BACK GROUND
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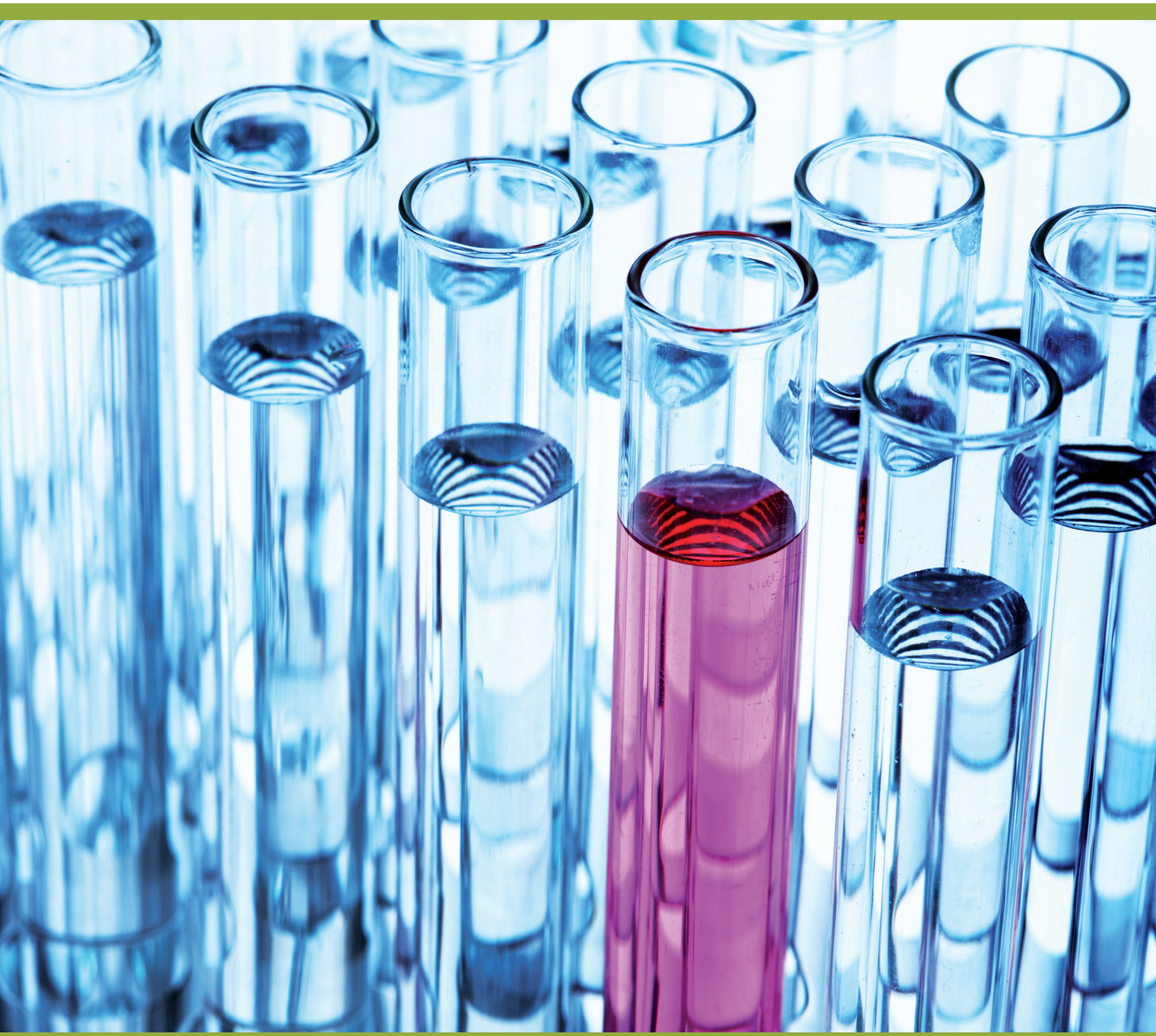
CHEMICAL RECYCLING OF BIO-BASED PLASTICS



ABSTRACT

Chemical recycling has gained increased attention as a promising recovery technology, especially for post-consumer plastic waste. It is seen as a complementary solution to mechanical recycling, being better suited for difficult to recycle plastics like multi-layer solutions or heavily contaminated plastics. Yet, its availability at commercial scale is currently still limited, and a legislative framework at European level still needs to be established.

