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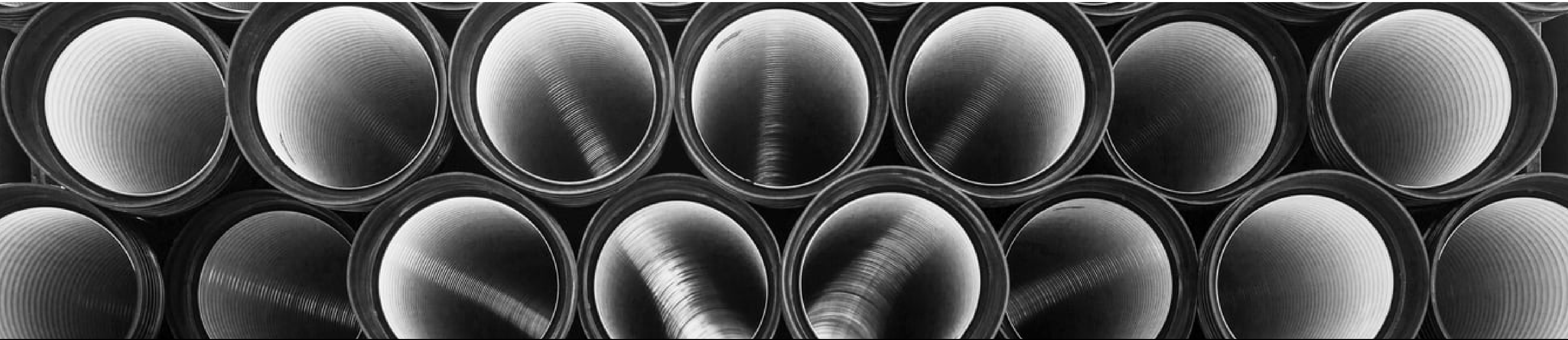


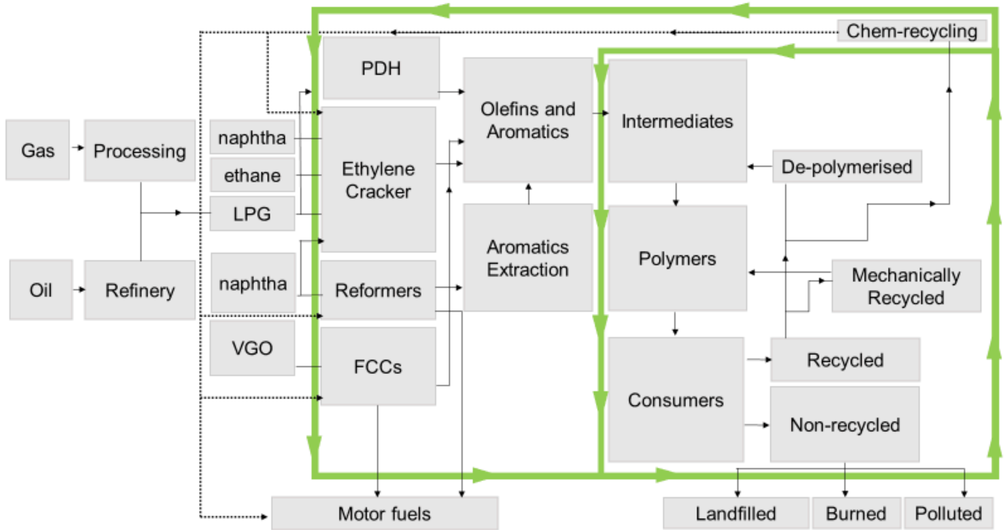
Chemical recycling: an overview of technology, market growth, and environmental impact

Platts Future Energy Outlooks Special Report

Non-energy demand for oil, particularly chemical feedstock demand, has been one of the fastest-growing portions of oil demand over the past decade. This trend is set to continue over the coming decades as fuel demand languishes on increasing decarbonization goals. Meanwhile, topline demand for polymers (HDPE, LLDPE, PP, PET) will continue to grow in the coming years with higher use in durable (automotive and construction) and non-durable applications (fibers and packaging). However, there are headwinds for continued increases in demand for feedstock naphtha, LPG, and ethane into petrochemical markets. Leakage of plastics into the environment (especially single-use plastics) has led to policy initiatives to reduce consumption or, in most instances, increase the amount of recycled content in packaging. An increase in reusing recycled content can happen in several ways and include mechanical, chemical and depolymerization recycling of plastics. In this special report, we look at the current state of chemical recycling, a proven technology with a small production base that is quickly growing in popularity due to its scalability and fungible outputs of LPG, naphtha and diesel-range products.

