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# The Circular Economy and Net Zero Goals for Plastics

Whitepaper

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# The Circular Economy and Net Zero Goals for Plastics

The development of a circular ecosystem for plastics is not occurring in isolation, but rather within the overall context of the broader energy transition to net zero. According to the Paris Agreement, to keep global warming below 1.5 deg. C, emissions need to be reduced by 45% by 2030 and reach net zero by 2050, As plastics production is highly integrated with base chemical feedstocks from the petroleum industry, chemicals/plastics producers must work simultaneously to reach targets for plastics circularity while reducing carbon emissions. When viewed from a scope 1 & 2 perspective, pursuing both objectives would appear to create conflicts that must be addressed.

It is well accepted that mechanical recycling has the potential to provide high-value recycled plastics with a carbon footprint lower than that from virgin production, but with limitations due to a number of factors including traceability of contents and requirement of a homogenous waste stream as feedstock. As such, processing the more difficult waste plastics streams via dissolution and chemical routes (e.g., pyrolysis) are projected to complement mechanical recycling. The dissolution recycling process involves sorted plastic waste which is first dissolved with solvents into a solution of polymers and additives and then separated to recover the polymer and solvents. The process is carbon efficient, when compared to the virgin route for polypropylene, and slightly less carbon intensive for polystyrene (PS/EPS). Pursuing a circular model for plastics, therefore, requires adoption of multiple options, often with additional emissions, which complicate the concurrent transition to net zero and driving home the need for transparent data and standardized analyses to advance both objectives.

## Scope 1 & 2 carbon emissions from chemical recycling present varying challenges depending on process and loading of recycle content.

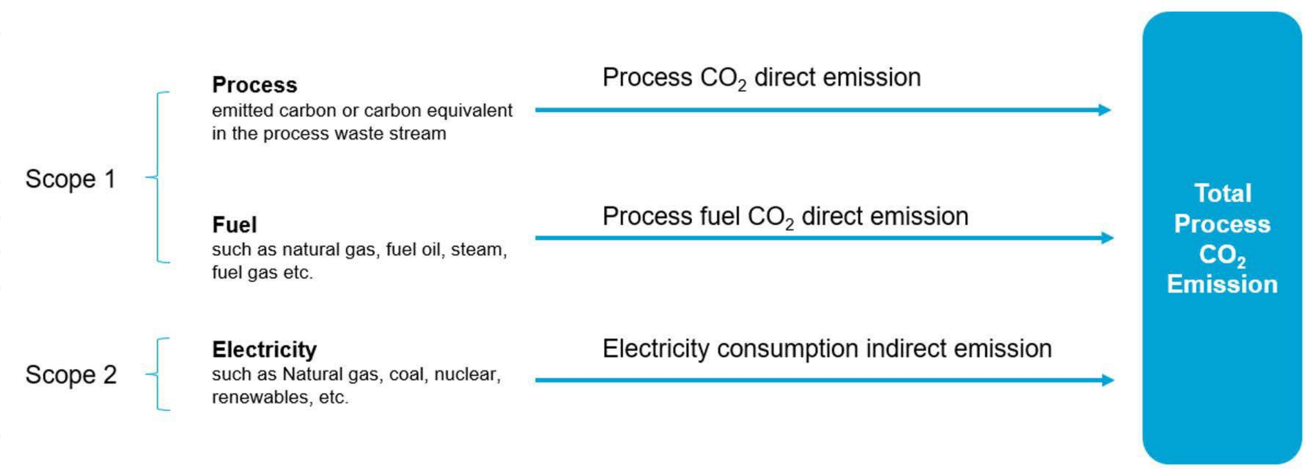
Virgin naphtha represents the combined carbon emissions of oil production and refining. Pyrolysis is energy intensive (with the intensity depending on the end-use of the naphtha produced) and has greater carbon emissions than virgin naphtha. The chemical recycling technologies examined have carbon footprints that are generally greater than the materials being replaced. This is especially true of the pyrolysis processes examined which have footprints that are from 50% to over 400% greater than the naphtha feedstock being replaced. Due to the complexity of decomposing most polymers, the carbon emissions of these technologies are expected to be either at or above the footprints of the virgin material they are replacing. While pyrolysis is preferable to sending plastics to a landfill, mechanical recycling's lower carbon efficiency places it at the forefront of the routes to carbon neutrality.

