Competing or complementary: the relationship between mechanical and chemical recycling of plastics

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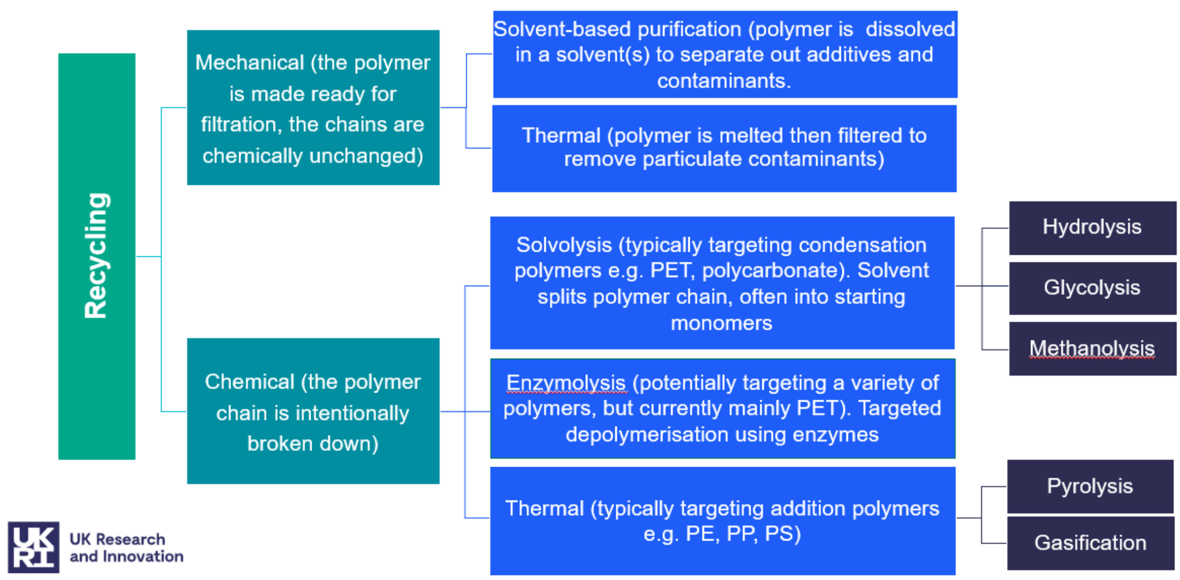
The chemical recycling of plastics is increasingly coming under the spotlight and this offers the opportunity for a more nuanced debate about the future role and value of this family of technologies, where it fits in the waste hierarchy, and how it aligns with the current and future management of end-of-life plastic.

It is a timely debate; public and political pressure is mounting to develop a more sustainable framework for plastics, and plastic packaging in particular. It is not just about plastic pollution – although the recent historic UN Environment Assembly resolution for an international legally binding agreement by 2024 to end plastic pollution is a clear signal that urgent action is needed in this space. It is also about resource conservation, circularity, carbon and the net zero agenda.

The million dollar question is whether mechanical and chemical recycling – and by this I mean plastic-to-plastic chemical recycling – compete or complement each other. In seeking to answer this question it is important to be clear what these processes involve. As mentioned above, chemical recycling is not a single technology but an umbrella term covering several processes that break the molecular bonds in the plastic waste to produce base chemicals and chemical feedstocks for different applications. Mechanical recycling can also involve different processes, but doesn't significantly alter the material's chemical structure. Figure 1 provides an overview:

Figure 1: Chemical and mechanical recycling processes



An evolving landscape

As plastic packaging recycling rates have risen since the early 2000s, mechanical recycling has become the primary recycling route for the main thermoplastics – polyethylene terephthalate (PET) and high-density polyethylene (HDPE) – used to make most of the drinks bottles in the household packaging waste stream, as well as bottles for laundry, personal care and household chemicals. In the last decade or so, increasing levels of recycling and improvements in sorting technology have brought in other polymers (mostly polypropylene [PP]) and packaging formats, such as pots, tubs and trays, and for these relatively clean and easy-to-separate plastic waste streams there is no question that mechanical recycling should continue to be seen as the optimum recycling route.

