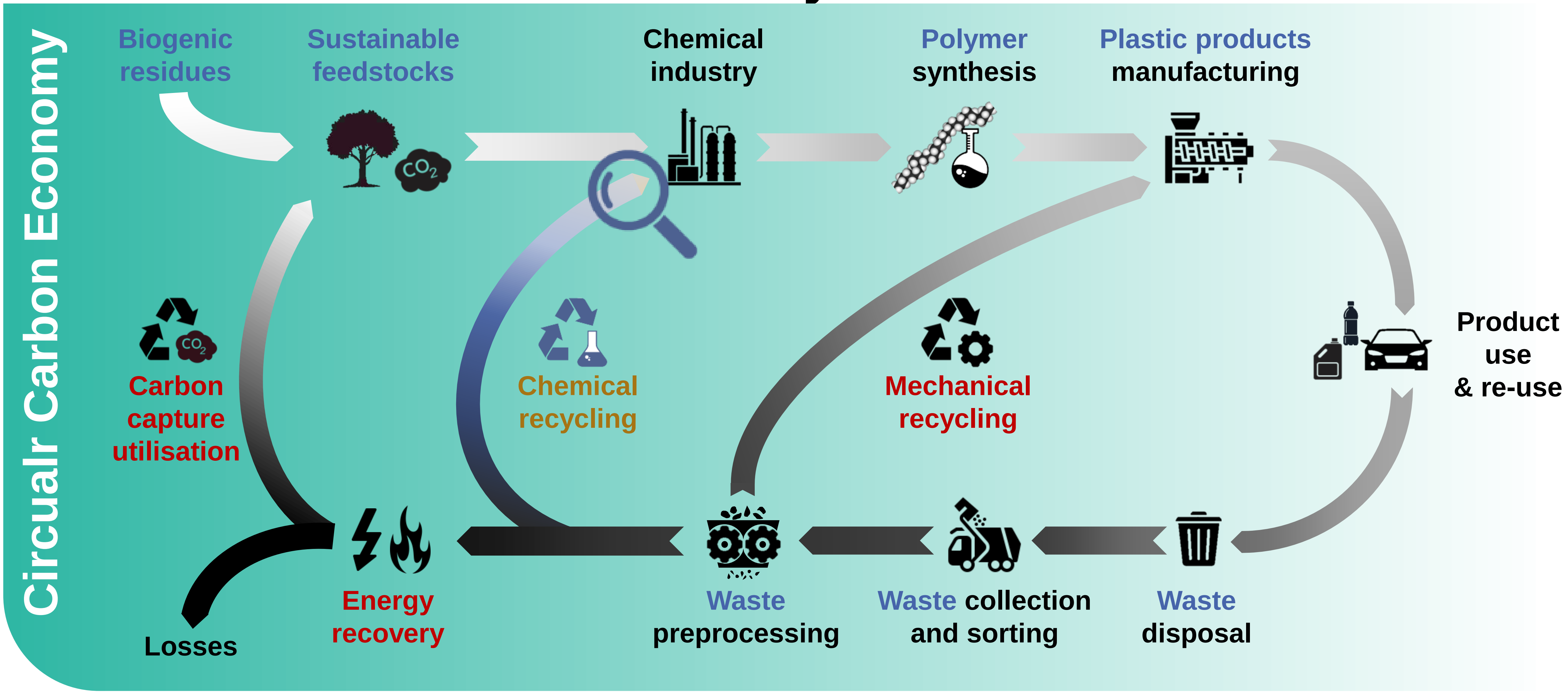
Advances in Chemical Recycling of Mixed Plastics

