Chemical Recycling and Recovery

Recommendation to Categorise Thermal Decomposition of Plastic Waste to Molecular Level Feedstock as Chemical Recovery

Position Paper - December 2021

ecos

Deutsche Umwelthilfe

ZERO WASTE EUROPE

Executive Summary

The objective of this briefing is to provide a recommendation for categorising thermal decomposition of plastic waste into feedstock molecules as chemical recovery. This covers mainly pyrolysis and gasification techniques.

The European waste hierarchy for a circular economy must be operationalised to favour reduction, reuse, and, as a last resort, recycling. It is, thus, essential to distinguish plastic waste recycling operations from recovery techniques. As such, pre-treatment of plastic waste into feedstock molecules shall be classified as chemical recovery and not chemical recycling based on the following rationale:

- Thermal decomposition via pyrolysis and gasification result in lowest level feedstocks which are used in the refining process. These preliminary-treatment methods generate molecules which are utilised at the onset of the plastic production value chain.

- Efficiencies and recovery rates of thermal decomposition-based reactions are low. Material leakages and energy requirements do not enable true circularity.[1]

- Pyrolysis and gasification result in significant carbon emissions. Pyrolysis and gasification, together with production of plastics from fossil resources, risk using up a significant amount of remaining carbon budget to comply with 1.5°C climate targets.

Additionally, Zero Waste Europe, Deutsche Umwelthilfe (DUH) and ECOS recommend effective implementation of design for reduction, reuse, and mechanical recycling based on the waste hierarchy across the plastic value chain. Chemical recovery processes, which have significant negative environmental impacts, should not be levers to tackle the plastic waste challenge. In this respect, we recommend amending current waste legislation as follows:

- **Conversion of plastic waste into molecules level feedstock via thermal decomposition (gasification and pyrolysis) should be classified as chemical recovery in the legislation.** Chemical recovery (polymer to molecular level decomposition) needs to be added as a new level in the waste hierarchy below chemical recycling (polymer to monomer level depolymerisation via techniques such as solvolysis) – see Visual 2 further below.

- From current knowledge, it is quite evident that mechanical recycling is more environmentally-friendly than chemical recycling and recovery.[2] Therefore, **the latter techniques should be below mechanical recycling in the waste hierarchy.**

- Competition for plastic waste feedstock is also becoming a significant concern for mechanical recyclers. Provided that design for reuse and mechanical recycling is prioritised, chemical recycling (and recovery) shall hence only deal with degraded and contaminated plastics - and never with plastics that can be mechanically recycled. To ensure this, **only rejects from sorting facilities should be used for chemical recycling (and recovery) facilities.**

- **Chemical recovery should be the very last resort for waste that cannot be mechanically or chemically recycled after effective inclusion of waste hierarchy principles into the design of plastics**. Ecodesign principles should focus on prevention, reduction, and reuse as main priorities. Specific design criteria for recycling should only be targeted to mechanical recycling,[3] and should not be established for chemical recycling and chemical recovery. With effective redesign of products using toxic-free materials,[4] chemical recovery should have a diminishing role and scope in plastics waste treatment.

