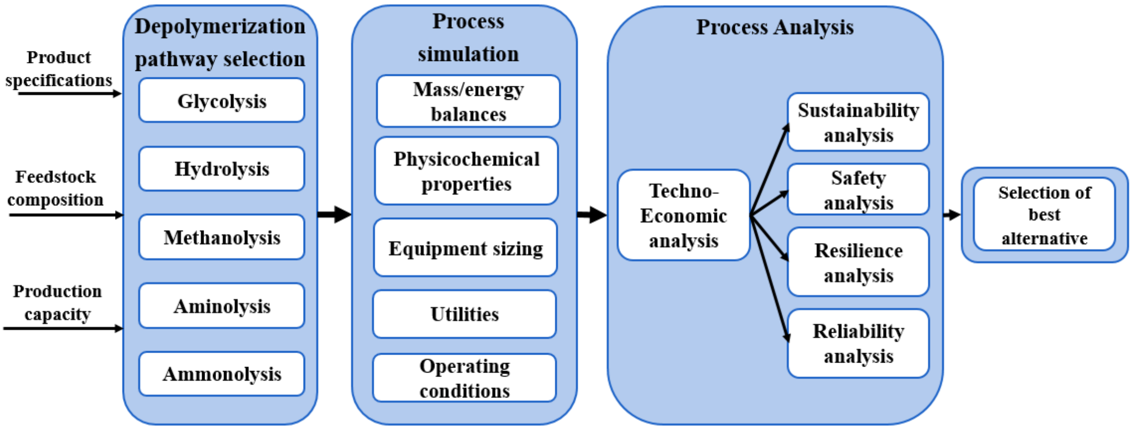

Figure 1. Schematic representation of the chemical process design tools implemented to the chemical recycling process design. Adapted from Moreno-Sander et al. (Moreno-Sader et al., 2019)

In this review, the objective was to highlight the current challenges and opportunities in the chemical recycling processes of four commercial polymers, namely poly (ethylene terephthalate) (PET), poly(lactic acid) (PLA), Polyurethanes (PUR), and Polyamides (PA) were explored presenteddiscussed. Patent database Espacenet and the Google Patents search engine were consulted besides engineering magazine articles, scientific papers, book chapters and review articles registered in the Scopus® Database; excluding other publications, such as editorial materials and letters. The chemical recycling pathways followed in the depolymerization of PET, PLA, PURs, and PAs were used as keywords and the initial search was limited to the most cited publications published in between 1994 and 2021. From the first screening, it was observed that glycolysis is the most discussed depolymerization method (Figure 2.), detectedbeing the design of more active and selective catalyst, the use of more efficient heat sources for the chemical reaction, purification strategies of the monomers recovered) are highlighted and the simulation, analysis and optimization of the glycolysis process the most explored topics. Afterwards, the approaches considered to overcome some case studies of the successful application of the chemical process design strategies as well as the process intensification principles to some of the depolymerization pathways already mentioned will be discussed some of the best practices will be presented in this field. For instance, McKay performed the comparative life of the flexible PUR foam glycolysis process against the incineration of the same type of waste through the GaBi LCA software, finding the chemical recycling had a lower environmental impact than the incineration (Mckay, 2018). In addition, Ügdüler et al. carried out the analysis of the purification of Na2-TPA recovered from the hydrolysis of colored PET plates with or without the addition of excess of water in Aspen Plus 10 as well as the Life Cycle Analysis (LCA) in OpenLCA (Ügdüler et al., 2020). From this study, it was concluded that by selective filtration and without excess of water, most of the impurities were removed and the process was less energy intensive.

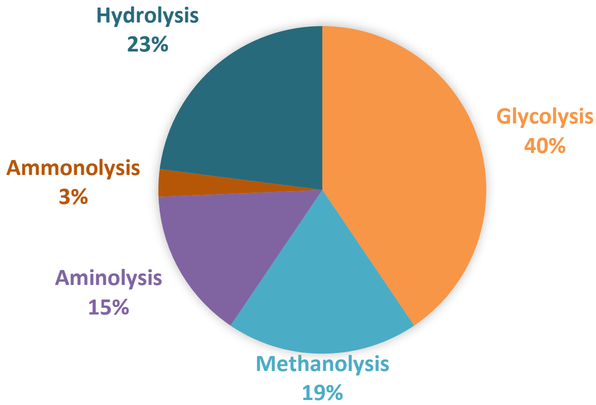

Figure 2. Literature material reported for the depolymerisation methods discussed.

References

Eurostat. (2021). *Plastic waste and recycling in the EU: facts and figures*. https://www.europarl.europa.eu/news/en/headlines/society/20181212STO21610/plastic-waste-and-recycling-in-the-eu-facts-and-figures

Glavič, P., Pintarič, Z. N., & Bogataj, M. (2021). Process design and sustainable development—a european perspective. *Processes*, *9*(1), 1–21. https://doi.org/10.3390/pr9010148

Jehanno, C., Pérez-Madrigal, M. M., Demarteau, J., Sardon, H., & Dove, A. P. (2019). Organocatalysis for depolymerisation. In *Polymer Chemistry* (Vol. 10, Issue 2, pp. 172–186). Royal Society of Chemistry. https://doi.org/10.1039/c8py01284a

Moreno-Sader, K., Jain, P., Tenorio, L. C. B., Mannan, M. S., & El-Halwagi, M. M. (2019). Integrated Approach of Safety, Sustainability, Reliability, and Resilience Analysis via a Return on Investment Metric. *ACS Sustainable Chemistry and Engineering*, *7*(24), 19522–19536. https://doi.org/10.1021/acssuschemeng.9b04608

Payne, J., & Jones, M. D. (2021). The Chemical Recycling of Polyesters for a Circular Plastics Economy: Challenges and Emerging Opportunities. *ChemSusChem*. https://doi.org/10.1002/cssc.202100400

Thiounn, T., & Smith, R. C. (2020). Advances and approaches for chemical recycling of plastic waste. In *Journal of Polymer Science* (Vol. 58, Issue 10, pp. 1347–1364). John Wiley and Sons Inc. https://doi.org/10.1002/pol.20190261