However, the plastics landscape is changing rapidly, which means we need solutions that go beyond these relatively easy to recycle waste streams.

Wide ranging policy, legislative and fiscal measures are being put in place around the world in an effort to tackle the problem of plastic waste by eliminating avoidable waste (e.g. single use plastic bans), increasing, expanding and improving recycling (e.g. deposit return systems, extended producer responsibility for packaging, recycled content taxes and targets) and tackling the export of the problematic waste streams to countries often less able to manage them in a responsible and environmentally safe way (tighter import and export controls). In parallel, there is a growing recognition that incinerating plastics is not the way forward from a carbon perspective.

Taken together, these significant policy interventions and developments will inevitably have a knock on effect on the downstream management and recycling of plastic waste. They will drive demand for recycling solutions for a wider range of polymers (any rationalisation of fossil-fuel based polymers could in the future potentially be offset by the growing number of biopolymers under development) and packaging formats and more challenging mixed and contaminated plastic waste streams, including:

- recyclable films and flexible packaging, which will be collected for recycling from both households and businesses across the UK by 31 March 2027 under current government proposals; and
- lower quality mixed plastics that are currently exported for sorting and recycling or disposed of via energy from waste facilities or landfill; in its 2020 'UK Household Plastic Packaging Sorting and Reprocessing Infrastructure' report, Recoup estimated that if the UK stopped plastic exports, domestic processing capacity would have to be boosted by around 140%.

They will also stimulate demand for high quality recyclate to allow packaging producers to hit the 30% recycled content threshold under the UK Plastic Packaging Tax regime. Again, Recoup's modelling suggested that the UK's reprocessing capacity may need to increase by 100% to meet 30% recycled content in all household plastic packaging placed on the market, and by over 200% to meet that target for food grade material. Very strict regulations governing the quality of recycled content used in food contact packaging, however, mean that this increased demand will be almost impossible to meet with mechanical recycling alone.

This is where plastic-to-plastic chemical recycling could play a complementary role to mechanical recycling. While these processes do have feedstock quality requirements, they are generally able to handle more mixed and contaminated plastic waste streams – particularly films and flexibles which are likely to have higher produce residues. And as they 'break' plastics back into the basic chemical building blocks for the manufacture of new plastic, chemically recycled material effectively becomes virgin material in terms of meeting food contact standards. This means chemical recycling has a potentially significant contribution to make to achieving higher levels of recycled content in these sensitive packaging applications in the future. How this contribution could be measured and accounted for is currently under discussion and there will be more on this is in a separate opinion piece.

Because of its potential to provide a solution for more diverse and lower quality feedstocks while still delivering a high quality output, chemical recycling has been described by some as the 'missing link' necessary to achieve a truly circular economy for plastics and Figures 2 and 3 show how the two technologies are essentially complementary. While it is true that further process innovation in mechanical recycling could result in some marginal overlap between the two technologies, even stakeholders who are cautious about the risk of technology 'competition' often acknowledge the potential role of chemical recycling as an 'additional' processing solution for plastic waste that would otherwise not be recycled.