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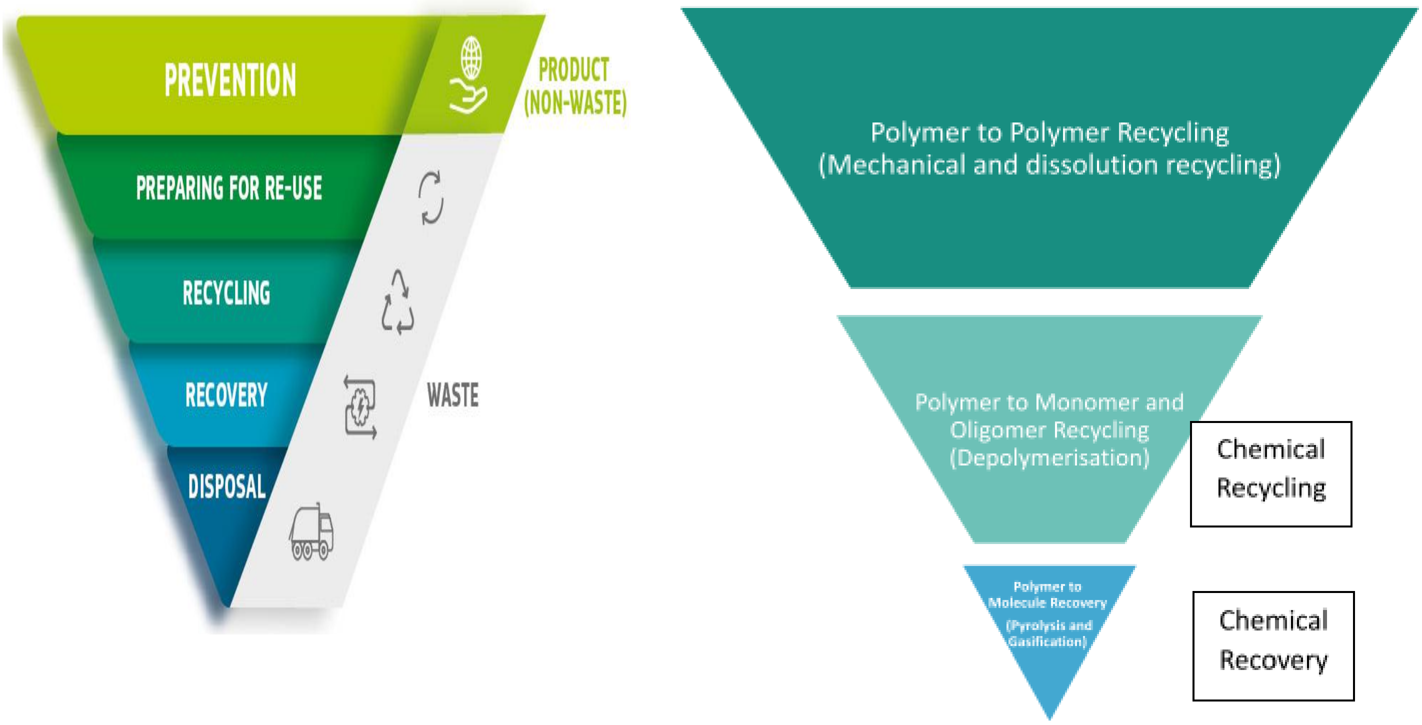
[1] Chemical Recycling of Polymeric Materials from Waste in the Circular Economy ECHA, 2021
[2] Understanding the Environmental Impacts of Chemical Recycling, ZWE, EEB, DUH, ECOS, GAIA, Rething Plastic, NABU, 2020
[3] Designing for real recycling, not plastic lock-in, EEB, ECHOS, Rethink Plastic, ZWE, 2021
[4] In line with the EU 'Chemicals Strategy for Sustainability: Towards a Toxic-Free Environment', October 2020

1. Waste hierarchy in the context of plastic value chain

The five-step waste hierarchy in the EU Waste Framework Directive provides an overview of the general approach for managing waste. The waste hierarchy needs to be further segmented, corresponding to existing and evolving recycling and recovery methods in the plastics value chain. The proposed waste hierarchy for plastics recycling and recovery is based on the assessment of evidence regarding circularity, material losses, energy requirements, and toxicity impacts of the different methodologies used for plastics waste treatment.

- If polymer is used to produce fuels and energy for internal and/or external purposes, then it should be considered as *thermal recovery*.
- Polymer to molecule conversion via chemical reactions such as pyrolysis and gasification is ***material recovery***. A new waste hierarchy should include chemical recovery under the recovery operations.
- Polymer to monomer and oligomer conversion via techniques such as solvolysis and chemolysis is ***chemical recycling***. Chemical recycling should be below mechanical and dissolution recycling. Chemical recycling does not cover pyrolysis and gasification, which result in conversion of polymers to molecules.



Visual 1. Current Waste Hierarchy[5] versus Proposed Waste Hierarchy zoom-in for plastics recycling and recovery

[5] EU Waste Framework Directive, 2008

A non-exhaustive list of the main techniques within each classification should be as follows:

Classification in Waste Hierarchy	Input - Output	Techniques
Physical Recycling[6]	Polymer to Polymer	Mechanical and solvent-based recycling
Chemical Recycling	Polymer to Monomers and/or Oligomers	Thermal depolymerisation to monomers and oligomers, chemolysis and solvolysis
Chemical Recovery	Polymer to Molecules	Thermal decomposition to molecules, pyrolysis and gasification

Table 1. Techniques within Waste Hierarchy levels

2. Recycling methodologies

As definitions and interpretation of key concepts related to plastic recycling and recovery methodologies are often used interchangeably, clear distinction between these approaches shall be made and the terminology shall be harmonised.

2.1. Polymer to Polymer Recycling

2.1.1. Mechanical recycling: Polymer intact

In mechanical recycling, the chemical structure of the plastic remains the same as prior to the process. It has the lowest environmental impact[7] and is the most widely used method to recycle plastics. Moreover, mechanical recycling techniques have a huge potential to improve even further, especially if ecodesign is promoted.