The basic pyrolysis process has been used in the chemical industry for several years in different applications, with many variations that can produce a wide range of materials, from synthetic crude oil to fuel products. Per ton CO2 emissions from pyrolysis varies significantly depending on the final product. Technologies that produce fuel or naphtha type materials have higher carbon footprints due to higher yield losses. This is evident in emissions from a pyrolysis naphtha cut (as fuel) which is a fractionated cut of naphtha from crude pyrolysis oil. Another is the hydrotreated r-naphtha obtained from the hydrotreatment of crude pyrolysis oil for use as a naphtha feed for ethylene crackers, which has lower emissions relative to a pyrolysis naphtha cut due to lower yield loss as compared to the fuel product. Due to the limited availability of pyrolysis oil, it is expected that a 5-15% integrated process case (e.g., mixing 5%-15% of hydrotreated pyrolysis oil with virgin naphtha in crackers) will be considered. These Integrated processes for HDPE production with gradual increases in Hydrotreated r-Naphtha is shown in the emissions chart, in comparison to 100% fossil-based HDPE. Each incremental increase in the Hydrotreated r-Naphtha content increases the carbon emissions for the HDPE integrated process. Similar patterns are seen when examining the integrated processes for LDPE and LLDPE.

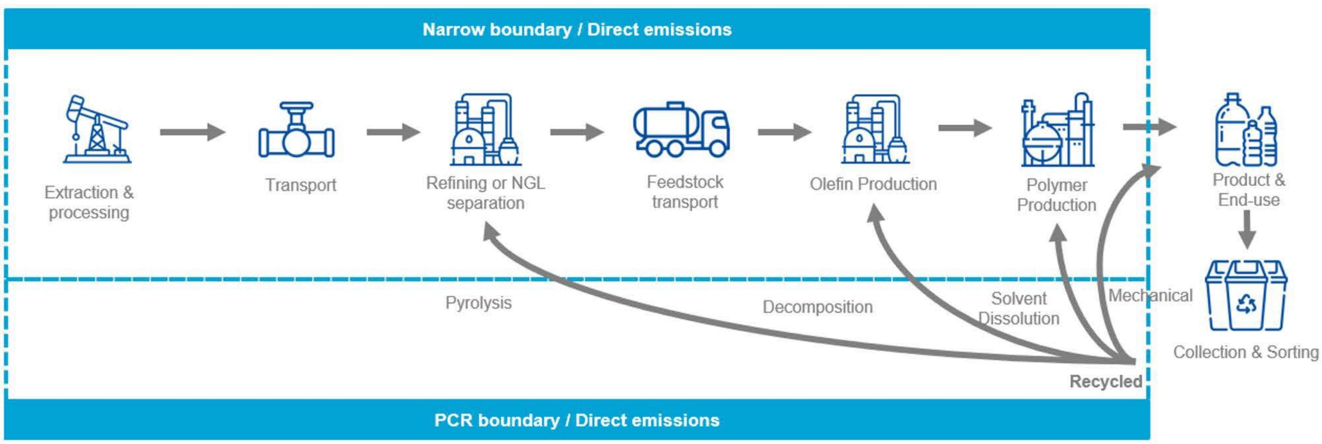
Even if we do not recycle the pyrolysis oil to a refinery cracker, the typical yield losses from conventional naphtha to plastics will remain the same. While some studies suggest that addition of pyro-oil with virgin naphtha in steam crackers increases olefins yields, this yield improvement has not yet been commercially proven. Using pyrolysis oil basically replaces an equivalent volume of conventional naphtha to crackers. The typical yield of pyrolysis oil from plastic pyrolysis can be considered in the range of 65-75% based on the mixed waste plastic feedstock properties, with the remaining being solids and gases. While gases may potentially be used within the process to supply heat, the solid char may have its own market value based on the type of feedstock used in the process.