As mentioned, there are three main routes to recycling plastics - mechanical, chemical and depolymerization. Currently, the market is dominated by mechanical recycling. In mechanical recycling, recycled content is collected at the curbside, transported to a sorting facility, cleaned, and then ground into flakes. Depending on the quality of the flake, an extruder can make food-grade or non-food grade pellets. These pellets can then be mixed with virgin plastics for either food-grade (beverage bottles or plastic trays) or non-food-grade applications (motor oil containers, fiber for cushion filing).

Technically, mechanical recycling is simple. However, there are challenges to scaling this form of recycling. One, there must be a high level of collection in place to have a product stream to convert to recycled pellets. In 2018, 32.5% of post-consumer plastic waste was collected to be recycled in Europe, according to the European Union. In the U.S. the number is even lower at around 15%. There are EU mandates now in place to increase those levels by 2025 and 2030 (see policy section). Another challenge in mechanical recycling is in the output stream. To reuse mechanically recycled plastic in virgin food-grade applications there must be a high level of purity, a factor that adds costs to the process.



Depolymerization is another recycling technology that allows for waste feed streams to be converted into their pure monomers. The most common application of this technology has been to the PET chain where the feed is converted to PTA and MEG. The PTA and MEG can then be reused to make polymers. Unlike pyrolysis, depolymerization of PET needs a feedstock that has a specific chemical composition. Depolymerization usually occurs using a solvent but companies are exploring other options. French-based company Carbios has developed an enzyme to break down PET into monomers. The company is building an industrial plant in France which is due online at the end of 2021.

Chemical recycling is a broad-based term but in general, it is the process of thermally breaking down plastics into chemical feedstocks which can then re-enter the chemical production process. **This area of the recycling market is garnering a lot of interest as it allows mixed feeds to come into the recycling system at the end of life**. In addition, chemical recycling produces products that are fungible with traditional hydrocarbons such as naphtha, propane, jet fuel, and diesel. As a result, chemical units can take naphtha from a chemical recycling unit and run it back into the naphtha cracker the same way it would use naphtha distilled from crude oil.

Proven technology

The most common method of chemical recycling is pyrolysis, a proven technology that has been around for decades. In pyrolysis, feed waste plastics are heated in the absence of oxygen (with or without catalysts) to break down long-chained molecules into shorter chained molecules. Temperatures in this cracking process range from 300–900°C and depend on the feedstock used (HDPE, LDPE, PP, etc.). The shorter chained "cracked" molecules are distilled into different purity streams that include products such as diesel, jet fuel and naphtha. These purity product streams can then enter back into refinery or chemical operations and be treated the same as "virgin" products derived from crude. A close analogy would be fully fungible renewable diesel being blended with non-renewable diesel.

As mentioned earlier, a challenge with mechanical recycling is sorting and cleaning. Recycled content from homes is usually mixed which means the recycling center must clean and sort the waste into individual streams such as HDPE, PP, PET, etc. In addition, there are very strict contamination limits on food-grade plastics, which results in mechanically recycled content often getting downcycled into alternative end uses such as non-food grade plastic bottles, tarmac filler, or decking. In the case of chemical recycling, the feed product has lower restrictions on what can be fed into the pyrolysis unit. Some plastics, such as PVC, present challenges in pyrolysis due to the presence of HCL but common plastics such as HDPE, LLDPE, and PP can be fed as a mixed stream.

In terms of yields, chemical recycling produces a range of products that range from gases to fuel oils. For the petrochemical market, naphtha is the most important feedstock. Yields of naphtha can vary based on the technology employed and feedstock used but companies have said yields of around 0.6 mt of naphtha feedstocks are possible for every mt of mixed feed.

Commitments and market growth

Chemical recycling has traditionally been a niche market with small-scale plants. However, with changing policy and stronger company commitments (see commitments on right) around recycling and reuse, there is strong investment growth into chemical recycling. Many of the world's largest petrochemical companies have entered into offtake agreements (see Table 1) with chemical recycling companies. For example, in Europe, Plastic Energy has entered into offtake agreements with SABIC and Total. Plastic Energy's naphtha output, TACOIL, is already being used at petrochemical facilities in the Netherlands and France and they have ambitions to grow their footprint into Asia. The company has signed a non-binding agreement with Petronas to develop projects in Indonesia.

Mura Technology announced in April that its Teeside, England, facility will supply pyrolysis naphtha to Dow's facilities. The 20,000 mt mixed-feed plastics facility will come online in 2022 and look to expand to 80,000 mt over the coming years, the company has said. In the U.S., several players are also procuring or are in plans to acquire naphtha from pyrolysis of mixed plastic feeds. Shell announced last year that it will extend an agreement with Atlanta-based Nexus fuels to purchase pyrolysis naphtha. CP Chemical also stated that it would be using naphtha from Nexus. Brightmark's Ashley, Indiana chemical recycling plant, which will be the largest chemical recycling plant in the world at 100,000 mt, is due to come online at the end of 2021. Brightmark has said that all the fuels will go to BP. In addition, Brightmark and SK Global Chemical announced in January they had signed a MOU to develop a 100,000 mt/year plant in South Korea.

