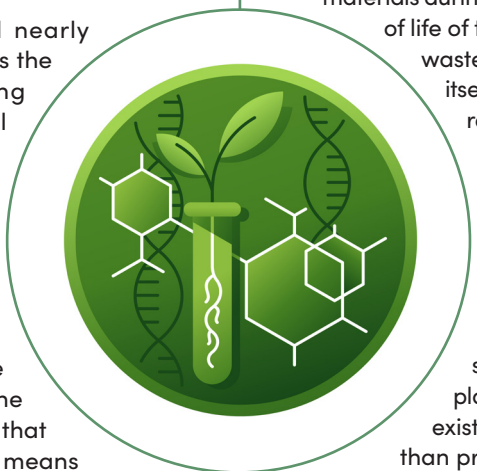
The Limits and the Opportunities of Plastics for Recycling

Global economy will triple by 2060 and this will drive the use of plastics. According to a OECD study "Global Plastics Outlook 2060" (2022), plastics use reached 460 Million tonnes (Mt) in 2019, and projections based on population growth trends and higher incomes in emerging economies will lead to 1231 Mt in 2060. Consequence of this is the generation of 353 million tons of plastic waste, that are projected to triple up to 1014 Mt in 2060. Plastic waste represents nowadays a big problem, but it can turn into a valuable resource if shared objectives and coordinated efforts to reduce plastics pollution at global level will be implemented. These could drastically reduce the projections of plastic use and waste for 2060 by more than 30% (global ambition policy scenario 2060), if all relevant phases of the plastics lifecycle are targeted.



In this article we will discuss some of the key plastics lifecycle steps, with particular emphasis on plastics recycling, their existing different types (e.g. mechanical recycling or chemical recycling) and the limits and opportunities of them.

Good news is that 29 Mt of plastics use was satisfied by plastics recycling on the base year 2019, but this is still too low proportion, compared to the higher 431 Mt contribution of primary plastics. Projections of plastics recycling in 2060 without coordinated global and regional action could reach 143 Mt (5 times the 29 Mt of 2019), counting for a plastics lifecycle that would only be 14% circular in 2060 (=143 Mt out of 1014 Mt of plastic waste).



Mechanical recycling represented nearly the entirety of the 29 Mt figure, as it was the only commercially mature processing infrastructure at scale in 2019. Chemical recycling on the other hand was in early and unquantified pilot stages. Mechanically recycling has a low environmental impact and an established infrastructure that must grow further, but there are some relevant limitations. The first limitation of mechanical recycling depends on the quality and purity of the waste input, visible when we compare the 29 Mt with the 55 Mt volume of plastics that was collected for recycling in 2019. This means that 22 Mt of plastic residues could not be mechanically recycled due to the materials composition or to the high level of degradation, mix and contamination. In addition, there were additional 4 Mt of process losses to be considered. The content of fillers (e.g. glass fibers) or of other component materials alone (e.g. multi materials) are very difficult to separate. In addition, the degradation of the polymer itself (e.g. molecular weight reduction, increase of monomer content depending on the considered polymer like BPA, formaldehyde, degraded halogen content etc..) and of the additives contained in the original formulation (e.g. flame retardants, colour pigments, UV additives, demolding agents etc..) make them not reusable and in some cases prejudicial for a second life purpose. Furthermore, waste feedstocks can come from virgin plastics that were already containing dangerous or restricted substances intentionally included (IAS: Intentionally Added Substances) to comply with their first life application purpose (e.g. FR materials with halogen content, Chlorinated organic compounds, etc..). Last but not least, there is the important issue of the Not Intentionally Added Substances (NIAS), that not only refer to the production of the plastic when it was a prime material, but also to the NIAS that will have migrated into the materials during the first application use, and after the end of life of the application, during the status of mixed waste plastics and during the recycling process itself. The study "Chemical content validation of recycled plastics" (OECD, 2026) quantifies in 13.000 the number of chemicals contained in virgin plastics alone, summing up IAS and NIAS substances. Several of them are chemicals of concern that can persist, migrate and accumulate in plastic waste, increasing environment and human health concerns. All these points set a second limitation of mechanically recycled plastics, which is related to the possible uses in existing applications: these are more restricted than prime plastics, as consequence of different reasons, like wider tolerances of material properties, lower batch stability or lower color properties.