Gasification technology has also been used in the chemical industry for many years in different applications. Starting from syngas, different end products can be produced such as hydrogen or ammonia. Due to the additional processing required, these will subsequently have higher carbon footprints. In the chart we have included the carbon footprint of ammonia from syngas via mixed plastic waste gasification.

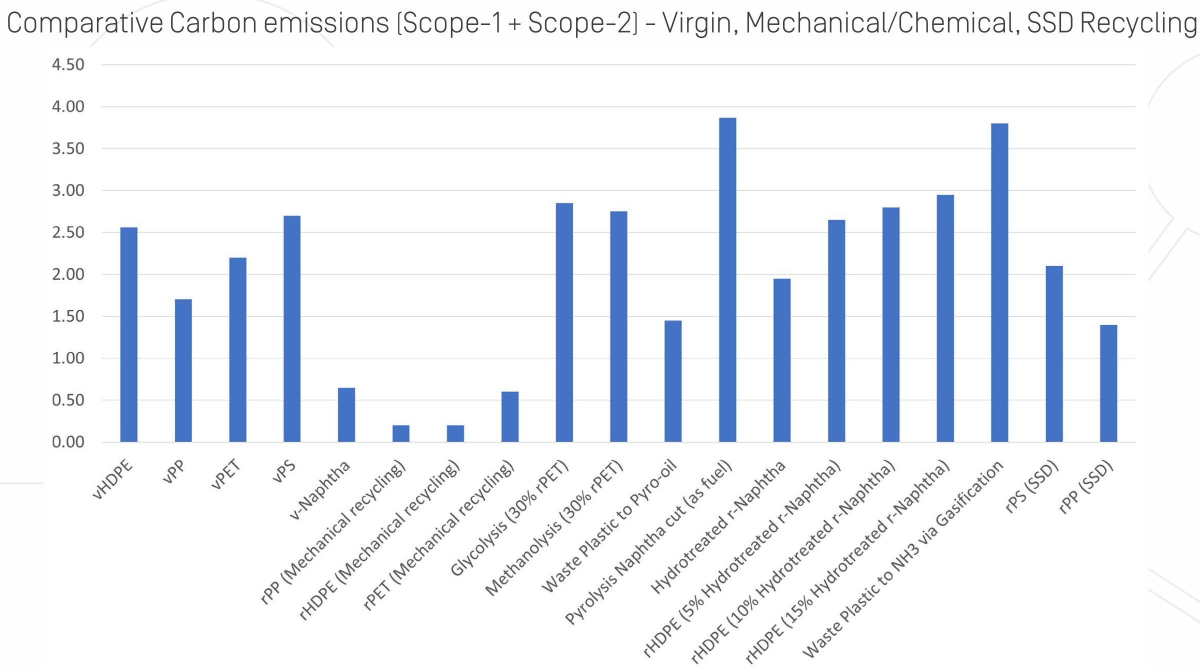
Alignment of methodologies with transparent data is critical to effectively understanding emissions tradeoffs and to implement effective counter measures. The Circular Plastics Service (CPS) from Chemical Market Analytics by Opis, a Dow Jones Company utilizes a straightforward, in-depth, analytical approach to quantify GHG emissions from both mechanical recycling and chemical recycling by first thoroughly researching patents, public literature, citations of different university works, and information available from technology and associated licensors. Based on this research, CPS prepares independent process designs and develops process flow diagrams to assess the inputs/outputs of the different recycling options. Using benchmark plant capacity and advanced analytical tools, comprehensive material and utility balances are prepared. Scope-1 emissions consist of Direct process as well as Direct Utility emissions, while Scope-2 emissions are the indirect emissions from electricity consumption




The model uses a proprietary supply/demand analysis for plastic waste generation and disposition as the basis for the simulation. Carbon emissions are measured starting with ethane, propane and naphtha and emissions for recycling technologies are compared to integrated routes for the linear virgin pathway, wherever applicable.