2.1.2. Solvent based recycling (Purification, Dissolution): Polymer intact

Solvent-based recycling involves purification of plastics via physical means. In this method, selective dissolution of the target polymer is followed by residue removal via filtration. The chemical structure of the polymer remains largely the same as before the recycling process.

2.2. Polymer to monomer and polymer to oligomer chemical recycling (Depolymerisation, Chemolysis)

Depolymerisation including thermal depolymerisation, chemolysis, and solvolysis methodologies cover the chemical recycling of plastics into their direct building blocks - oligomers (partial depolymerisation) and monomers (full depolymerisation). It is

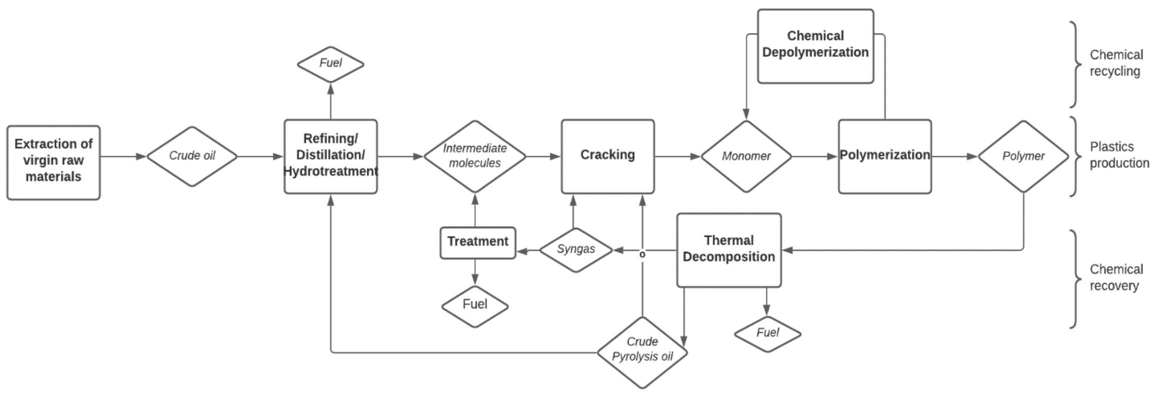
[6] 25 Years of Making Plastics Circular, 2021, PRE
[7] Based on knowledge from several sources such as www.chemicalrecyclingeurope.eu/copy-of-about-chemical-recycling, "Life Cycle Assessment Of Plastic Energy Technology For The Chemical Recycling Of Mixed Plastic Waste", Plastic 2020

important to note that thermal depolymerisation is different from thermal decomposition, which breaks polymers into basic molecular level feedstock.

3. Chemical recovery (thermal decomposition, polymer to molecular feedstock conversion)

Thermal decomposition, mainly pyrolysis and gasification, turns plastics into their basic molecular level building blocks. These chemical reactions result in feedstock, which can be used as fuels or input molecules for refining or cracking processes. The degradation typically results in the scission of polymeric bonds at random positions, different from the controlled breakdown in chemical depolymerisation.[8] The resulting mix of molecules consists of a variety of hydrocarbon products which require further energy and intensive purification before it can be used as a feedstock for polymer production. As pyrolysis oils and syngas serve as feedstock for consecutive production of plastics operation, these preliminary treatment methods should be approached as chemical recovery and not chemical recycling.

Chemical recovery relies on the existing virgin polymer value chain assets to produce monomers at the later step. Therefore, even if plastics are produced from chemical recovered feedstock, this should not be classified as a recycling operation; and these materials cannot be classified as "recyclates".



Visual 2. Simplified plastic production flowchart including chemical recycling and chemical recovery (excluding energy requirements)[9]

3.1. Pyrolysis (conversion to pre-monomer stage)

Pyrolysis is a process through which crude pyrolysis oil, char, and CO_2 are produced. Crude pyrolysis oil needs to be purified to reach the target quality to be used in a steam-cracker. This step either takes place in a refinery using the virgin based petrochemical infrastructure or in a hydrotreatment plant. Both refinery and steam-crackers processes result in a variety of output molecules, including fuels.[10] There are significant material losses with pyrolysis, as:

[8] Chemical Recycling: State of Play, Simon Hann, Toby Connock, 2020, Eunomia
[9] Visual compiled based on several resources
[10] Mass balance approach to evaluating recycled content in reaching targets under the SUP Directive, PlasticsEurope