Considering the medical sector and medical device applications, mechanically recycled plastics or a compound of prime plastics with mechanical recycled content is not even an option, because the presence of NIAS accumulated during the first application use and the posterior waste status will make it impossible to pass Extractables and Leachables

(E&L) analysis and fulfil with key required properties like biocompatibility. These considerations underline the need for a plastic with recycled content that preserves the high quality of prime plastics on one side to fulfil with the sector application and on the other that guarantee higher efficiency outputs for the future collection at even bigger scale. For example, the 2022 OECD study projects 6 times higher volume plastics collection for 2060 (approx. 302 Mt from the 55Mt in 2019), with an estimation of 126Mt recycling residues and 33 Mt of process losses (scraps) in 2060. This would represent a 47% of recycling efficiency (143Mt out of 302Mt) on collected plastic waste for recycling, with a slight decrease from the 52% obtained on the base year 2019 (29Mt out of 55Mt). Here chemical recycling technologies can make the difference, introducing new ways to recycle collected plastic waste into higher quality feedstocks that can be reincorporated at progressively higher levels of the chemical polymer supply chain: from the polymer (dissolution), to the monomer (depolymerization), up to the direct alternative of the fossil oil (pyrolysis) as input feedstock alternative for the cracking process.

By going up in the supply chain, the number of possible plastics that can be produced with the chemically recycled output increases, scaling up the volumes that can be produced. On the other hand, chemical recycling techniques need a strong push from regulatory authorities to promote investments, focus on synergies and cost optimization, create the missing part of the circular supply chain that needs to be put in place and let the existing chemical supply chain industry to adapt to their use. As starting point idea, compared to global petroleum production, the actual worldwide feedstock availability for chemical recycled plastics is very low, approximately 0.10% to 0.19% on a relative weight/mass basis.

