Topic Sheet

Chemical Recycling

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Plastics-to-plastics chemical recycling offers a promising solution in complement to mechanical recycling.

Chemical recycling (CR) is the broad term used to describe a range of technologies capable of recycling plastics using chemical processes as opposed to strictly mechanical ones. It has the potential to process plastics such as mixed rigids, films, multi-material plastics and laminated plastics. By turning plastic waste back into base chemicals and feedstocks, some types of CR can yield virgin-quality feedstock that can be suitable for food-grade packaging. These technologies could therefore effectively complement mechanical recycling in achieving a circular economy because they can recycle a wider variety of plastic and provide food-grade recycled content.

As plastics recycling is receiving a lot of scientific, industrial and legislative attention, the abundance of nomenclature being released into the world can lead to a dispersed use of terminology in the scientific world, grey literature and policy. The table below provides high level definitions; while García-Gutiérrez *et al.* (2023)[1] provide a much more in-depth description of these and additional recycling options and their related impacts.

Chemical conversion	Plastics-to-plastics (P2P) chemical conversion	Plastics-to-fuel (P2F) chemical conversion
Chemical conversion, refers to a number of technologies (pyrolysis, depolymerization and gasification) that uses chemical agents or processes to break down plastic into basic chemical building blocks, either to make new plastic or other materials.	Several technologies are being developed that can turn plastic waste back into chemical compounds to be reintroduced as plastic feedstock with the same properties as virgin plastic. These technologies are therefore considered as recycling.	Refers to technologies where the output material of the chemical conversion is refined into alternative fuels such as diesel and therefore is not considered recycling because the fuel is subsequently burned for energy.

P2P is preferred over P2F because it is a circular solution. P2P conversion is an evolving technology, with patents on this area increasing by five per cent annually between 1995 and 2017[2]. As P2P matures and scales, more analyses and scientific research is required regarding the performance and environmental impact of the different P2P technologies.

Chemical conversion is a controversial technology because it is still in its early stage of development, has high energy requirements and accurate assumptions about its impacts and contributions cannot yet be made. Critics fear that it is being positioned by some advocates as a panacea; however, despite having an important role to play for low-value plastic, P2P chemical recycling certainly cannot solve the crisis on its own.

The technology is still evolving, and available content is likely to be in extremely short supply in the near term, if not longer. It will likely take a few years before the supply of CR content reaches a scale and consistency that brand owners can rely on for their procurement strategies. Also, to successfully scale CR, users should not overlook the need to secure feedstock supply and grow collection.

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[1] Garcia-Gutierrez, P., Amadei, A.M., Klenert, D., Nessi, S., Tonini, D., Tosches, D. *et al.* (2023). Environmental and economic assessment of plastic waste recycling A comparison of mechanical, physical, chemical recycling and energy recovery of plastic waste. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/0472.

[2] OECD. (2022). Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options.

What could chemical recycling at scale look like?

High investments and substantial capacities are planned

Chemical conversion technology should only use feedstock that cannot be reduced, substituted or mechanically recycled, following a set of principles to ensure chemical conversion does not divert resources from higher priority solutions. While chemical conversion can be used to process both flexible and rigid plastics, there is a preference to apply it on flexible and multi-layer plastics because mechanical recycling is a more sustainable option for most rigid plastics as long as they are not highly contaminated.

Using existing investment in chemical plastic-to-plastic conversion as reference, and accounting for feedstock availability and the time to build infrastructure, the analysis in this report suggests that P2P chemical conversion could reach an annual capacity of 13 million metric tons per year by 2040, with an investment requirement estimated at USD 30 billion[3].

This study suggests that chemical conversion would provide a solution for approximately five per cent of the plastics volume in short-lived products by 2040 that cannot be recycled mechanically. The greenhouse gas (GHG) emissions generated when producing one metric ton of plastic through P2P (including collection and sorting) considered in this study are 19 per cent lower than the emissions of producing one metric ton of virgin plastic that is later collected, sorted and incinerated. P2P emissions are 10 per cent higher when compared to producing one metric ton of virgin plastic that is later collected, sorted and landfilled. Figure 1 provides a broader assessment of the multiple technologies available.