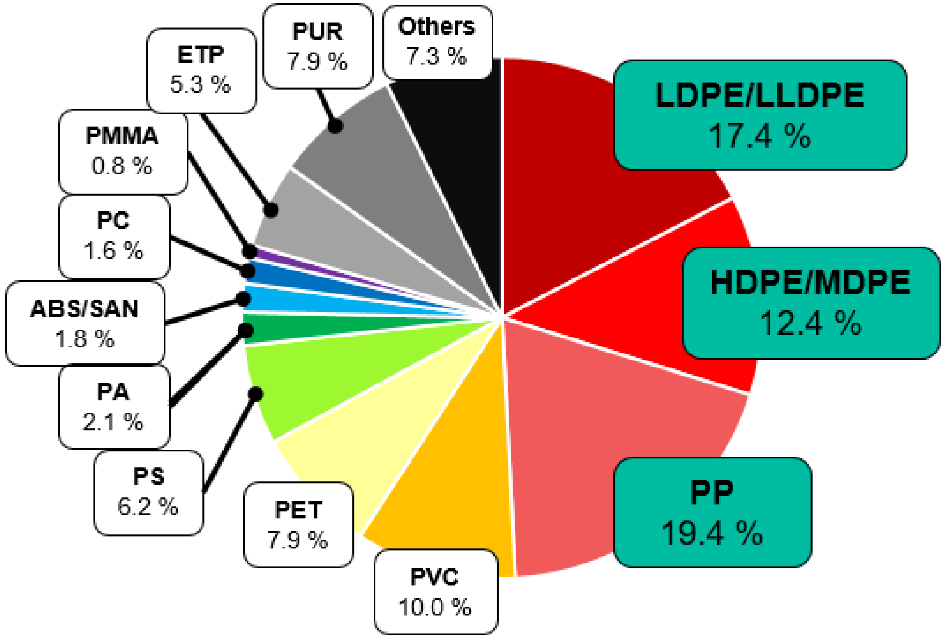
Karlsruhe Institute of Technology

Dieter Stapf,
Advanced Recycling of Plastics, Brussels, Nov. 13, 2025

The Sustainable Plastics Lifecycle



The Plastics Waste Recycling Challenge



Plastics production EU28+NO/CH, 2019*: 61.8 Mn t (thereof GER: 19.9 Mn t)

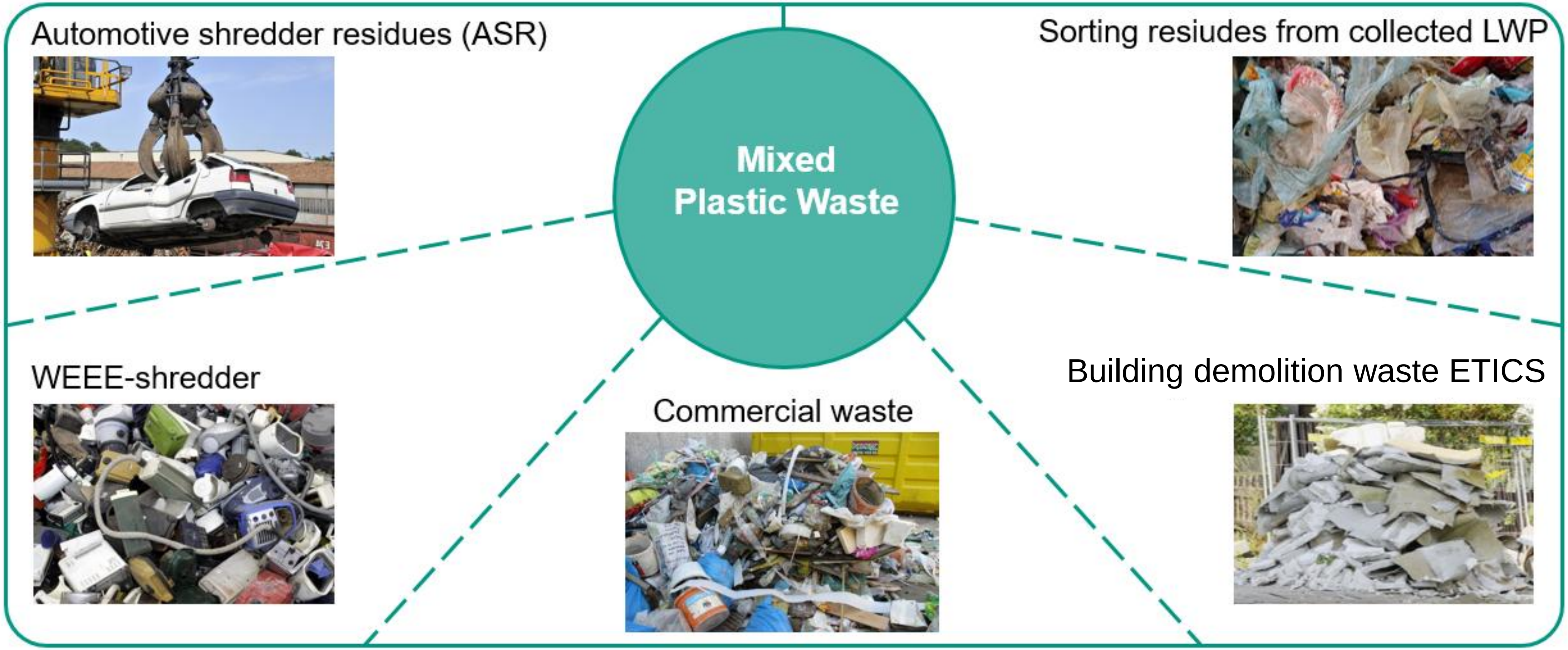
Post-Consumer Wastes, 2018*:

	GER 5.3 Mt	EU 28+NO/CH 29 Mt
Mechanical Recycling	38.4 %	32.5 %
Chemical Recycling	0.2 %	
Energy recovery	60.7 %	42.6 %
Landfilling	0.6 %	24.9 %

EU recycling objective 2030: 55%

*) PlasticsEurope (2020); production numers include rubber & coatings

Examples of Plastic Waste Produced

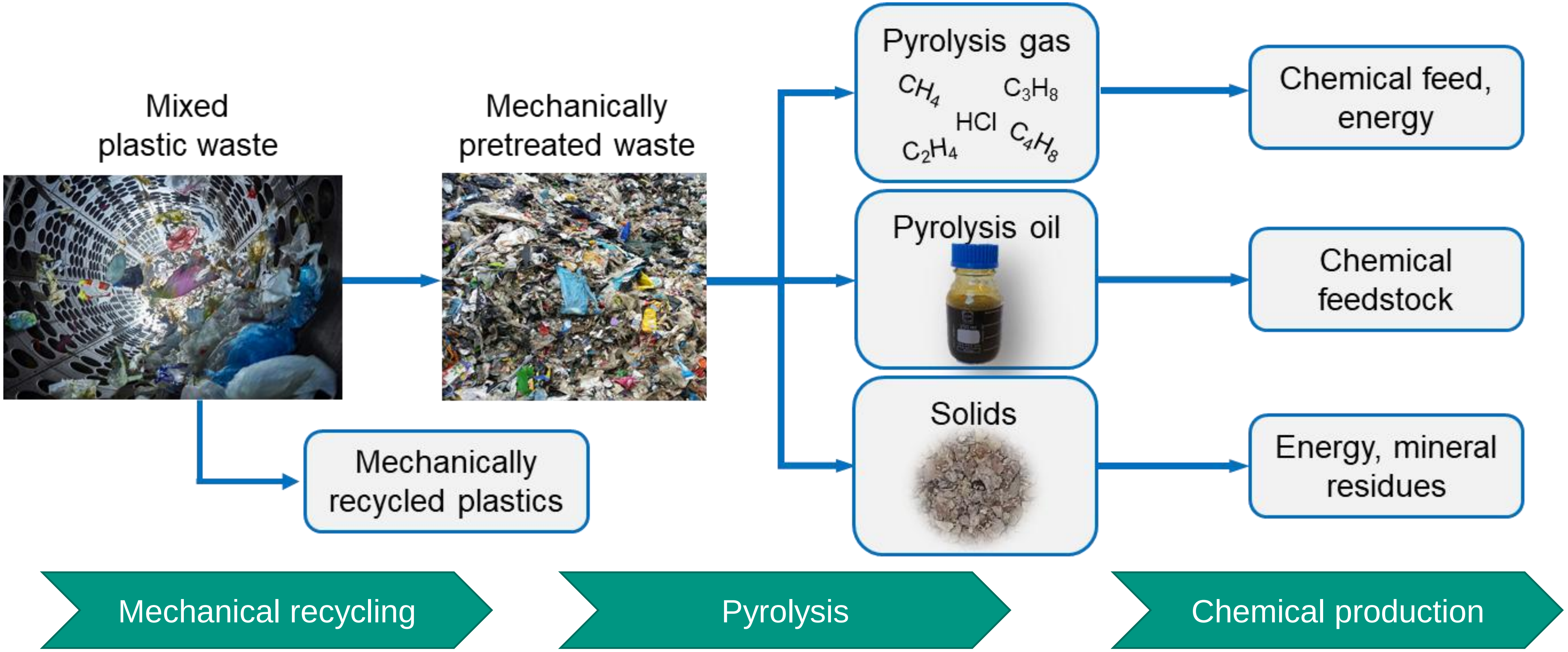


WEEE = Waste of Electrical and Electronical Equipment

LWP-SR = Sorting Residues from Light Weight Packaging Waste collected

ETICS = Thermal Insulation Composite System

The Recycling Value Chains Based on Pyrolysis



Plastic Energy´s Operational Recycling Plants in Spain

Almeria

Operational 2016

Sevilla

Operational 2017

©Plastic Energy

Through joint ventures with partners Total and Sabic, two more chemical recycling facilities are currently commissioned

- Grandpuits, France