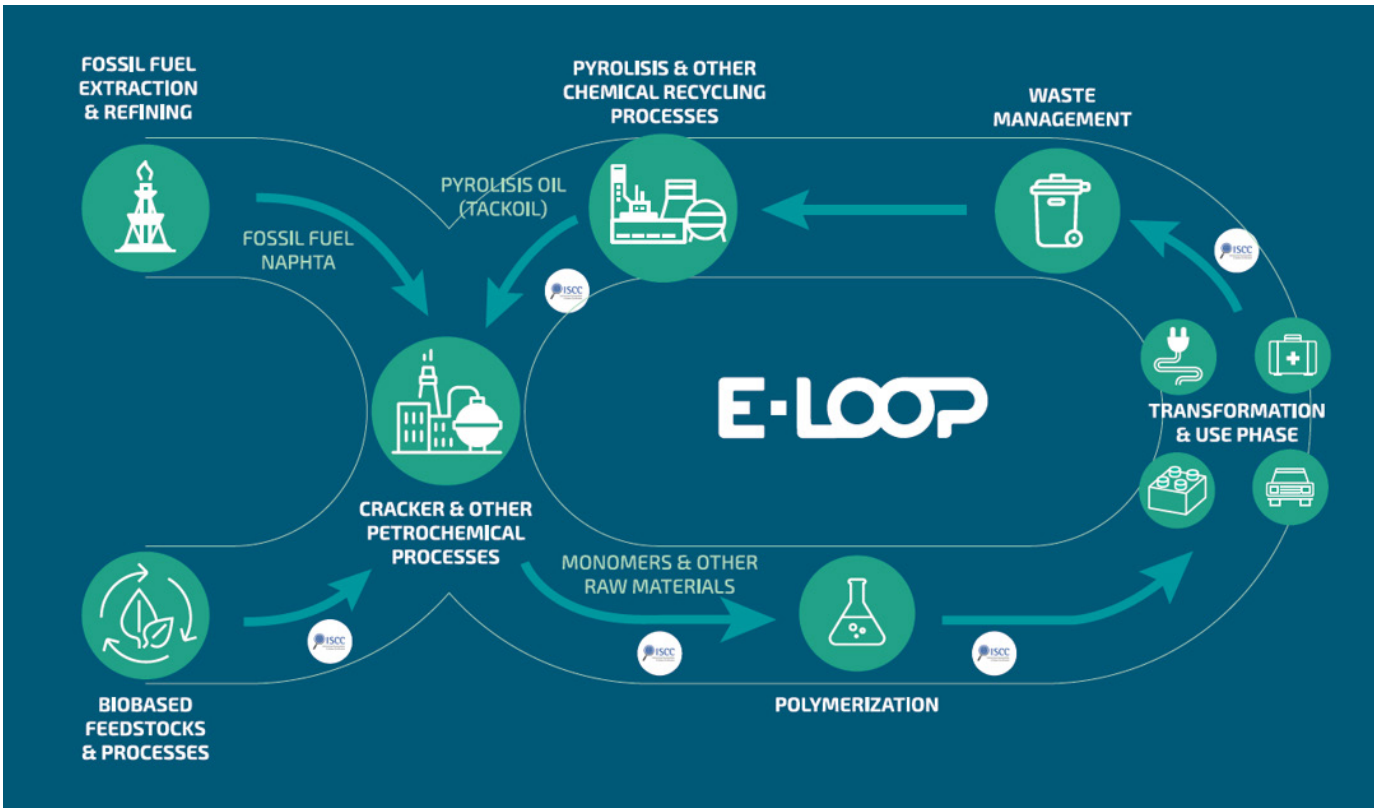
Considering the plastics lifecycle, a critical point is when the End of Life (EoL) of the device application is reached: here several and relevant plastics stream outputs are generated. Ideally, it would be fantastic to be able to convert 100% of the EoL plastic waste into collected waste input for recycling. The reality is completely different: there are not enough recycling infrastructures implemented in many regions and cooperating together, regulatory directives still need to be developed, put in place and coordinated in a global scenario, especially in emerging countries like Asia and Sub-Saharan Africa, where plastic use and waste production is going to grow at highest pace. As result, 79 Mt of 353 Mt (approx 22%) of plastic waste was completely mismanaged on base year 2019 (OECD study 2022), leading not only to a lower base of collected plastic waste for recycling, but to the highest negative impact for the environment, from aquatic leakage (6Mt), terrestrial leakage (13Mt), Dumpsite (34Mt) and open-pit burning (26 Mt). Mismanaged plastic waste could double from 79 Mt to 153 Mt in 2060, similarly to plastics leakage, from 22 Mt (the mentioned aquatic and terrestrial leakages from mismanagement + leakages during plastics use and plastics production and logistics, approx 3Mt) to 44 Mt in 2060. On the other hand, if combined regional and global policies will be implemented with international engagement, there is a OECD projection of more than halving these estimations for 2060.



Another important development drive for the chemical recycling segment is the need to divert plastic waste from landfills. Landfilling of plastic waste is the second worse option for the environment, that could triple from 174 Mt into 507 Mt in 2060 according to the OEC study. Plastics incineration (67Mt in 2019 with projection 179Mt for 2060) is an improved solution compared to landfilling. Partial energy recovery from the incineration process is possible, but there are high levels of CO2 equivalent emissions into the environment. According to the OECD study, plastics incineration volumes would also triple from 67Mt (base year 2019) to 179Mt (2060 projection). Chemical recycling is an important remedy to avoid landfilling of plastics waste and it is an optimal solution to reduce incineration volumes too. Most important, the output products are not just emissions with some energy recovery, but valuable new raw materials feedstock in solid, liquid (e.g. pyrolysis oil) or gas (e.g. syn-gas) form that can feed back again the chemical polymer supply chain to produce high quality plastics. In this way, circularity with waste feedstocks is created, emissions are reduced (especially compared to the incineration alternative) and energy recovery is enabled.