Figure 2: Complementarity between chemical and mechanical recycling

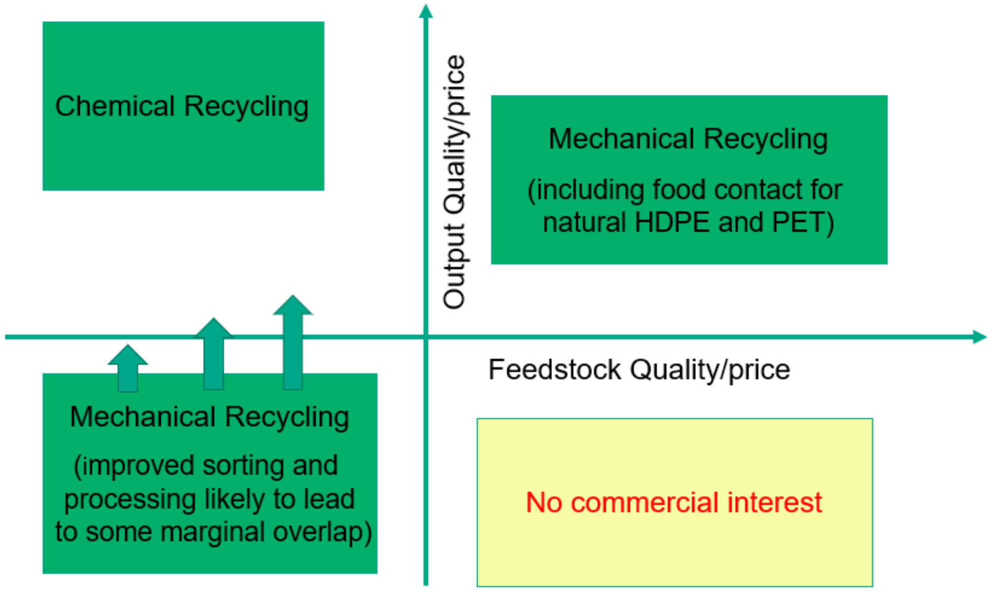


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Figure 3: Viability assessment of chemcial and mechanical recycling

Property	Mechanical Recycling	Chemical Recycling
Feedstock Sensitivity	High. Variable feedstock quality has large impact on yield as well as output quality	Lower but there are limits (especially PVC) and the limits are more stringent than often expected. Still TBC
Feedstock price	High, especially for consistent quality feedstocks	TBC but likely low/gate fee
Opex	Relatively low	Higher
Capex	Circa £1000/t/a	Very early but likely to be higher than mechanical recycling.
Output quality	Only natural HDPE and PET bottles convertible to food contact. Properties are generally diminished over multiple cycles	Feedstock capable of producing virgin polymer. May need hydrotreating / refining to be a cracker feedstock
Regulatory certainty	Very high	Status with regard to UK Plastic Packaging Tax is clear but not (yet) for Extended Producer Responsibility
Technical risk	Low	High, very few reference plants built and operating
Environmental outcome	Good CO_2/ good circularity/could be improved with greener solvents	Medium CO_2 (could be improved with electrification.etc)/ good circularity/could be improved with greener solvents

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Cleaner and greener

Circularity is not the only goal however; the net zero agenda is increasingly shaping the decision-making landscape. Chemically recycled feedstocks can deliver benefits in the petrochemical supply chain from a fossil fuel, carbon and potentially an energy perspective (one of the innovative technologies awarded funding from the SSPP Challenge will be publishing an LCA shortly indicating that in their process less energy is required to produce pyrolysis oil than virgin naphtha) and by reducing CO_2 emissions through the diversion of plastic waste from energy recovery. However, plastic-to-plastic chemical recycling is still currently more energy intensive than its mechanical counterpart, and efforts to decarbonise the energy input to these recycling processes will be an important factor in the business case for these technologies moving forwards.

