Inventory of alternative end-of-life routes of bio-based products – A Review

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Introduction

The inventory review represents the first stage of the techno-economic sustainability analysis of alternative end–of–life (EOL) routes for bio-based chemicals, added value products and polymers. The scope is to promote the re-manufacturing, reusing and recovering of bio-based by-products and waste streams along the whole chain of their production and use, starting from alternative feedstock sources up to the final post-consumer valorization. The aim is the implementation, in this way, of the basic principles of the circular economy: minimization of waste, efficient and sustainable use of resources. The expected impacts include reduction of public health and environmental pollution problems, preservation of natural resources, reduction of GHG emissions, avoidance of landscape deterioration and littering.

Alternative end-of-life routes for bio-based products

Reuse: Reusing (bio-based) materials / products is the most effective way to reduce waste (EPA, 2017). The impact may be measured in terms of CO_2 emissions and carbon footprint reduction with respect to a single bio-based product life cycle. Exceptions include the targeted biodegradation.

Mechanical recycling: Bio-based plastic waste equivalent to conventional polymers (drop-ins; e.g. bio-PE, bio-PET) can be easily managed through the mechanical recycling streams of the corresponding conventional plastics as they are chemically identical (European Bioplastics, 2015). The possibility to develop mechanical recycling streams and recycling industry specifically dedicated to bio-based products depends on: a) recyclability of a given bio-based product; b) growth of bio-based plastics volumes to the level that their waste management scaling-up and the corresponding investments are economically viable; c) development of new markets for recycled bio-based plastic raw materials.

Chemical or feedstock recycling: Feedstock or chemical recycling describes techniques used for breaking down plastic polymers into their constituent monomers. The recovered monomers can be used in refineries, or bio-refineries, or petrochemical and chemical production.

Aerobic composting: The main condition for the bio-based materials and products to be acceptable for industrial composting is their conformity to the compostability requirements defined by EN 13432. In addition 94/62/EC (European parliament, 1994), PPWD defines essential requirements to be met for organic recycling by biodegradable and compostable packaging.

Anaerobic digestion: Bio-waste from bio-based products that cannot be used as a secondary resource by bio-refineries or recycled may be used, if compostable under anaerobic conditions, as a secondary bio-based products source (soil improvement compounds) and bio-energy (bio-gas) through anaerobic digestion.

Energy recovery – incineration: The potential use of bio-based products waste for energy recovery is considered as an alternative EOL route provided that the options of recirculation, mechanical, chemical, or organic recycling (in order of priority), are not available. However, this is not considered as a preferred option for bio-based products.

Landfilling: This is not an EOL option for biodegradable bio-based products as these products will undergo anaerobic digestion producing the harmful greenhouse gas methane.

Results and discussion

Large numbers of various bio-based plastic products (e.g. bio-PET, bio-PE, PLA and starch) are reused following the required preparation. When not useable anymore, they can follow the EOL routes of the waste management hierarchy described above.

Possible contamination of conventional plastics recycling streams up to 10% by bio-based biodegradable plastics is not expected to introduce any problems to the recycling processing or the quality of the produced recyclate (European Bioplastics, 2015). The question to be investigated is whether the approach of designing conventional food packaging with priority set on the design requirements for enhanced food quality and prolonged shelf life rather than on recyclability, is applicable also to bio-based packaging. The inherent properties of bio-based materials should allow for a more environmental friendly design of the bio-based packaging with emphasis placed on recyclability without compromising the functionality of the product, or even improving its functionality (Mistriotis et al., 2016). Additional coatings, layers and packaging information like labels should be redesigned for bio-based products to be compatible with the recyclability requirements but also compostability requirements of the final product. The mechanical recycling of post-consumer biodegradable bio-based plastics will be possible in the near future as the volumes in the market and their use, especially of PLA and starch based bio-based plastics, increase to the scale that allows for covering the investments required. PLA and other biodegradable bio-based plastics are mechanically recyclable with the same recycling processing and technologies used for conventional plastics, but with adjusted processing parameters.

The advantage of chemical recycling by chemical depolymerization is that the process generates pure value-added products while the disadvantages are that requires high volumes in order to be cost effective and is mainly limited to condensation polymers such as polyesters. Specifically for bio-based products, research work has been performed for chemical recycling of PLA (Gironi et al., 2016, Clark et al., 2016). At the industrial level, NatureWorks© the producer of the Ingeo© PLA resin, describes chemical recycling (also kwon as feedstock recovery) as a process for returning PLA-based products (or waste) back into the chemical monomer (lactic acid) (NatureWorks). At industrial level chemical recycling is used for returning PLA-based products / waste back into the chemical monomer LA by hydrolysis. This is used for PLA resin production.

Bio-based food packaging contaminated by organic residues not accepted for recycling and labelled as compostable under industrial composting conditions cannot be disposed to a home composting bin as it will not biodegrade. If no industrial composting facilities exist in the region compostability of the product is useless. It has been proposed that the separate collection of biodegradable waste across Europe becomes mandatory. To avoid contamination of biowaste streams by non-degradable plastics, or the opposite, to avoid plastic waste streams highly contaminated by organic entering mechanical recycling streams biodegradable, compostable plastic products are used for food packaging and single service food applications.

Concerning chemical recycling, in a two-phase fermentation: a) bio-based materials may be produced by the hydrolysis and acidification phase and b) from the subsequent methanogenic phase of the anaerobic digestion process: biogas and possibly methane along with digestate, from which fertilizer may be produced.

As far as incineration, strong objections are raised to the energy recovery option as it destroys resources, even though it produces renewable energy. Bio-based plastic waste may be used in higher added value routes. Recycling saves raw materials, energy, creates more jobs, it is more profitable, flexible and dynamic.

Landfill is not a desired option, ranking at the bottom of the WFD. Several regulations and directives try to minimize and eventually eliminate this waste treatment practice. Several countries have already banned landfilling of plastic waste, include bio-based plastics. A European-wide ban on landfilling for plastic and bio-based products is proposed. Apart from loss of valuable resources, biodegradable bio-based plastics in landfills can generate methane, contributing to the GHG emissions.

The design of bio-based products should incorporate technical specifications for enabling prioritized alternatives or specific targeted EOL routes, depending on the product applications and functionalities. Additional design requirements are set to prolong their use as resource materials after the end of the product's useful life time through *recirculation*.

Conclusions

One key factor considered in the techno-economic sustainability analysis of alternative end-of-life routes for bio-based products is how the integrated design and engineering of bio-based products starting from the selection of alternative renewable resources and moving to the selection of alternative processing routes and materials can affect its resource efficiency and not just optimal functionality and/or high bio-based content.

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