Chemical recycling also poses a valid end-of-life option for bio-based plastics: By keeping the renewable content in the loop even longer, it promotes a circular bioeconomy and provides high-quality recycled bio-based plastics.

1. DESCRIPTION OF TECHNOLOGY AND CURRENT DISTRIBUTION

The term chemical recycling, also known as feedstock or tertiary recycling, comprises different varying technologies that convert plastic waste into an upstream feedstock resulting in secondary raw materials that have the same quality as virgin materials.

In contrast, mechanical recycling - currently the predominant recycling technology - results in plastics that are usually downcycled into applications with less demanding specifications than those the primary materials were designed for, due to the mixed waste streams, hence lower quality recyclates, as well as economics. Only where separate collection and good economics for recycled materials are in place, mechanical recycling is a feasible method, for example in the upcycling of PET to fibre applications or the use of HDPE recyclate for bottles for detergents or shampoos.

Chemical recycling technologies provide an opportunity for plastic waste streams that generally are not mechanically (or otherwise) recycled, directing them away from landfill or energy recovery and towards higher quality recycling. Suitable waste fractions include mixed or contaminated plastics as well as blends or multi-layer applications. So far, however, chemical recycling technologies are still facing economic and technical challenges, which have an effect on their potential for commercial development in Europe.

Chemical recycling encompasses different technologies varying according to the resulting level of decomposition. The industry association Chemical Recycling Europe defines chemical recycling as “any reprocessing technology that directly affects either the formulation of the polymeric waste or the polymer itself and converts them into chemical substances and/or products whether for the original or other purposes, excluding energy recovery.”[1]

Chemical depolymerisation, solvent-based depolymerisation

Chemical depolymerisation (or decomposition) describes a process in which plastic waste is broken down into oligomers or monomers through a chemical reaction, usually with the help of heat and catalysts. Different terms such as hydrolysis, alcoholysis, or aminolysis refer to the solvents used as reactant. Chemical depolymerisation allows the plastic material to be chemically recycled again and again, since new virgin polymers can be produced after each depolymerisation. The technique is most efficient when applied to mono-material streams, but contaminated plastics can be processed as well.

Thermal depolymerisation

Thermal depolymerisation is a process in which the plastic waste is heated up either in the absence of oxygen (pyrolysis or thermal cracking) or with limited oxygen (gasification). Pyrolysis is carried out at moderate to high temperatures and results in hydrocarbon compounds resembling to crude oil, which can be treated with conventional refining technologies to produce monomers and other chemicals. Gasification of plastic waste mainly results in a mixture of hydrocarbons and syngas. Air, steam, and plasma can be used as gasifying agents and determine the composition of the syngas, which is used to produce hydrogen and other chemicals.[2] Ideally, the resulting oil and gas products of pyrolysis and gasification would be used as building blocks for new plastics.

[1] See Chemical Recycling Europe: www.chemicalrecyclingeurope.eu. Last accessed April 2021.
[2] Solis, M. and Silveira, S., Technologies for chemical recycling of household plastics – A technical review and TRL assessment. Waste Management 105, 128-138 (2020).

Thermal depolymerisation produces a feedstock that can be used for chemicals as well as fuels. However, only material-to-material recycling is suitable for the concept of plastics recycling.

Excursion: Enzymatic recycling

Enzymatic recycling describes a process whereby plastics (e.g. PET) are depolymerized by tailored enzymes into monomers, which then are purified and can be re-used again for new polymers, e.g. PHA.[3] Currently, the technology is not available at commercial scale, but intense research in this field is ongoing.