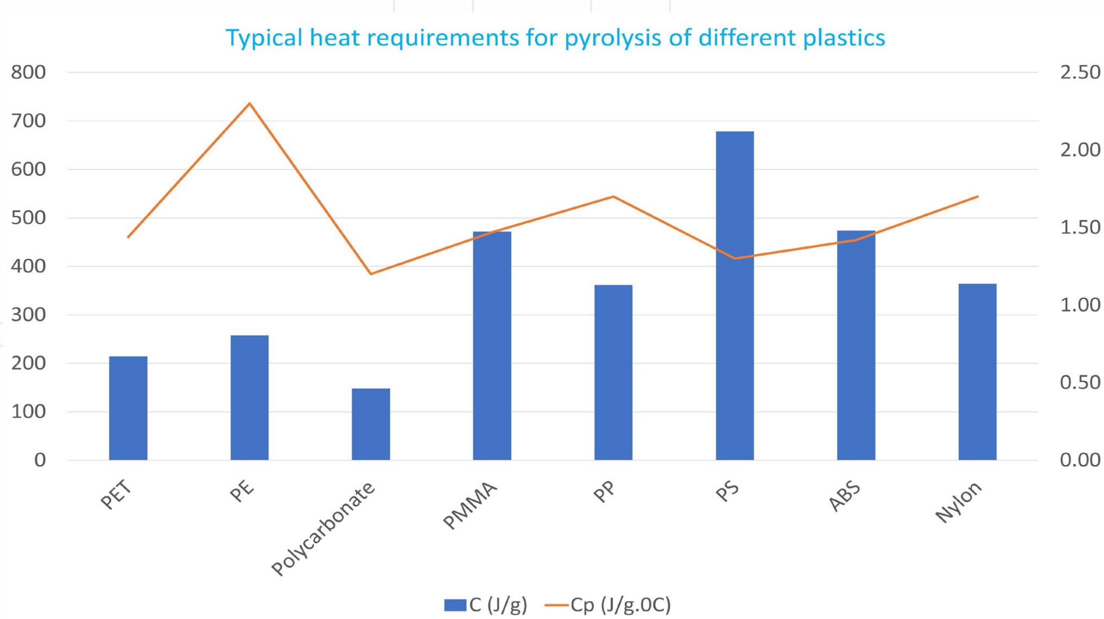


The results from CPS's modelling quantifies the distinct contributions of mechanical and chemical recycling technologies to the recycling of plastics waste, and the resulting impact from emissions. The chart below compares emissions from virgin plastic production with various recycling approaches, illustrating the dilemma between a circular model for plastics and net zero aspirations.




## Practicality and understanding

Company claims of "low temperature processes" can easily be misunderstood without proper context, as all chemical processes require some degree of elevated temperature to break apart the polymer bonds of synthetic plastics. Temperature requirements vary for any given chemical recycling process depending on the feedstock composition, as shown in the chart below, using pyrolysis as an example. Depending on the net feedstock composition of the waste mixed plastic going to pyrolysis, the net energy requirements to raise the temperature in the pyrolysis process from T1 to T2, can easily be calculated. Supplying that much energy to the process via fossil fuels (Natural gas, fuel oil etc.) certainly contributes to emissions.



## The CO2 calculation

CO2 emissions differ greatly depending on the product produced and scale of the asset. Pyrolysis technology companies are pursuing scaling and commercial viability of their process, but at present the typical product is directed to fuels so we cannot rely on data from these semi-commercial assets, but rather need to understand the projected product slate at commercial scale to measure tradeoffs to both virgin production and alternative recycling options.