Petchem Producer Commitments to Recycled Plastics

- **BASF** has set itself the goal to process 250,000 mt/year of recycled feedstock annually from 2025 onwards.
- Dow rollout of 1 million mt/year of recycling capacity by 2025.
- **Shell** targets to process 1 million mt/year of plastic waste for recycling by 2025
- **Lyondell Basell** to produce and market 2 million mt/year of recycled and renewable-based polymers annually by 2030
- **Braskem** recycled products portfolio to sales of 300,000 mt/year by 2025 and 1 million mt/year by 2030

Source: Various company announcements

Several companies are also utilizing recycled styrene through Agilyx's technology. This process breaks down polystyrene into feedstock styrene which can then be used again in the production of polystyrene or used for other styrene derivatives such as ABS. Agilyx is supplying American Styrenic's plants with styrene. Agilyx technology is also being used in Europe by INEOS and Trinseo.

Table 1: Chemical recycling capacities and offtake agreements

Company	Offtaker	Location	Waste input Capacity (mt)	Start	Output
Plastic Energy	SABIC	Geleen	20,000	2022	Pyrolysis naphtha
Plastic Energy	TOTAL	Grandpuits	15,000	2023	Pyrolysis naphtha
Plastic Energy	TOTAL	Seville	5,000	2017	Pyrolysis naphtha
Plastic Energy	TOTAL	Almeira	5,000	2015	Pyrolysis naphtha
Plastic Energy	Exxon	Notre Dame Gravenchon	25,000	2023	Pyrolysis naphtha
Plastic Energy	INEOS	Kohln*	30,000	2023	Pyrolysis naphtha
Quantafuel	BASF	Skive	16,000	2019	Pyrolysis naphtha
New Energy	BASF	Budapest	8,000	2018	Pyrolysis naphtha
Feunix Ecogy	Dow	Ternuezen	-	2019	Pyrolysis naphtha
Mura	Dow	Teeside	20,000	2022	Pyrolysis naphtha
Recycling Technologies	Ineos	Wingles	15,000	[illegible]	Styrene

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https://insight.spglobal.com/story/future-energy-outlooks-special-report-chemical-recycling/page/2/4

Environmental benefit or cost?

Chemical recycling is touted by some as the silver bullet solution to addressing environmental concerns associated with waste plastic and to lessen the reliance on oil-derived feedstocks to meet plastics demand. One of the key benefits of chemical recycling is a greater allowance of mixed streams of plastics and the ability to use output pyrolysis naphtha as a fungible product to virgin naphtha derived from crude oil. The nature of the chemical recycling process means there isn't any "downcycling" which often occurs with mechanical recycling when the product is not of the highest purity. However, chemical recycling does have an environmental footprint that must be weighed against alternatives in determining its net environmental impact relative to alternatives such as virgin sourced plastics.

With chemical recycling, the waste product streams need to be collected, sent to a chemical recycling plant, processed (using high levels of energy in pyrolysis crackers) and then transported back to cracking units which can then crack the pyrolysis naphtha. Various life cycle analyses have been done around the environmental costs of chemical recycling versus different alternatives. Results of those analyses vary greatly and depend on the assumptions made around the alternatives to chemically recycling the plastic. For example, there are generally three main end-of-life routes for plastics: landfilling, incinerating, or recycling (mechanical, depolymerizing, or chemical).