Chemically recycled content is not widely available to brands and retailers today, but this could change in the next 5 to10 years if the sector scales up and technology is further developed. In the mid-term, securing CR content largely relies on off-take agreements and partnership between brands and chemical companies (e.g. Unilever with Sabic developing magnum ice cream tubs from chemically recycled polypropylene). Also due to relative immaturity of technology and commercial infrastructures, CR costs cannot yet be asserted with full confidence (García-Gutiérrez *et al.* 2023).

In 2021, European plastics manufacturers announced a significant increase in their planned chemical conversion investments, from EUR 2.6 billion in 2025 to EUR 7.2 billion by 2030. This shows that they acknowledge the opportunity for scaling these technologies as a tool to recycle problematic plastics (that cannot be recycled mechanically) and prevent pollution. In another example, Eastman announced in 2022 a USD 1 billion investment for the construction of a new P2P recycling facility in France with an annual capacity of up to 160,000 metric tons, targeting plastic that otherwise would be incinerated. High investments in chemical conversion however can deter action to reduce plastic production, particularly when governments are locked-in to 'deliver or pay' contracts. This was observed in Oregon, where the presence of a pyrolysis plant was used to argue against a partial ban on polystyrene.

What are the benefits and disadvantages of chemical recycling?

CR technologies are appealing but still in an early stage and with many limitations

Chemical conversion offers certain advantages over mechanical recycling which can complement and increase retention of plastic in the economy:

1. **High-quality output:** The product of chemical conversion can be used in applications that demand high-quality packaging, including the food sector, and may be able to make up 100 per cent of a package's plastic requirements without decreasing quality. This includes food-grade quality, which typically isn't the case for most mechanical recycling plants.
2. **Higher tolerance for contaminated feedstock:** Chemical conversion has more tolerance to different materials and conditions for feedstock with lower yield losses in comparison to mechanical recycling (e.g. multi-material packaging, food residues and lubricants).
3. **Increased versatility:** Chemical conversion can facilitate many more recycling loops than most mechanical recycling processes. It can therefore be used in synergy with mechanical recycling to address plastic types, such as films, multi materials and contaminated plastic, but this will require building chemical conversion capacity that today is very low.

[3] The PEW Charitable Trusts and Systemiq. (2020). Breaking the Plastic Wave.

However, while this technology has benefits relative to mechanical recycling, it also has some important shortcomings:

1. High energy requirements, unproven yields and economics for certain applications in some geographies. Early studies suggest that P2P chemical conversion has high energy requirements, leading to GHG emissions that may be double that of mechanical recycling and may be 10 per cent higher than landfilling and producing new virgin plastic (Quantis 2020). García-Gutiérrez *et al.* (2023) provide an updated appraisal of various plastic recycling options from an environmental and economic perspective. For instance, Figure 1 provides an overview of the climate change impacts per ton of plastic waste managed following different technologies.

2. Potential presence of impurities in recyclate. While in theory CR 'purifies' the polymers, it is not fully clear whether substances of concern present in the input waste could be reintroduced into the output recyclates, and further evidence needs to be gathered for this.

3. Potential presence of hazardous chemicals in discharges and emissions from CR. Further research into air pollutant emissions (as well as emissions through liquid effluents and solid waste) from the CR process is important to understand all potential impacts. This is highlighted in a recent LCA study of pyrolysis commissioned by the Consumer Goods Forum, which quantifies emissions of nitrogen oxides, ammonia and dioxins among other relevant emissions[4]. As discussed in the report, some types of chemicals can cause adverse health risks to vulnerable populations. Men and women are impacted differently, e.g. with impacts on pregnancy and reproductive health.

Going forward, CR should be scaled with careful consideration and more work is needed to evaluate the full potential (cost, yield, GHG and other impacts) of CR in processing various types of feedstocks.