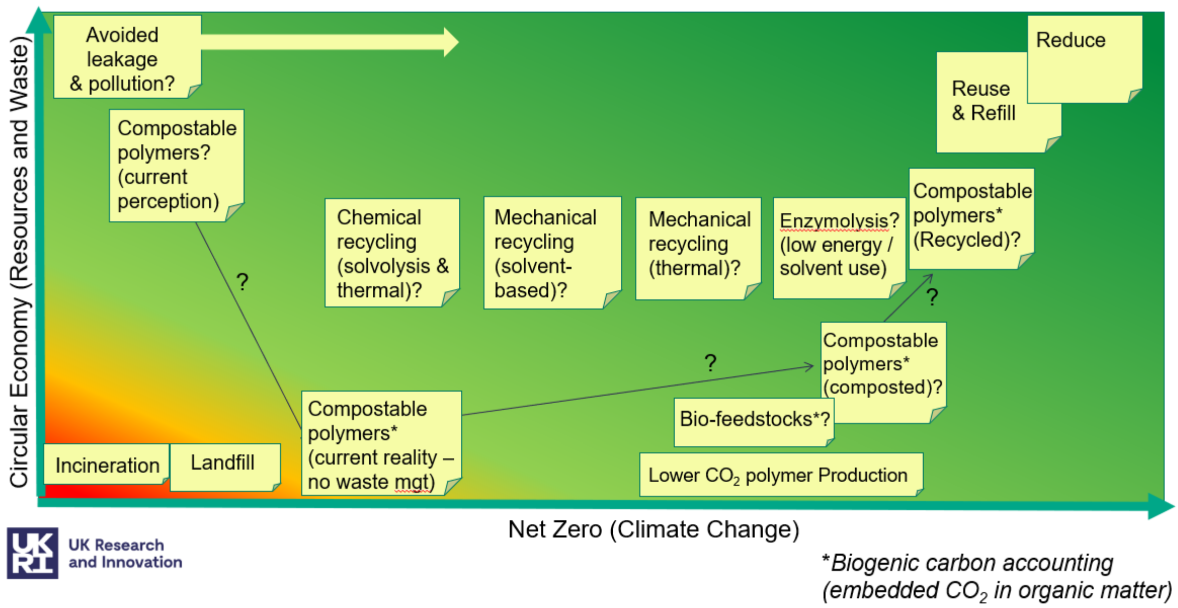
In addition, more information will be needed to address concerns about solvent use, recovery and recycling, how well hazardous chemicals can be removed (predominantly in non-packaging waste streams), and how the resulting process wastes are managed. A 2020 report by Eunomia Research & Consulting for CHEMTrust (Chemical Recycling: State of play) notes that consideration of these technologies is hampered by a general lack of transparency on these issues and observes that: "In the interests of confirming the role, scale and scope of these technologies, there is an urgent need for more transparency within the chemical recycling industry."

It is, however, important to remember that plastic-to-plastic chemical recycling is still in its infancy and there is significant innovation still to come. For this reason, the Smart Sustainable Plastic Packaging Challenge has awarded funding to a number of plastics-to-plastics chemical recycling projects, including two demonstrator plants and research into the use of super-critical water and CO_2 as greener solvents.

Mapping the options

So how do we balance all these factors when making decisions about future infrastructure? To deliver a step change in the way plastic waste is managed we will need to deploy a range of solutions. Pitting technologies against each other is often counter-productive – what we need to do is to map the combination of pathways that can help us deliver against the desired future outcomes.

Figure 4: Mapping the sustainable plastics landscape – a guesstimate



There will be no silver bullet; we have to think beyond the status quo and have an eye to the opportunities that exist for further innovation to help us on the journey.

Figure 4 is a rough attempt to start to capture the complexity of the current plastics sustainability landscape plotted against the twin priorities of circularity and net zero. What this shows is a complex and fluid situation, where different solutions are likely to move in response to different drivers and developments (technological/process innovation, policy and market shifts, etc) and decision making will almost always involve some sort of trade-off.

Notwithstanding global efforts to stop plastics leaking into the environment, and a growing focus on reducing unnecessary packaging, developing our recycling capacity also has to remain a priority. The OECD's Global Plastics Outlook, published earlier this year, shows that between 2000 and 2019, annual production of plastics doubled from 234Mt to 460 Mt, plastic waste more than doubled from 156Mt to 353Mt and the global recycling rate reached just 9%. With further growth in plastic production and waste forecast, we must recognise that mechanical recycling alone cannot meet this challenge and now is the time to build a better understanding of plastic-to-plastic chemical recycling and start thinking holistically about the role it could play in the journey to a more sustainable future for plastics.

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