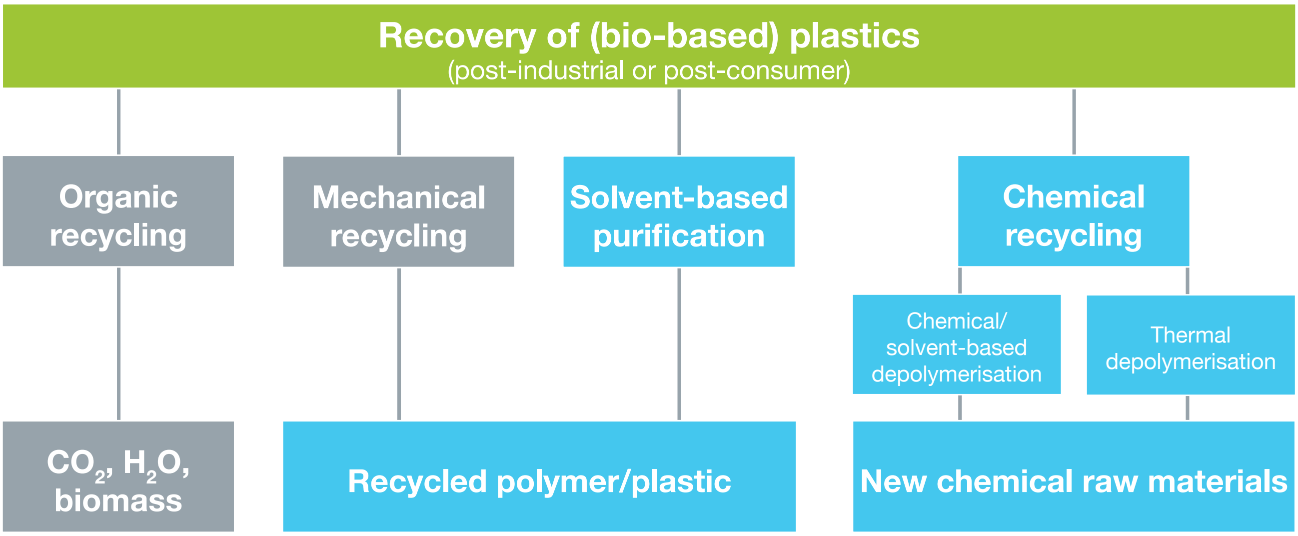
Solvent-based purification

Solvent-based purification is a physical process and not seen as chemical recycling in some definitions, but rather related to mechanical recycling. Plastic waste is broken down into the pure polymer stage. It does not disconnect the chemical bonds in a polymer and is, therefore, not a depolymerisation process.[4] Specific solvents remove impurities, such as additives, colours etc., present in plastic products. For the solvent-based purification method, mono-streams of plastic materials are necessary and a specific solvent depending on the type of polymer and the desired end product. Due to a possible decrease of the polymer chain length throughout the process, this type of recycling cannot be repeated endlessly without decreasing the quality of the material.

Chemical recycling in Europe

Some companies started to explore chemical recycling in the mid-1990s, yet with little success due to limited demand and poorly developed waste management and separation systems. In recent years, the interest in chemical recycling in Europe has grown significantly. Start-ups, universities, and companies, often cooperating in research consortia, are working on the development of these new technologies.[5] So far, only very few companies in Europe reached commercial scale. To run chemical recycling in a profitable way, large investments into new plants and large amounts of suitable plastic waste streams are necessary. As scale plays an important role for some material streams and technologies, new plants have to be located close to their sources of feedstock in order to make them profitable.[6]

With the demand for recycled plastics expected to increase in the coming years, due to new legislative requirements and more consumers opting for products with recycled content, chemical recycling can be a valid option for post-consumer waste streams in the future, particularly since mechanical recycling often has difficulties reaching the required qualities. Yet, further innovation and funding is needed to make chemical recycling technically and economically viable. And, being a relatively new technology, longer-term environmental and economic impacts of chemical recycling must yet be assessed more thoroughly.



Overview on different recycling technologies

[3] Currently, French company CARBIOS is leading this technology with its „enzymatic biorecycling".
[4] See also: Altnau, Dr. Gerald: The CreaSolv® Process is neither a Solvolysis nor Chemical Recycling. Published on LinkedIn on 16 January 2020.
[5] The EU Horizon 2020 project DEMETO for example, aims to chemically recycle PET at industrial scale. In France, Recycling Technologies, Total, Nestlé and Mars have formed in late 2019 a consortium to develop a chemical recycling industry. The industry association Chemical Recycling Europe, established in 2019, unites several companies engaged in chemical recycling in Europe.
[6] See: Chemical & Engineering News: Plastic has a problem; is chemical recycling the solution? October 6, 2019. Appeared in Volume 97, issue 39.

2. REGULATORY FRAMEWORK

A specific regulatory framework for chemical recycling does not yet exist in Europe, although there are several (legislative) initiatives that could affect these technologies.

The *EU Waste Framework Directive (2008/98/EC)* refers to chemical recycling in the definition of recycling. This definition, however, does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations. Consequently, only plastic-to-plastic recycling falls under this definition, excluding plastics-to-fuels technologies.

