CHEMICAL RECYCLING VIA PYROLYSIS – CLOSING THE LOOP IN THE PLASTICS INDUSTRY

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An established technology becomes commercially viable

Over the past five years, the amount of plastics waste generated by consumers in the European Union grew to around 33 million tons, an increase of roughly three percent year-on-year. Only 40 percent of that waste is recycled, the majority ending up as landfill or in incinerators. The result? Non-recycled plastic pollutes our fields, rivers and oceans, plastics escape from landfills after storms or flooding, and incineration causes harmful CO2 emissions. A solution is urgently needed. Could the established technology known as pyrolysis be the answer?

The European Union has taken numerous actions to address the growing problem of plastic waste, such as enacting measures reducing the use of single-use plastics (2015), a plastics waste strategy that is limiting the amount of waste going to landfills and pushing an increased recycling ratio (2018) and a ban of single-use plastics (2021). The plastics waste issue is also recognized as a large and growing global problem, which is now also tackled by the UN: In March 2022 175 nations endorsed a landmark resolution at the UN Environment Assembly in Nairobi to end plastic pollution. The vision is to forge an international legally binding agreement by the end of 2024, which addresses the full lifecycle of plastics.

But while new recycling initiatives show promising results, there are limits on what conventional recycling can achieve. In particular, the recycled materials produced are often of lower quality than non-recycled materials and therefore of limited use to the food, personal care/cosmetics and pharmaceuticals/healthcare industries.

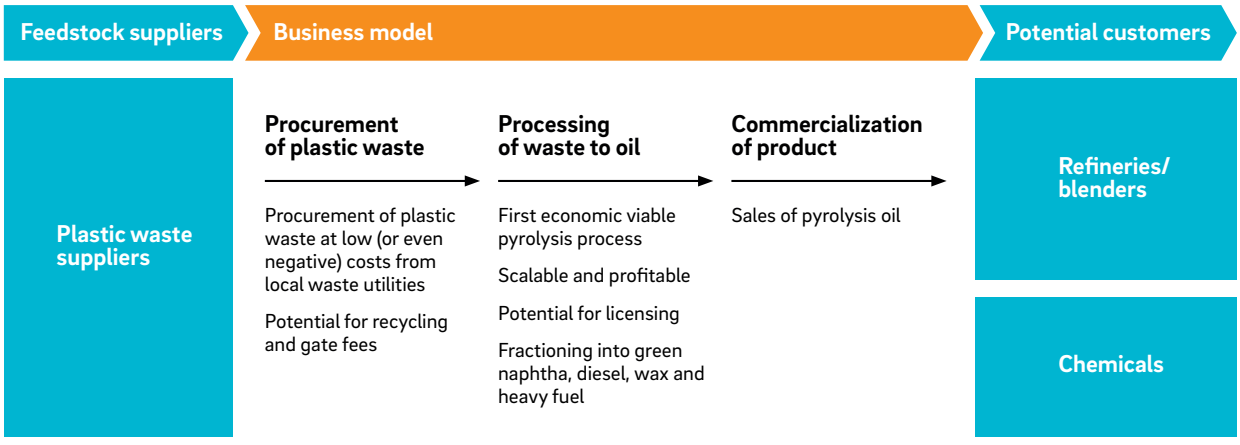
Pyrolysis – an established technology finds a new application

Chemical recycling could be a solution to complement the mechanical recycling and handle this significant mixed plastics waste stream. Chemical recycling can be differentiated into pyrolysis, gasification, and solvent liquefaction or solvolysis. Recently several players in the industry have announced activities in pyrolysis – so we will have a closer look. The pyrolysis process is a well-known, established technology in certain applications – e.g., to produce charcoal. However, its use in the treatment of plastic waste is still relatively new. Several pilot plants around the globe successfully demonstrated the concept. The technology is particularly suitable for treating mixed plastic waste. And best of all, the circular products from this form of chemical recycling come without any compromise in terms of quality or suitability for end-use applications – be it naphtha, distillates or waxes.

Today, pyrolysis plants already exist with a processing capacity of up to 20,000 metric tons of plastic waste per year. However, this is an order of magnitude that covers only a small fraction of a single chemical plant's annual demand for naphtha, for example. A number of market players have announced the construction of new facilities over the coming five years that will have capacities of more than 200 kilotons each, either as single unit or as several smaller units running in parallel. The increase in total capacity will result in scale effects and the pyrolysis is beginning to be used commercially as important solution for chemical plastics recycling, opening the door to a potentially multibillion euro market.