  - 15.000 tonnes/year
- Geleen, Netherlands
  - 20.000 tonnes/year

Indaver´s Plastics2Chemicals Plant at the Port of Antwerp

- Pyrolytic depolymerisation of (packaging) polystyrene to styrene monomer
  - ca. 26.000 tonnes/year
- Operational since Sept. 2025
- Waste delivery & product uptake agreements

Chemical Recycling Plants Operating in Germany
Pyrolysis

Carboliq, Enningerloh

- Input: Mixed polyolefins
  - ca. 4.000 tonnes / year
- Various pyoil uptakers

Pyrum Innovations AG, Dillingen

- Input: Waste tyres shredded
  - ca. 6.000 t/a -> 60.000 t/a
- Product uptake
  - Recyled Carbon Black rCB: Schwalbe, Continental
  - Pyoil: BASF

Arcus Greencycling Technologies, Frankfurt Hoechst

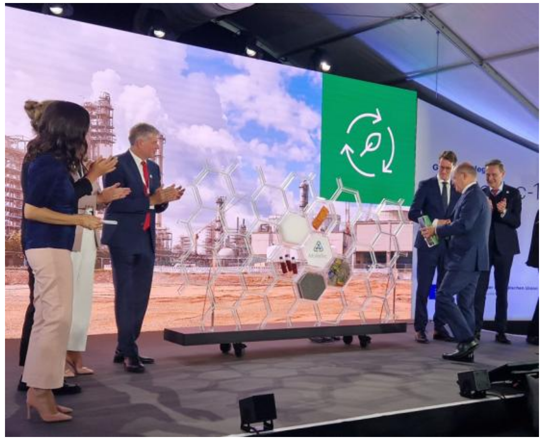
- Input: Mixed plastics
  - ca. 4.000 tonnes / year
- Pyoil uptake by BASF