CO2 emissions per-ton of finished product, vary significantly depending on the product. While today's small-scale plants (10-50 tpd of waste input feedstock) are typically limited to diesel fuel type products, where the net yield is only around the 40-45% range. This yield loss results in a very high CO2 footprint of >3.0 ton/ton of the product. When we consider the energy requirement on the feedstock basis, the net energy required to raise the temperature of one ton of typical mixed plastic waste bales from 20 deg C (T1) to 650 deg C (T2) in a pyrolysis unit, is around 2.6-3.0 MMBtu.

For larger scale plants, assuming the final product is equivalent to pyrolysis oil naphtha that can be mixed in refinery steam crackers, we can expect a maximum yield of around 60-70%. But even here, the net energy requirements for the other units that are needed to process the hydrotreated pyrolysis oil increases the heat load.

Overall, a hot oil heater unit supplies heat to all major areas where energy is consumed (e.g., extruders, pyrolizer heaters, HDT charge heater, fractionator charge heater, reboiler, and fluidized bed dryer). All of this energy requirement may well lead to a net 4.5-5.5 MMBtu/ton for waste plastic bales, assuming natural gas energy feed.

Achieving net zero for pyrolysis is also challenged by the byproduct production of pyrolysis gas representing 10-20% yield, depending on the feedstock composition. Some technology providers claim an energy savings via recycle of byproduct gases from the pyrolysis unit. But there are problems associated – there are problems associated with preparing the recycle gases that result in emissions. Some of the challenges are cleaning the gas, cost associated with treatment, impact of its re-use on availability and reliability of the plant operation etc.  From a practical perspective, it has been found that this pyrolysis gas is typically flared due to these challenges.  Even if we assume that this gas can be recycled to reduce the net energy requirement for the pyrolysis process, this gas is burned in the pyrolizer heaters/ovens resulting emissions. Switching to renewable energy sources does not eliminate the volumes of gases that need to be addressed to achieve net-zero.

## Summary and conclusions

Achieving net zero while transitioning to a circular model for plastics presents challenges seemingly impossible to overcome when focused simply on scope 1 and 2 emissions. However, with proper context one comes to realize that the goals are complementary and necessary for each to achieve its goal. Eliminating plastics in favor of other materials would result in unacceptable environmental damage, as does continued plastics waste lost to the environment.

A range of solutions will need to be employed, including managed consumption, re-design of products and packaging for reuse, repair and recycling, enhanced waste collection along with both mechanical and chemical recycling. Even then, off-setting emissions and associated costs will still be necessary. The underling question is how to pay for that final increment – either via credits or via physical investment. Addressing these questions will in effect define each stakeholder's competitive position in a net zero world.

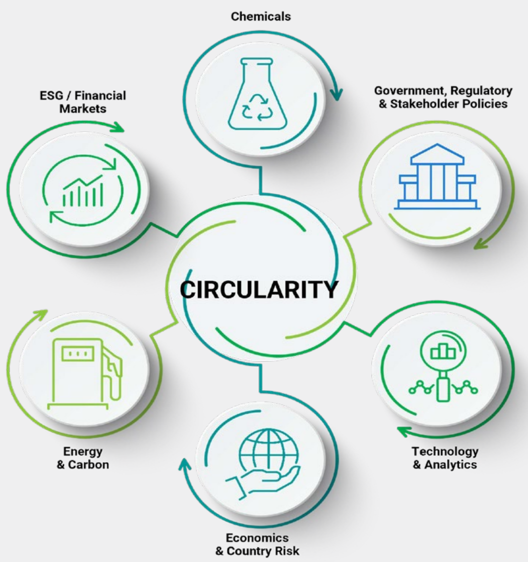
# Circular Plastics Service

Expert source in providing data and addressing the critical questions being raised by the plastics transition to circularity

A comprehensive, scenario-based evaluation of how the plastics value chain is expected to transition from a linear to a circular economy. The service addresses the implications of carbon intensity and the impact on future capital investments within the context of energy transition and carbon valuation, amid changing policies and regulations.