- Only a portion of the plastic waste can be converted into pyrolysis oil. It is estimated that the carbon recovered in the form of polyolefins is less than half of the starting carbon available in waste feedstock.[11] Additionally, reaction yields are highly dependent on the incoming waste composition.[12]

- Produced crude pyrolysis oil does not meet steam cracker requirements. Projects such as BASF´s ChemCycling Project dilute pyrolysis oil with conventional petrochemical feed to meet specifications.[13]

3.2. Gasification (conversion to pre-monomer stage)

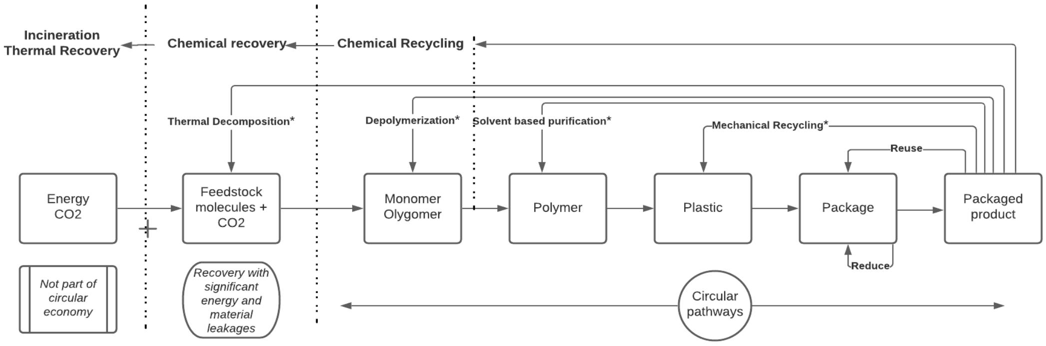
Chemical recovery based on gasification of plastic waste results in syngas, which is treated further to obtain intermediate molecules such as naphtha. Whilst preliminary syngas treatment emits CO_2 emissions, further utilisation via methanol and Fischer Topsch pathways are energy intensive.

4. Incineration (Thermal recovery)

Plastic waste incineration, which generates significant levels of CO_2, is not part of the circular pathways for plastics. Any produced fuels from chemical recycling or recovery processes should be classified at this level.

5. Plastic waste treatment overview including recovery and recycling pathways

The diagram below summarises the traditional plastic production, as well as pathways to recycle and recover it. Molecules obtained from chemical recovery via means for thermal composition are typically further treated along the traditional petrochemical infrastructure to make the quality fit with successive recycling requirements.



Visual 3. Plastics value chain overview including recovery and recycling pathways (overview does not cover waste and does not exclusively cover energy flows)

[11] State of the art review of chemical recycling technologies, Ludwig Georg Seidl, Technische Universitat Bergakadamie Freiberg, NK2 Workshop Chemical Recycling, 2021
[12] Influence of the Feedstock on the Process Parameters, Product Composition and Pilot-Scale Cracking of Plastics, MDPI, 2021
[13] State of the art review of chemical recycling technologies, Ludwig Georg Seidl, Technische Universitat Bergakadamie Freiberg, NK2 Workshop Chemical Recycling, 2021

Conclusions

Pre-treatment of plastic waste into feedstock molecules via thermal decomposition covers mainly pyrolysis and gasification techniques. These recovery processes are technically and environmentally different from chemical recycling of plastic waste into monomers and oligomers.

Due to low material recovery rates, energy requirements and CO_2 emissions, thermal decomposition-based chemical recovery methods do not enable a true circular approach for plastic waste. Therefore, techniques such as pyrolysis and gasification should be classified at a lower level in the waste hierarchy than other recycling methods and must be classified as ***recovery***. Output molecules of chemical recovery are used at the onset of plastic value chain, and should thus not be classified as recyclates.

The upcoming review of the Waste Framework Directive in 2022 shall bring clarity to the classification of the different technologies. Our recommendation for the classification (Visual 1) should be considered for this review.

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Zero Waste Europe, 2021

Zero Waste Europe is the European network of communities, local leaders, experts, and change agents working towards the elimination of waste in our society. We advocate for sustainable systems and the redesign of our relationship with resources, to accelerate a just transition towards zero waste for the benefit of people and the planet.

Environmental Action Germany (DUH) has been campaigning to preserve the natural foundations of life for more than 40 years. In doing so, it brings together protecting the environment with consumer protection like no other organisation in Germany.

ECOS is an international NGO with a network of members and experts advocating for environmentally friendly technical standards, policies and laws. We ensure the environmental voice is heard when they are developed and drive change by providing expertise to policymakers and industry players, leading to the implementation of strong environmental principles.

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