©Arcus

Pyrolysis Technology Transfer for the Industry Transformation: Industry cooperations

Germany‘s first chemical recycling plant for mixed plastics waste (2023):

- KIT licensee Arcus Greencycling Technologies operates the scale-up of screw reactor pyrolysis technology at Frankfurt Höchst supplying BASF with recycled feedstock



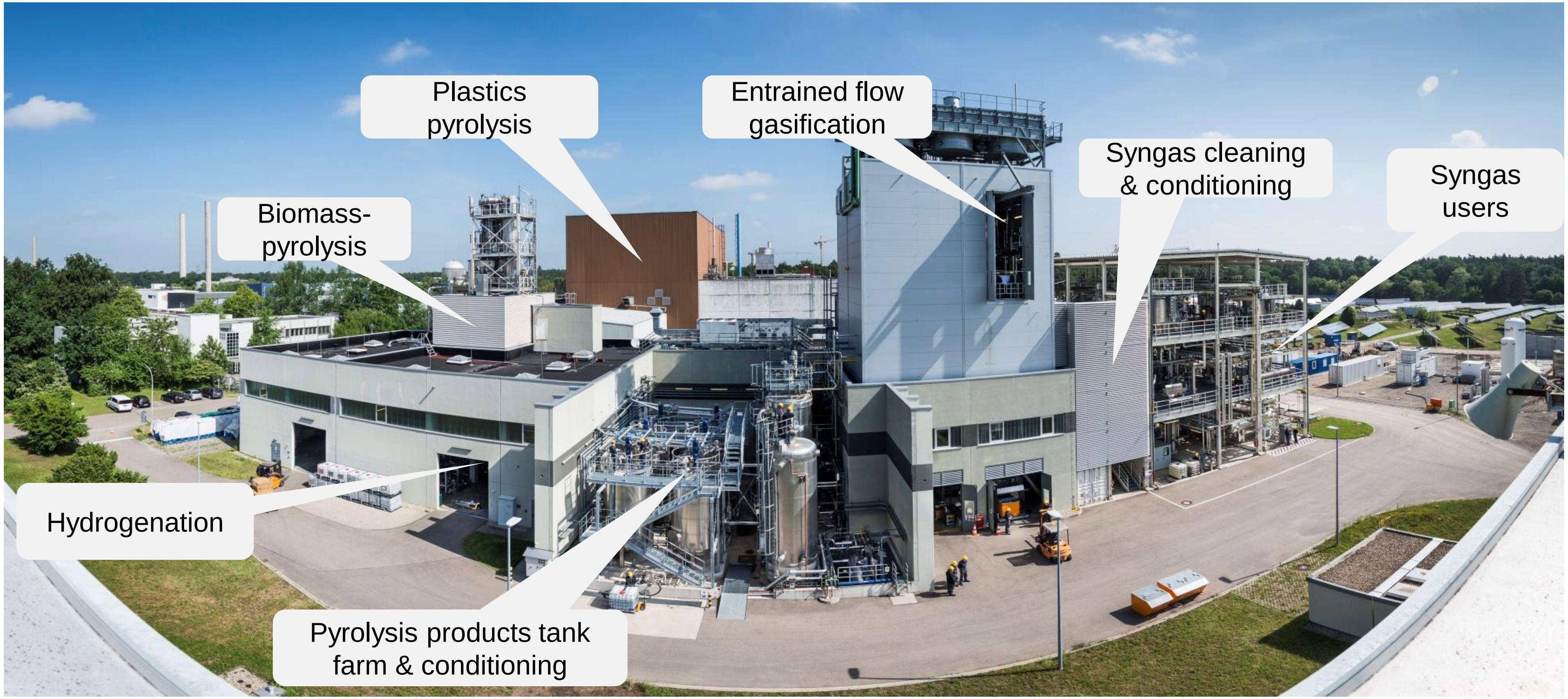
LyondellBasell: Germany‘s largest chemical recycling plant under construction