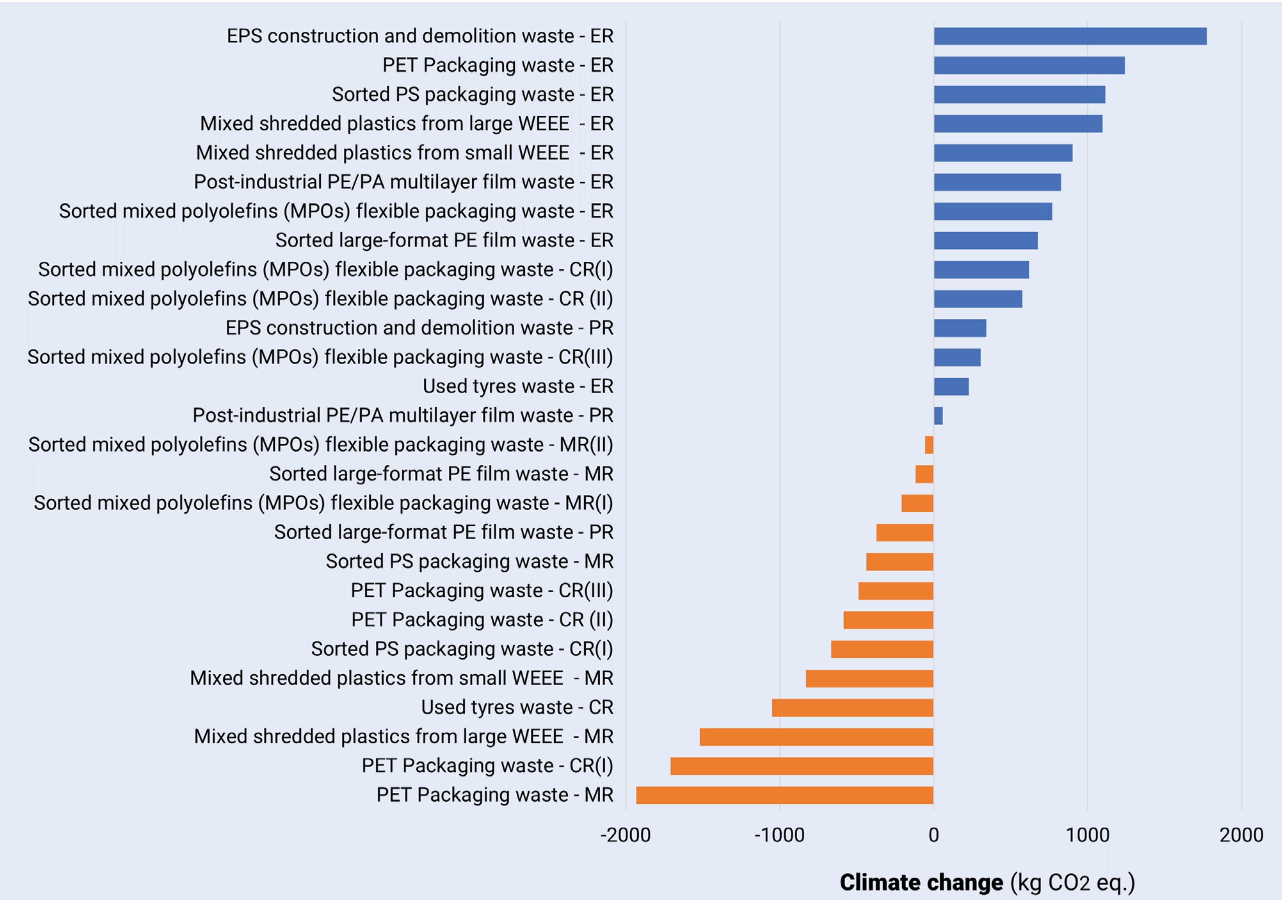

Figure 1: **Summary overview of climate change potential impact associated with the management of one ton of various plastic wastes via different technologies.**

Source: Figure 18 in García-Gutiérrez et al. (2023)

Note: Negative values (orange bars) represent net GHG savings, while positive ones (blue bars) represent net GHG burdens. See Garca-Gutirrez *et al.* (2023) for a description of the different treatment scenarios/technologies. CR = chemical recycling; ER = energy recovery; MR = mechanical recycling; PR = physical recycling.

[4] Sphera. (2022). Life Cycle Assessment of Chemical Recycling for Food Grade Film. https://www.theconsumergoodsforum.com/environmental-sustainability/plastic-waste/key-projects/chemical-recycling/.

