Running round in circles?

David Sudolsky, Anellotech, USA, talks practical solutions for a circular economy, highlighting plastic waste as an alternative feedstock pathway for virgin polymers.

The rising tide of plastic usage has had a positive impact on our daily lives – but it also has a downside that threatens to overwhelm its societal benefit. According to some predictions, "If plastics demand follows its current trajectory, global plastics-waste would grow from 260 million tpy in 2016 to 460 million tpy by 2030, taking what is already a serious environmental problem to a whole new level".[1]

The chemical industry has begun to view the pursuit of viable techno-economic recycling pathways as an issue that is universal and worldwide in its impact. Responses from governments currently swing between banning certain single-use plastics and incentivising reduction, reuse and recycling – with uncertainty surrounding how aggressively to move on either response.

Beyond this broad-based mix of consumers, industry and government players, technology developers are considering varied approaches. To be successful, these solutions must be integrated, from the waste plastic supply chain (sourcing, composition, variability) to the product value end of the supply chain. Technological solutions are only one link in the chain, yet are essential to build a circular economy (Figure 1).

Therefore, the guiding premise for creating technological solutions are the traditional process development basics for the chemical industry: simple flow sheets, high yields, low by-product production, fewer environmental issues, plus the flexibility to adapt to wide compositional variations feeding the processes. These have been the guidelines for Anellotech's development of its plastic waste conversion process, named Plas-TCat™.

Broadly speaking, technology approaches fall into mechanical recycling or chemical recycling types. A promising example of this latter approach is the application of Anellotech's new thermal catalytic technology platform, Plas-TCat, to the conversion of mixed plastic waste directly into olefins and aromatics. The new process is the sister technology to Anellotech's Bio-TCat™ bio-based process analogue – described in a previous issue of *Hydrocarbon Engineering* – which aims to commercialise the innovative production of renewable chemicals and fuels from non-food biomass.[2]

The company plans to leverage its technology, laboratory facility, pilot scale infrastructure and partnerships to develop a process which would economically convert plastic waste into commodity chemicals. Using the Plas-TCat process, aromatics and olefins would be produced which can potentially be used to make virgin polymers to use in food and beverage packaging, textiles and plastic components for consumer products, the automotive industry and other markets. The process can also potentially allow conversion of mixed plastics streams, including composite films.

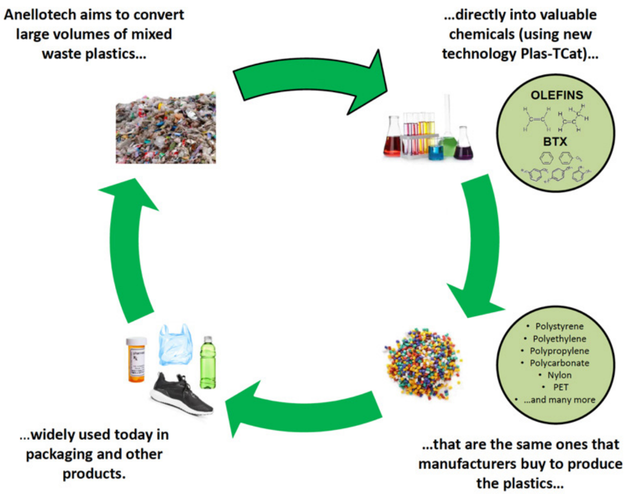

Figure 1. The plastic circular economy.