The European Commission *Regulation (EC) No 282/2008 on recycled plastic materials and articles intended to come into contact with foods* only refers to mechanical recycling; chemical recycling is still excluded from this regulation. This might change in the near future as the European Commission recommends updating European waste legislation, establishing consistent definitions, and defining standards for quality of recycled plastics in the near future.[7]

Incentives to explore new options for the recycling of plastic (packaging) waste are given in the *EU waste package*[8], which sets general recycling targets for municipal waste at 55% by 2025, and 60% by 2030. For plastic packaging waste, recycling rates of 50% by 2025 and 55% by 2030 are targeted[9].

To what extent EU Member States will explore chemical recycling to reach these recycling targets remains to be seen, as attitudes towards chemical recycling vary considerably. Whereas the Netherlands, for instance, appear to be open to building new waste management infrastructures, there seems to be some reluctance in promoting such new technologies in Germany.[10]

Furthermore, stakeholders from the plastics recycling industry call for legislative measures on chemical recycling to ensure that the obtained output material is clearly defined and distinguished from energy recovery.[11] In a joint statement, several NGOs under the umbrella of the Rethink Plastic alliance demand a policy framework that is guided by the precautionary principle towards these technologies and their environmental impacts.[12]

The consultancy Eunomia has been commissioned with a study for the European Commission to develop with the industry and its stakeholders methods to measure the recycled content of the produced plastics and chemicals, including chemically recycled material. The Ellen MacArthur Foundation, together with stakeholders from the chemical industry, developed a White Paper on how a mass balance approach could be applied in this context, and first market introductions can be seen based on this principle.[13]

[7] European Commission. DG Research and Innovation. A circular economy for plastics. January 2019.
[8] This waste package (Directive (EU) 2018/851) amended the Waste Framework Directive (2008/98/EC).
[9] The UK Plastic Packaging Tax that will come into effect on 1 April 2022 foresees a tax for all plastic packaging that does not contain at least 30% recycled material. Chemical and other innovative recycling technologies are considered equally to mechanically recycling.
[10] See “Circularity matchmaking: Is the chemistry there?” In: Plastics in Packaging. Issue 226, August 2020. Pp. 30.
[11] See for example the statement of Plastics Recyclers Europe: https://www.plasticsrecyclers.eu/chemical-recycling. Last accessed 27 April 2021.
[12] Chemical recycling. 7 steps to effectively legislate on chemical recycling. Zero Waste Europe. July 2020.
[13] Ellen MacArthur Foundation: Enabling a circular economy for chemicals with the mass balance approach. 2019.

3. . BIO-BASED PLASTICS IN CHEMICAL RECYCLING

Chemical recycling is an option for bio-based plastic to the same extent as it is for fossil-based plastics. It is possible to develop feedstock recycling for a number of bio-based drop-ins such as bio-based PE, bio-based PET, and bio-based PP. However, current research suggests that the most energy efficient feedstock recycling for these polymers would be thermal conversion to gasoline or depolymerisation to e.g. propylene in the case of PP, liquid fuels and waxes in the case of PE.[14] PLA can already be recycled by chemical depolymerisation. It is reprocessed to lactide or lactic acid, mostly at pre-consumer level.[15] It has been shown that chemical recycling can also be used to separate PLA and PET with both materials being recycled in a two-step process.[16] Recently, researchers succeeded in chemically recycling PLA waste into a biodegradable solvent using a zinc-based catalyst.[17]

Chemical recycling of bio-based plastics contributes to a circular bioeconomy by keeping renewable content in the loop even longer, requiring not only fewer fossil resources, but also less renewable feedstock to produce new, high-quality bio-based plastics.

[14] Rahimi, A. and Garcia,J.M. Chemical recycling of waste plastics for new material production. Nat. Rev.Chem. 1, 0046. 2017.
[15] PLA producers NatureWorks and Total Corbion perform in-house recycling of production waste.
[16] Sherwood, J.: Closed- loop recycling of polymers using solvents. Johnson Matthey Technology Review, 64, pp. 4-15. 2020.
[17] Luis A. Román-Ramírez et al.: Chemical Degradation of End-of-Life Poly(lactic acid) into Methyl Lactate by a Zn(II) Complex. Industrial & Engineering Chemistry Research. 2020.

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