Designing policies for chemical recycling

Chemical recycling still requires critical groundwork and support

Further research is needed to fully understand the life cycle GHG profile, economics, process yields and feedstock tolerance. In addition, the following items also need consideration and development:

- **Common accounting:** The creation and adoption of a set of rules that codifies the technical details about which plastics can be recycled using CR, and which can be produced using CR-generated feedstock, may assist the growth of CR technologies. For example, the American Chemistry Council (ACC) developed a set of mass balance principles and the National Institute of Standards and Technology (NIST) was mandated to review existing standards (e.g. Roundtable on Sustainable Biomaterials [RSB] and the International Sustainability and Carbon Certification PLUS (ISCC+) as part of Save Our Seas 2.0 Act. It has been suggested that the NIST review could lead to a standardized methodology.
- **Legal and regulatory support:** Key discussion points that need to be resolved to enable more widespread adoption of CR content in food packaging include a well-developed legal and regulatory framework setting out whether CR facilities producing fuel or other feedstocks such as industrial waxes should be treated as recycling facilities. Agreements from regulators that CR content is food safe and can be counted as 'recycled content' and regulations aimed at keeping hazardous contaminants out of the CR stream and/or ensuring they have been fully removed from plastic waste during CR processing, are key discussion points that need to be resolved to enable more widespread adoption of CR content in food packaging. The European Chemicals Agency (2020) finds "fragmented knowledge about the fate of substances of concern in various chemical recycling processes, and a paucity of scientific papers discussing regulatory issues in chemical recycling".
- **State-sponsored Research and Development (R&D):** Public-sector co-funding could help accelerate R&D partnerships and address the higher risk areas and stages of CR development (e.g. bridging the 'valley of death' and coordinating innovation across the whole value chain) with specific focus on developing P2P technologies.
- **New feedstock collection and cleaning:** Successful collection and aggregation of quality feedstocks will be critical to provide the scale needed to run CR facilities. In addition, CR will need to process both post-industrial and post-consumer materials to fully realize a circular economy for packaging. Additional investment will be needed to ensure the full suite of materials to feed CR is collected at a level to support a capital investment (i.e. post-consumer film collection needs more scale).
- **Collection and logistics:** CR plants need large volumes of consistent, economically feasible feedstock to be viable. To process the difficult-to-recycle materials, those items must be segregated and sent to the chemical recycler at relatively low cost and high quality, in turn necessitating widespread logistical planning and investment in local and regional collection networks.

How could an international approach enhance chemical recycling?

Chemical recycling still requires critical groundwork and support that international policies could provide. This can be summarized along three axes, to be tackled in tandem:

- **Create environmental objectives for chemical conversion:** Agree on the specific environmental outcomes to be met for chemical conversion (specific technologies therein) to be considered as part of the solution. These outcomes would take into account LCA, technology assessment including environmental and energy performance using best practice.

For example, a beneficial GHG emissions balance compared to a suitable baseline (e.g. incineration or landfill); minimum material yield (e.g. 60 per cent of input material as useful material output / PCR); no use of the resulting product as fuel; regulatory regime to protect the environment, considerations of storage, use handling and transport of chemicals to be used and protection of public and occupational health; and adequate control of input, output and process emissions.

- **Create environments that incentivise investment:** Leverage policy and industry groups to increase R&D funding and blended capital to finance capacity expansion, and de-risk investments in infrastructure, especially until the technology reaches commercial viability. This could include the assurance that recycled material coming from chemical recycling facilities that comply with the standard discussed above can be accounted for in policy-established recycling targets.
- **Include the informal collection sector:** If chemical conversion facilities are in place, plastic types that were not recyclable before - and therefore its waste had no use - will become valuable. Informal waste pickers will add to the available solutions to collect these plastics if they can access fair prices. Women (often the majority of waste pickers) are often exposed to higher levels of chemicals and experience gender inequalities related to management of chemicals and waste, as highlighted in the topic sheet on '**Just Transition**'.

Additional resources

Plastic IQ solutions database. https://plasticiq.org/solutions/chemicalrecycling.

The Consumer Goods Forum Library. https://www.theconsumergoodsforum.com/news-resources/?_type=publications.

Kaushik, M. and Morgan, M. (2019). Is chemical recycling a game changer? IHS Markit 5. https://cdn.ihsmarkit.com/www/pdf/0820/Is-chemical-recycling-a-game-changer.pdf.

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The European Chemicals Agency [ECHA]. (2020). Chemical Recycling of Polymeric Materials from Waste in the Circular Economy. https://echa.europa.eu/documents/10162/1459379/chem_recycling_final_report_en.pdf/887c4182-8327-e197-0bc4-17a5d608de6e?t=1636708465520.

UN environment programme

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