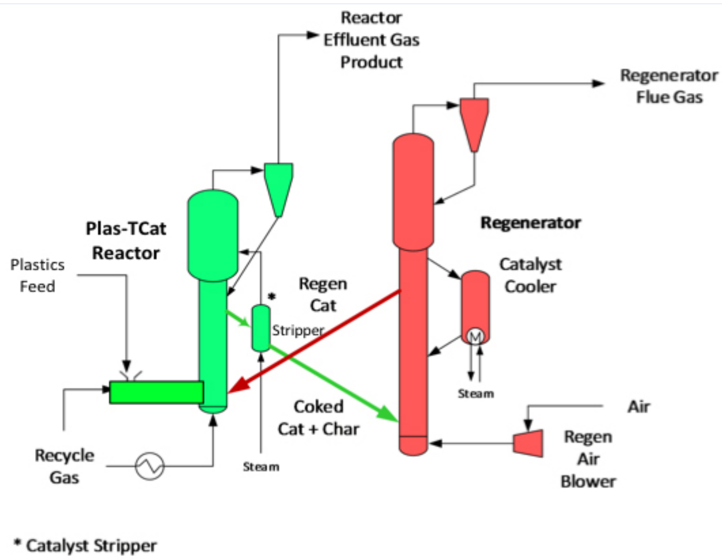

Figure 2. The Plast-TCat process.

By using this modern technology to recycle plastic waste, companies could produce aromatics and olefins directly – which can be more efficient than non-catalytic pyrolysis, the products of which require further upgrading in steam crackers. Making valuable products with a high yield could also allow payment for waste feedstock in countries without subsidised waste collection.

Textiles are another alternative feedstock being explored through the Tex-TCat™ process, which also leverages Anellotech's technology platform. Under consideration for conversion are cotton fabrics, synthetic fabrics (polyester, nylon, Lycra/Spandex, etc.) as well as blends, to turn into valuable aromatics and other chemicals to use as a 'drop-in' replacement for the petroleum-derived aromatics used to make the same virgin synthetic fabrics, or biofuels.

The Plas-TCat process is a simple process patterned on the familiar refining process of fluid catalytic cracking (FCC) as depicted in Figure 2.

Solid plastics feedstock would be ground into particles to be injected into a fluid-bed reactor. A combination of thermal cracking, pyrolysis and catalytic reactions converts solid materials into hydrocarbon products, which exit the reactor in the vapour phase. The fluid-bed catalyst may be temporarily deactivated by coke deposits that are a by-product of the plastic waste conversion – however, the coke is readily removed by oxidation in the catalyst regenerator. Catalyst continuously circulates between the reactor, a catalyst stripper for removing adsorbed hydrocarbons and the regenerator, via standpipes, and is controlled by slide valves in a manner analogous to a refinery FCC unit.

The pyrolysis of plastic waste is an ongoing area of R&D which began in the 1970s and continues to the present day. In the 1980s and 1990s, major corporations built large pyrolysis pilot plants, but never managed to reach commercialisation, presumably due to inadequate economics. More recently, start-up companies have rediscovered plastic pyrolysis as a solution to mixed plastic waste recycling and a variety of technologies are being piloted or commercialised. Plas-TCat technology is quite distinct from plastic pyrolysis technologies due to its effective use of proprietary catalysts. The process' potential for waste plastic conversion is showing early indications of economic and technical viability.

Plastic pyrolysis has been categorised into three operating ranges, low temperature (‹ 400˚C), mid-range (400 – 600˚C), and high temperature (› 600˚C) processing. The technology fits most comfortably into the mid-temperature category and provides additional benefits of in-situ catalytic conversion. At mid-range temperatures, most plastic types are expected to be converted in the process to a mixture of light olefins such as ethylene and propylene, light paraffins such as methane and ethane, BTX aromatics, and by-products especially coke-on-catalyst, char, and light heteroatom gases and vapours depending on the heteroatoms present in the plastic waste (e.g. CO, CO_2, H_2O, NH_3, H_2S, HCl, etc.). The formation of coke should not necessarily be discouraged, since regeneration of the catalyst by burning away coke deposits in the regenerator releases heat which returns to the reactor with the circulating catalyst stream. This interchange of energy is what drives the pyrolysis and catalytic reactions in the reactor and is the same principle applied in refinery FCC processing. The fluidised bed of catalyst in the reactor also facilitates and promotes heat transfer which is an important element of the technology. Rapid heating of the feed helps to minimise the formation of char, tar and heavy hydrocarbon materials.