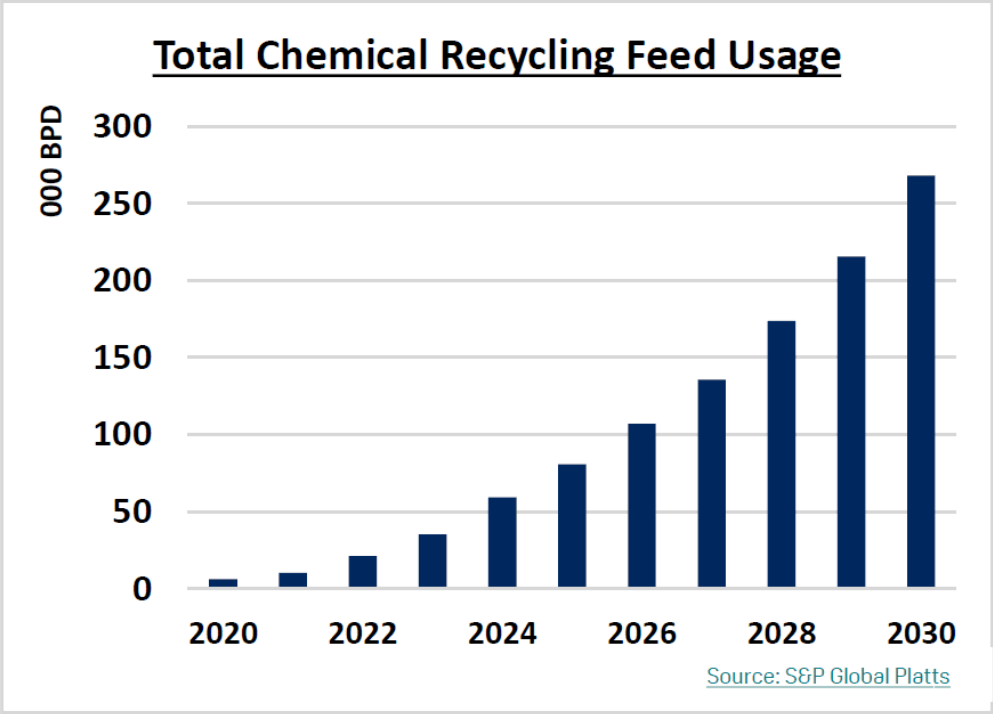
Recently, BASF conducted a study to compare the carbon footprint of chemical recycling versus other end-of-life options for plastics. The study, which was independently reviewed, concluded that chemical recycling emits 2.3 mt less CO2 as compared to an alternative of producing plastics from fossil sources. A key assumption was that a credit of 3.7 mt CO2 was given to chemically recycled plastics as it avoided emissions from incineration. The study also showed that utilizing chemical recycling and mechanical recycling to produce new plastics emits around the same level of emission per mt of plastics produced. The BASF study did not compare the CO2 impact of landfilling waste plastics instead of recycling or incineration. However, Plastic Energy conducted an independent life cycle analysis study of chemical recycling in 2020 and compared landfilling as an end-of-life option for plastics. The study concluded that landfilling had the lowest environmental impact out of the three end-of-life options. The study concluded: **"For climate change, landfill shows the lowest impact, followed by chemically recycled LDPE, and incineration. For resource use, fossil chemically recycled LDPE is the most favorable solution, showing environmental credits related to the avoided production of virgin naphtha."** The Plastic Energy study concluded the following in terms of re-using resources: **"compared to virgin (fossil) LDPE, chemically recycled LDPE has lower climate change and resources depletion scores."**

In summary, the environmental costs associated with chemical recycling depends on what assumptions are made about the end of life of plastics. If the assumption is that plastics will be burned or leaked into oceans, then chemical and mechanical recycling are better options. However, if landfilling and monitoring the landfill site with strict protocols is the alternative, then this plastic is a form of carbon capture as the carbon molecules in the plastic are highly stable.

Small but poised to grow

One clear challenge to chemical recycling, and recycling in general is economies of scale. The largest world-scale chemical recycling plant is currently under construction and will only be able to take in 100,000 mt/year of mixed plastics. By comparison, it is common to see polyethylene or polypropylene facilities with 300,000-500,000 mt/year of capacity. Typically, at least 2-3 of these plants come online every year. This small level of scale in recycling is a function of the market's logistics. Most waste comes from disparate locations that need to be aggregated and then transported to sorting and then chemical recycling plant. These all add costs along the value chain. By comparison, a world-scale naphtha or ethane cracker will be connected by a pipeline to storage terminals.

Despite these challenges, the industry is moving in a growth direction regarding circular plastics. Companies such as BASF have come out with goals in terms of recycled feedstock usage. BASF's target is 250,000 mt by 2025, which equates to roughly 6,000 bpd of naphtha. Other companies have released targets for recycled plastics content production, where a combination of both mechanical and chemical recycling will most likely be used. To put chemical recycling into context, global naphtha usage into ethylene production will be about 250 million mt/year or 6.3 million bpd in 2025. That amount could come from either virgin naphtha, bio naphtha or pyrolysis naphtha through recycled mechanisms. Currently, we estimate that chemical recycling volumes arearound 10,000 bpd. If we assume that just 1% of cracker feeds come from chemical recycled feedstocks by 2025, this would represent 2.5 million mt/year (63,000 bpd) of naphtha from chemical recycling going into crackers. The virgin feedstock reduction from chemical recycling Source: S&P Global Platts equates to about 50% of a world scale naphtha cracker in 2025. However, as the chart on the right shows, increasing growth in chemical recycling means that **chemical recycling will only displace the need for about two world-scale naphtha crackers by 2030**.



- Mike McCafferty, scenarioanalytics@spglobal.com