This service quantifies the magnitude and timing of substantial market shifts, identifies key regulatory and societal risks, and provides ongoing tracking of fast-moving developments. Clients will understand government regulations and policies, prepare a plan to mitigate risk, determine which part of your company is most vulnerable, and assess opportunities for investment.

The plastics transition to circularity raises critical questions that must be addressed through shared goals and standards, with supporting data to determine the best path forward.

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| Regulations, Policy, ESG | Global regulations, stakeholder policies, alliances' & NGOs' targets, and initiatives |
| Demand Risk | Scenario demand modeling, visualization and insight for virgin and mechanically recycled plastics with regional and end-use segmentation |
| Waste Collection & Repositioning Plastics Waste into Valued Feedstock | Scenario modeling and insight for collection and disposition of plastics waste via landfill, incineration, mechanical recycling, and chemical recycling.<br>Analyses of plastics waste supply, including categories, volumes, specifications, and quality requirements. |
| Plastics Recycling Technology | Technology scanning and scenario-based economic modeling for recycling technologies.<br>Database of recyclers' capacities, alliances, inputs & outputs, and facilities commercialization progress. |
| Economic & Environmental Assessment | Scenario-based modeling and insight to evaluate the economics and emissions for circular plastics production compared to the incumbent, fossil-based linear model for producing plastics. |
| Strategic Issues & Implications | Semi-annual update of strategic conclusions derived from the detailed analyses targeted at identifying risks, investment opportunities, infrastructure needs, and recommended positioning & and actions for industry participants. |

## Gain a Tactical Advantage and Reformulate Your Company Strategy

- Track government regulations, policies and targets established by brand owners, industry alliances, NGOs and ESG investors and understand what this means for your business in the countries and regions where you have operations
- Prepare a plan to mitigate against major sustainability-driven shifts in downstream plastics consumption
- Determine which parts of the company's product offerings are most vulnerable to reductions in demand for virgin (non-recycled) plastic.
- Assess opportunities for investment collaboration in circularity
- Assess the relative value propositions of competing recycle technologies and anticipate where investments will be directed to scale infrastructure.
- Anticipate the timing and magnitude of the impact on feedstocks that will develop during the plastics transition to circularity.

## Benefits of the Service

### Anticipate future recycling volumes under different scenario

- Understand the evolving risk of resins, monomers, and feedstocks being replaced by recycling
- Assess opportunities for investment collaboration in circularity e.g., mechanical recycling

### Quantify the timing and magnitude of impact on feedstock markets

- See how changing plastics consumption may impact feedstock requirements into chemicals
- Prepare a plan to mitigate against significant shifts in downstream consumption

### Understand different regulatory regimes and track and anticipate changes globally

- See how regulations are likely to impact the plastics value chain and recycling rates
- Understand which sectors of the value chain are most likely to need additional support from government and associations

### Compare competing mechanical /chemical process technologies and understand which may prevail

- Understand how they will fit into the value chain
- Determine which recycling technology to invest in

### Evaluate the level of societal demand in different markets

- Avoid being surprised by evolving consumer preferences
- Develop actionable policies for plastics use and waste to manage consumer perceptions
- See how consumer/system behavior is expected to change in the long-term

### Technology and technology trends

- See when and where new chemical and mechanical recycling facilities are being built and who is building them

### Understand which chemical companies might prevail

- Find out where new investments are likely in the future across the plastics value chain
- See which companies are most likely to be winners or losers

### Calculate emissions and unit costs based on different infrastructure types

- See how unit costs compare across asset types and infrastructure types

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