The potential yields of plastic pyrolysis products will depend strongly on the chemical makeup and stoichiometry of the polymer material, especially its effective hydrogen to carbon molar ratio. In general, catalytic pyrolysis yields are controlled by thermodynamic driving forces and the amount of hydrogen and carbon remaining in the reaction system after the thermodynamically most-favoured compounds are accounted for. In oxygen-containing systems, carbon dioxide is the energetically most-favoured light molecule, followed by water, then carbon monoxide. In nitrogen-containing systems, ammonia is favoured. Yields of hydrocarbon products from the catalytic pyrolysis of waste plastics are expected to be highest for polyolefins and to be lower for materials that contain significant heteroatom content. In a mixed waste plastic stream, the overall yield will depend on the concentration of each type of plastic in the mix and the chemical structure of the repeating units in each polymer. Additional yield effects will include the type of catalyst, the reactor temperature, residence time, pressure, and heat-up rate.

RESIN NUMBER	ABBREVIATION	FULL NAMES	SOME COMMON APPLICATIONS	LAB SCALE STUDIES
1	PETE	Polyethylene terephthalate	Soda bottles, water bottles, food packaging	✓
2	HDPE	High-density polyethylene	Detergent bleach, milk, motor oil bottles	✓
3	PVC	Polyvinyl chloride	Plastic piping, toys, furnishings	UNDER DEVELOPMENT
4	LDPE	Low-density polyethylene	Plastic wrap, grocery bags, sandwich bags	✓
5	PP	Polypropylene	Clothing, bottles, tubs, ropes	✓
6	PS	Polystyrene	Cups, foam food trays, packing peanuts	✓
7	Other	Other	Various applications	Poly-isoprene, Tires, Nylon, Cellulose Acetate, Cellulose

Figure 3. Anellotech laboratory screening results.

Anellotech is well-suited to develop this critically-needed plastic waste recycling technology. Its fully operational laboratory testing units in Pearl River, New York, US, and its large-scale TCat-8 pilot plant in Silsbee, Texas, US, have been used to validate the wood conversion application and can be adapted for developing a plastics conversion process.

The company is in the process of adapting its wood conversion process for mixed waste plastic feedstocks and plans to generate the engineering data required for process design, scale-up, and economic analyses in the 2020 – 2021 timeframe. Some of these tests are to ensure the Plas-TCat process is robust and capable of running long-term, on a range of real-world waste plastics feedstocks, with all the impurities that come with them.

The company has undertaken laboratory studies to assess performance in the Plas-TCat reaction environment (Figure 3).

The process has the potential to transform plastic waste such as composite films, mixed plastics and plastics with biomass – such as paper labels – directly into valuable chemicals. It can handle oxygenated polymers, an important advantage over pyrolysis processes that produce complex oil mixtures which require upgrading and additional conversion in steam crackers. This allows the technology to align with most hydrocarbon processing industry sustainability goals.

This new process offers an enabling and economically sound solution to the growing problem of plastic waste, in pursuit of a circular solution to ameliorate the adverse environmental impact of plastics pollution.[1] While plastics is a segment of materials essential to our modern economy, Plas-TCat tackles the consequences of unchecked plastic waste and could help transform the chemical industry.

References

1. HUNDERTMARK, T., MAYER, M., MCNALLY, C., SIMONS, T.J., and WITTE, C., 'How plastics waste recycling could transform the chemical industry', McKinsey & Company Chemicals Insights, (December 2018), https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry
2. SORENSEN, C., SUDOLSKY, D., FEUGNET, F., and BECCAT, P., 'Seeing the wood for the trees', *Hydrocarbon Engineering*, Vol. 24, No. 3, (March 2019), pp. 134 – 139.