- First-of-ist-kind catalytic pyrolysis of 50 kt/a of mixed polyolefins to directly yield monomers

Carbon Cycle Lab: Pilot Plants & Value Chain Demonstration

CCLab

Karlsruhe Institute of Technology



R&D infrastructure for scale-up of technologies, transfer to industry, teaching & training

Technology Assessment

Mechanical and Chemical Recycling Complement Each Other

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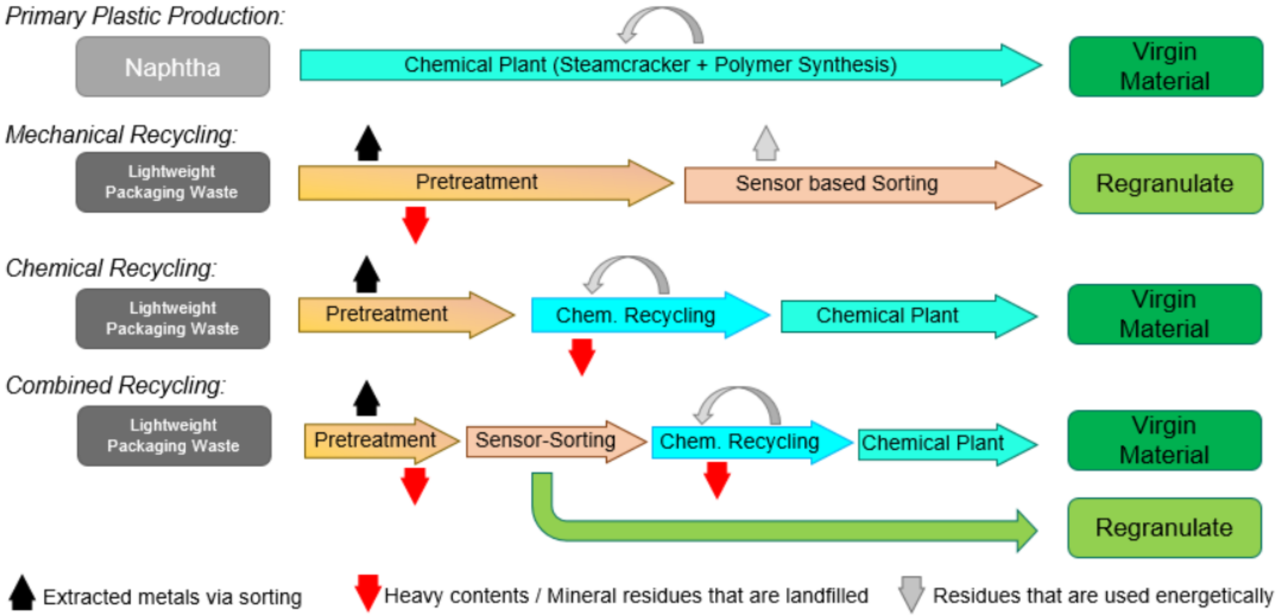

Leightweight packaging waste recycling routes compared to primary plastics production of HDPE (base scenario)

Recycling pathway	Cost [€/kg_{Input}]	CED [MJ/kg_{Input}]	GWP [$kgCO_2e/kg_{Input}$]	Overall Carbon Efficiency
Mechanical recycling, 22% yield	-0.08	-3.5	0.8	22
Chemical recycling	-0.23	-14.4	0.4	59
Combined recycling	-0.26	-21.6	0.1	66


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RESEARCH AND ANALYSIS
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Techno-economic assessment and comparison of different plastic recycling pathways