The business model consists of three steps

Sourcing of plastic waste, conversion through pyrolysis/fractioning and sales of final products



Source Roland Berger

A truly circular solution

In brief, pyrolysis is a thermochemical treatment that can be applied to any organic (that is, carbon-based) waste material, including both sorted waste and mixtures. It involves exposing the material to a high temperature in the absence of oxygen, thus breaking down various chemical molecules. This distinguishes it from incineration and gasification processes, which oxidize all or part of the material. Pyrolysis produces solids such as coke or carbon black, liquids such as naphtha or diesel, wax, or non-condensable gases such as hydrogen, methane, CO, or CO_2 – the feedstock and temperature used determine the composition and yield of the products.

For a continuous process, the feedstock material is fed into the reactor via a lock and heated. Inside the reactor, the material is transported by a screw conveyor at a defined speed to the end of the process. Gaseous products are condensed into pyrolysis oil and, if required, separated into individual circular hydrocarbon fractions by a distillation unit. Part of the gas is separated beforehand and used to heat the process.

Using pyrolysis to treat mixed plastics is a truly circular solution. The basic raw materials produced can be processed into new products for the chemical industry and are particularly suitable as basic raw materials for further processing into fuels as they contain no sulfur, or at least much less than the typical streams of fossil gasoline or diesel from crude oil. The incineration of plastic waste to produce electricity, typically generates carbon emissions of 2.5-3.0 tons of CO_2 per ton of plastic waste. Compared to that the carbon footprint of pyrolysis is far smaller, at around 0.35-0.4 tCO_2/t plastic waste. If the CO_2 emissions from crude oil production and transportation are included in a well-to-plastic consideration, the CO_2 benefits of the technology are even greater. Pyrolysis also eliminates the risk of pollution to fields, rivers and oceans, or of mixed plastic waste ending up as micro-plastic in the organisms of humans and wildlife.

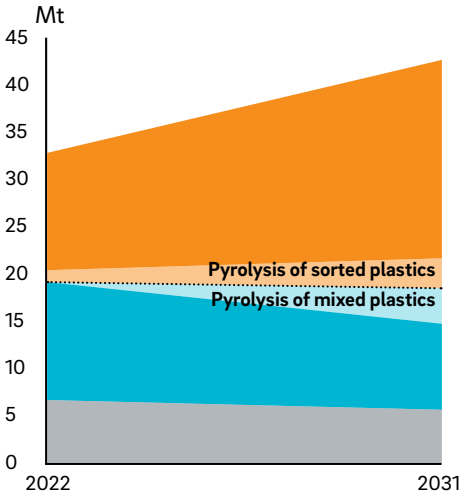
WALTER PFEIFFER
Partner

"Chemical recycling closes the loop for the plastics industry by re-converting plastic waste into its original components – potentially opening the door to a multibillion-euro market."

Understanding the market

In 2022 Europe generated around 33 million tons of plastic waste. Pure waste such as transparent or single-color PET bottles is mechanically recycled (collected, sorted and shredded) and reused as flakes in the manufacture of new plastic products. Currently, less than 40 percent of the total plastic waste generated in Europe is recycled mechanically. The share with more than 60% is mainly mixed plastic waste. It is sent for incineration for power generation, burned in cement kilns, or is sent to landfills.

Potential post-consumer plastic waste addressable market in Europe[1] of 3.4 Mt in 2030



1 EU27, UK, Norway and Switzerland, assuming recycling targets are met

Source: Plastics Europe; European Commission; Roland Berger

Sorted plastic waste

RECYCLING: Increasing share due to recycling targets
(EU Circular Economy Package: 55% plastic packaging recycling in 2030)
MECHANICAL RECYCLING is currently penetrating the market –
bold EU targets, but many drawbacks and obstacles
CHEMICAL RECYCLING of sorted plastics (including by pyrolysis)
will increase in the future
DEVELOPMENT OF PYROLYSIS MARKET
based on Plastics Europe forecast with a recycled plastics production
of approx. 3.4 Mt from chemical recycling in 2030

Mixed plastic waste

LANDFILL: Decreasing share due to landfill targets
(EU Landfill Directive: 10% in 2035)
INCINERATION: Decreasing due to increasing awareness about carbon emissions
DEVELOPMENT OF PYROLYSIS MARKET
based on Plastics Europe forecast with a recycled plastics production
of approx. 3.4 Mt from chemical recycling in 2030

Recycling Incineration Landfill

Roland Berger

As an alternative to incineration or landfill, pyrolysis (plastic-to-chemicals and plastic-to-oil) will increasingly replace these traditional treatment methods in the coming years. In a market model developed by Roland Berger we calculate the potential addressable market value of mixed plastic pyrolysis in 2022 to be around EUR 5.6 billion. Even with higher mechanical recycling we expect this figure to remain largely stable over the coming decade. The products from the pyrolysis process are mainly naphtha, diesel, heavy fuel oil and wax, with naphtha and wax particularly attractive for the downstream industry and hence able to achieve price premiums. Potential off takers for pyrolysis oil are refineries/blenders for fuels and chemical companies for feedstock. Products with a circular end-use such as naphtha to produce circular plastics and waxes are in high demand and can achieve a premium in the market.