Plastic waste can be collected and sorted by type (for example tires), recovered as new feedstock to produce high quality plastics (e.g. pyrolysis oil composed by liquid hydrocarbons) increasing recycling efficiency, requiring lower temperatures than incineration to operate and reduce emissions levels. As reference, the incineration process requires between 850° and 1100°C in presence of oxygen to ensure complete combustion and prevent the release of toxic pollutants. The use of only pre-sorted and specific types of waste let the fine tuning of the recycling process of those residues, reducing the amount of energy required for the process. In addition, to prevent fire and combustion (burning) of plastic waste, the oxygen is removed. This step is important in most chemical recycling techniques (except for gasification, where limited oxygen is needed for partial oxidation), otherwise the plastics waste would be consumed as fuel and turned into carbon dioxide, ash, and smoke instead of chemical recycling products. By applying high heat in a strictly oxygen-free or inert environment, the thermal energy acts like a pair of "scissors" rather than a flame. It vibrates and cracks the long polymer chains apart cleanly into smaller hydrocarbons without oxidizing them.

Temperature levels along with the technology in use determine the grade of thermal breakage of plastics waste and therefore the type of feedstock output that can be obtained. This defines where that regenerated feedstock can



be re-introduced as input raw material in the chemical plastics supply chain. Conversion chemical recycling uses 800–1000°C in the case of gasification and 300–900°C for pyrolysis (or liquefaction). Depolymerization chemical & solvolysis recycling uses temperatures between 150°C and 450°C (extending up to 800°C for thermochemical variants), while dissolution typically requires temperatures between 30°C and 200°C. For reference, mechanically recycling requires temperatures between 150°C and 300°C (to melt and reform the material without changing its fundamental chemical structure).

Discussing waste, we referred to end of life plastics, but there is also another important type of waste that can be recycled into plastics. This is bio-waste, for example used cooking oil and tall oil from agricultural and forest waste. By hydrotreating such types of oils, Hydrogenated Vegetable Oils (HVOs) can be produced and refined into Bio-Naphtha. Bio-Naphtha can substitute fossil Naphtha as input feedstock for the petrochemical cracking process, which is the starting point of the polymers supply chain industry*. An example for ABS (Acrylonitrile Butadiene Styrene) is an existing biocompatible and bio-circular medical ABS grade which is ISCC+ certified bio-attributed origin from used cooking oil, agricultural waste and biogas. For plastics waste certified content, alternative versions with ISCC+ certified chemical recycled content from used tires are also available. These ABS grades are identical to the traditional fossil version and can be used as enclosure plastics in biocompatible medical device applications, fully fulfilling all medical regulatory requirements. By increasing the demand for alternative sustainable versions, without renouncing the primary plastics performances, it is possible to support the future recycling challenges.

As we have seen for the case of ABS polymers, Bio-waste can be recycled to produce new conventional plastics that are normally associated to petroleum. The main sustainable advantages in this case are the use of bio-waste as feedstock, the fossil substitution and important CO_2 emission reductions.

Also, plastic waste can be recycled to produce again virgin plastics. It is important to raise awareness about chemical recycling technologies as parallel paths to move forward. The reasons are multiple: not only to complement mechanical recycling by reprocessing its residues and scraps (practically half of what is collected for recycling), but also to gradually address a set of even more relevant problems. These are: mismanaged plastics (which would double by 2060), plastics deposited in landfills (which would triple), and incineration high emissions without output feedstock for recycling (which would also triple by 2060).

*see also my previous article published at IPI: “Certified ABS Plastics from Bio-Circular and Chemical Recycled Sources Instead of Fossil Ones”

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