A German case study

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Abstract
Greenhouse gas (GHG) emissions need to be reduced to limit global warming. Plastic production requires carbon raw materials and energy that are associated today with predominantly fossil raw materials and fossil GHG emissions. Worldwide, the plastic demand is increasing annually by 4%. Recycling technologies can help save or reduce GHG emissions, but they require comparative assessment. Thus, we assess mechanical recycling, chemical recycling by means of pyrolysis and a consecutive, complementary combination of both concerning Global Warming Potential (GWP) [CO_2e], Cumulative Energy Demand (CED) [MJ/kg], carbon efficiency [%], and product costs [€] in a process-oriented approach and within defined system boundaries. The developed techno-economic and environmental assessment approach is demonstrated in a case study on recycling of separately collected mixed lightweight packaging (LWP) waste in Germany. In the recycling paths, the bulk materials polypropylene (PP), polyethylene (PE), polyvinylchloride (PVC), and polystyrene (PS) are assessed. The combined mechanical and chemical recycling (pyrolysis) of LWP waste shows considerable saving potentials in GWP (0.48 kg CO_2e/kg input), CED (13.32 MJ/kg input), and cost (0.14 €/kg input) and a 16% higher carbon efficiency compared to the baseline scenario with state-of-the-art mechanical recycling in Germany. This leads to a combined recycling potential between 2.5 and 2.8 million metric tons/year that could keep between 0.8 and 2 million metric tons/year additionally in the (circular) economy instead of incinerating them. This would be sufficient to reach both EU and German recycling rate targets (EC 2018). This article met the requirements for a gold-silver *JIE* data openness badge described at http://jie.click/badges.

KEYWORDS
carbon management, chemical/feedstock recycling, circular economy, environmental accounting, GHG emissions, plastics recycling

Chemical Recycling Outperforms Incineration

Feedstock Recycling of Automotive Shredder Residues (APW)


DOI: 10.1111/jiec.13416

RESEARCH ARTICLE

JOURNAL OF INDUSTRIAL ECOLOGY WILEY

Economic and environmental assessment of automotive plastic waste end-of-life options

Energy recovery versus chemical recycling

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Abstract

Most automotive plastic waste (APW) is landfilled or used in energy recovery as it is unsuitable for high-quality product mechanical recycling. Chemical recycling via pyrolysis offers a pathway toward closing the material loop by handling this heterogeneous waste and providing feedstock for producing virgin plastics. This study compares chemical recycling and energy recovery scenarios for APW regarding climate change impact and cumulative energy demand (CED), assessing potential environmental advantages. In addition, an economic assessment is conducted. In contrast to other studies, the assessments are based on pyrolysis experiments conducted with an actual waste fraction. Mass balances and product composition are reported. The experimental data is combined with literature data for up- and downstream processes for the assessment. Chemical recycling shows a lower net climate change impact (0.57 to 0.64 kg CO_2e/kg waste input) and CED (3.38 to 4.41 MJ/kg waste input) than energy recovery (climate change impact: 1.17 to 1.25 kg CO_2e/kg waste input; CED: 6.94 to 7.97 MJ/kg waste input), while energy recovery performs better economically (net processing cost of –0.05 to –0.02€/kg waste input) compared to chemical recycling (0.05 to 0.08€/kg waste input). However, chemical recycling keeps carbon in the material cycle contributing to a circular economy and reducing the dependence on fossil feedstocks. Therefore, an increasing circularity of APW through chemical recycling shows a conflict between economic and environmental objectives.

KEYWORDS
automotive plastics recycling, carbon management, chemical recycling, circular economy, climate change impact, industrial ecology

1 | INTRODUCTION

The amount of plastic in automobiles increased considerably in the last decades to realize the advantages of plastic components, such as lower costs and weight reduction (Wilts et al., 2016). Therefore, more automotive plastic waste (APW) will have to be handled in the future. Defect plastic components are replaced during the use phase generating mixed APW. At the end-of-life (EoL), a highly heterogeneous automotive shredder residue (ASR) contains mixed plastics of different origins. Currently, landfilling and energy recovery are the dominating waste-handling options for APW and ASR in Europe (Cossu & Lai, 2015; Mehlhart et al., 2018), resulting in high environmental burdens and a loss of valuable resources