We identify two main drivers of market growth: Sustainability considerations by the participants in the value chain and a strong regulatory push. Sustainability considerations are leading to growing pressure on companies to decarbonize, make their products circular and deliver against ESG criteria (environmental, social and governance). Looking at regulation EU directives and their implementation in local laws are driving the market development. However, the current regulatory framework in Europe does not acknowledge the potential of pyrolysis oil technology. For instance, pyrolysis plants are covered under EU ETS (Emissions Trading System) regulation if they exceed a certain size and are not classified as waste incineration plants, which for the time being are exempt from the ETS. The European Union provides support mainly for the plastic-to-plastic route. However, given the European Union's ambitious recycling targets for 2025 and 2030, the plastic-to-chemicals route will form an essential complement to this. The proven mass balance approach can ensure that the end products from pyrolysis are certified as circular products for further processing.

"Climate change and CO2 mitigation are one of the biggest challenges of our time – Circular economy is an effective building block"

JOERG KLASEN
Principal

The current regulations support mainly the plastic-to-plastic route

Waste

European legislation requires increasing recycling quotas for plastic waste.

Taxonomy for chemical recycling not yet standardized across countries.

Chemical

Products made from plastic-to-plastic will be accounted for as circular pro rata according to share of circular feedstock.

Role of chemical recycling is set to grow if regulation clearly acknowledges its value for waste reduction.

Fuel

EU requires fuel distributors to blend fossil fuels with decarbonized fuels.

Plastic-to-fuel is allowed in principle on a European level – countries can opt in or out.

Other

Uncertain if pyrolysis is regulated under the EU ETS.

Pyrolysis plants would profit if exemption for waste incinerations were stopped, as is currently being discussed.

Source Roland Berger

Roland Berger

Competition is heating up

As the market begins to evolve, the number of players is also growing – although all players are currently in the investment phase and not yet making money. The competition consists of direct market participants, that is, players that operate pyrolysis plants transforming plastic waste to pyrolysis oil, and there are also indirect market participants, with players from the waste and recycling industry and players that produce pyrolysis oil from other feedstock, such as vehicle tires or biomass. Only a few players have so far been able to take their concepts from demonstration stage to pilot plant, and finally to commercial plant level. Plant sizes are generally under 20 kt/a at the moment but are expected to exceed 200 kt/a within the next five years. Several players have entered strategic partnerships with chemical or oil companies and subsequently announced major investments in the construction of larger plants. While some players will certainly succeed in the market, it is expected that others will fail to reach commercial viability.

Our research shows that the main barrier to market entry at present is specific knowledge about the pyrolysis process, in particular experience running it successfully on a commercial level. According to market players, key criteria in the market are the consistent quality of the outputs in line with the specifications, reliable supply and volume. Individual chemical recycling and pyrolysis companies vary in terms of the specific feedstocks they use, their processing technology and their off-taker partners and alliances.

What lies ahead?

As we have seen, pyrolysis is a potential solution for closing the loop in the plastics industry by re-converting plastic waste into its original components. It can help to substantially increase the recycling rate and to make a valuable contribution to the circular economy and the acceptance of the petrochemical industry. For example, "green naphtha" made from pyrolysis oil can gradually displace conventional naphtha from crude oil in the ethylene cracker.

For the success of pyrolysis as a circular solution it is essential that the legal framework is acknowledging its potential. Particularly pyrolysis and other chemical recycling technologies should count towards the recycling quotas required under EU legislation – if the mass-balance of the process is verified by an independent certification company. Even if this is addressed, market players still face the challenge of scaling up to commercial operations in order to supply a sufficiently large quantity of pyrolysis oil of consistent quality to the fuels and chemicals industry. Players with strong technological capabilities and a smart setup with access to adequate volumes of mixed plastics waste will have the greatest chance of success, creating substantial value for shareholders and investors. Their journey will be considerably simpler if regulators accept pyrolysis as part of the solution and a vital component in the transition into a circular world.

Further reading

CLOSING THE LOOP ON THE CIRCULAR ECONOMY
➔ rb.digital/closing_the_loop_on_the_circular_economy

SUSTAINABILITY AND THE EMERGING CIRCULAR ECONOMY
➔ rb.digital/sustainability_and_the_emerging_circular_economy

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