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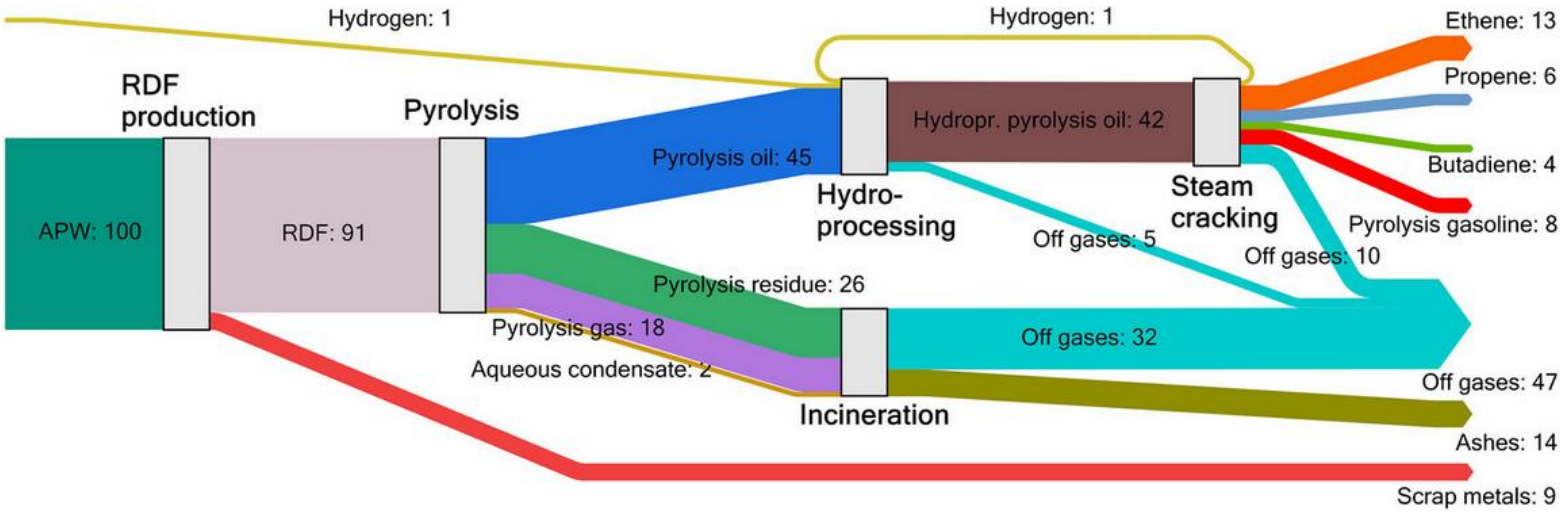

Chemical recycling:	0.57 kg CO_2e / kg waste
Incineration:	1.25 kg CO_2e / kg waste
Challenge:	Economies of Scale

Stallkamp, C., Hennig, M., Volk, R., Stapf, D., Schultmann, F. (2024): Pyrolysis of mixed engineering plastics: Economic challenges for automotive plastic waste. Waste Management 176, 105-116. https://doi.org/10.1016/j.wasman.2024.01.035

Advances in Chemical Recycling of Mixed Plastics

Demonstration Plants & Chemical Recycling Technology Assessment

- Mechanical recycling applicable to **easy-to-sort, clean, pure** plastics products
- Chemical Recycling can recycle many of the plastics mechanical recycling can't accept
  - Potential to significantly increase plastics recycling
- Chemical recycling overcomes plastics downcycling issues
  - Virgin quality output
  - Fate of contaminants
- Recycling in general: favorable over fossil feedstocks based plastics
  - **Lower** GHG emissions | **Lower** energy demand
- **Most advantageous:** combined mechanical and chemical recycling
- R&D efforts and regulative support are essential