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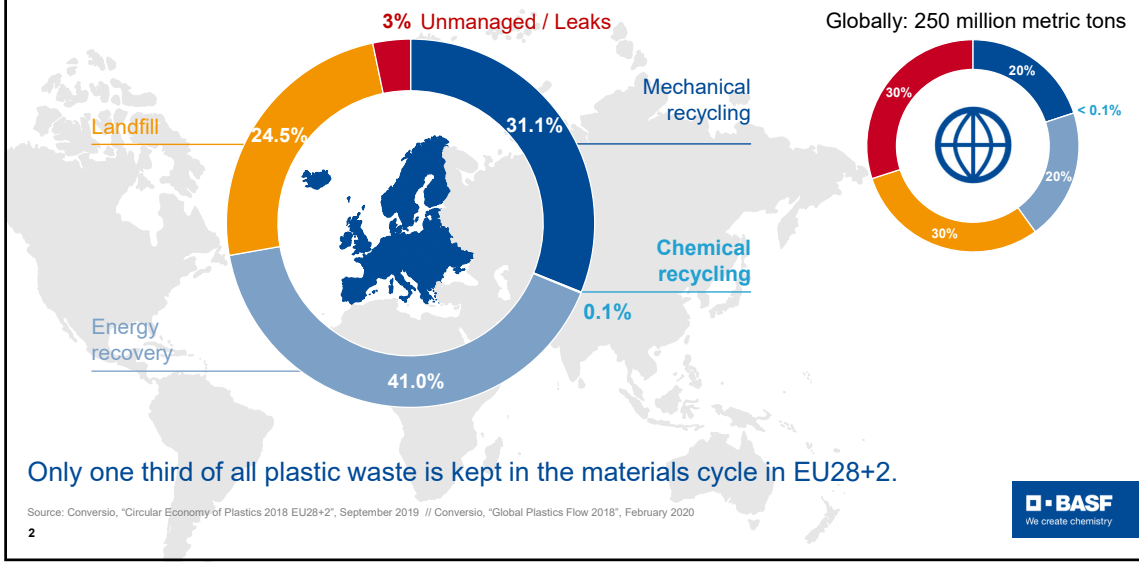
Today's recycling landscape for plastic waste

Fate of 30 million metric tons of plastic waste generated in EU28+2 in 2018



Only one third of all plastic waste is kept in the materials cycle in EU28+2.

Source: Conversio, "Circular Economy of Plastics 2018 EU28+2", September 2019 // Conversio, "Global Plastics Flow 2018", February 2020

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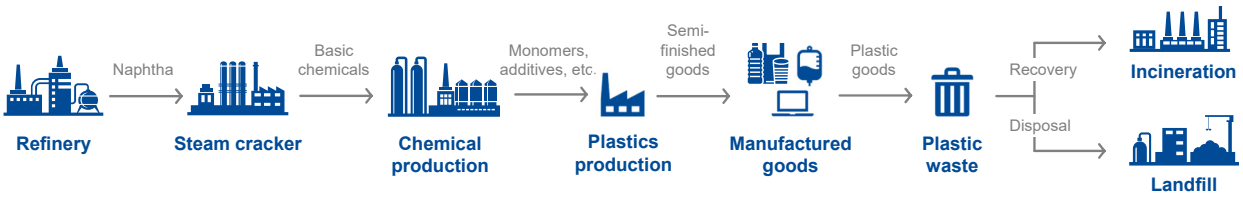
Chemical recycling can increase the overall amount of plastic waste recycled



ChemCycling™ is complementary to mechanical recycling.

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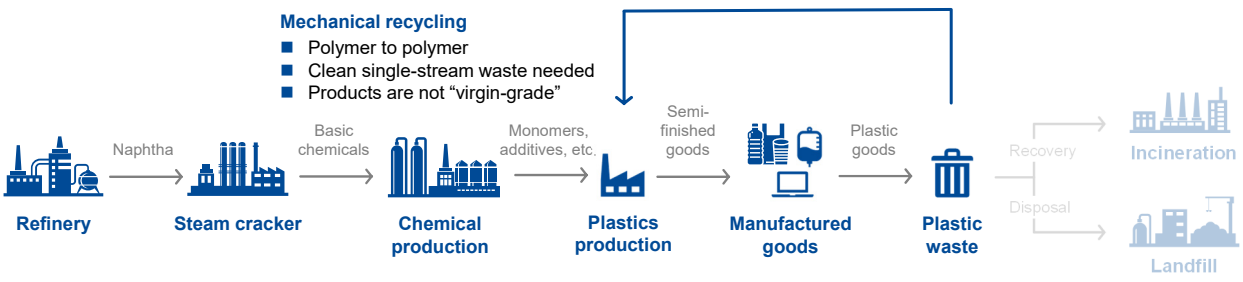
Chemical recycling can increase the overall amount of plastic waste recycled

Mechanical recycling
- Polymer to polymer
- Clean single-stream waste needed
- Products are not “virgin-grade”



ChemCycling™ is complementary to mechanical recycling.

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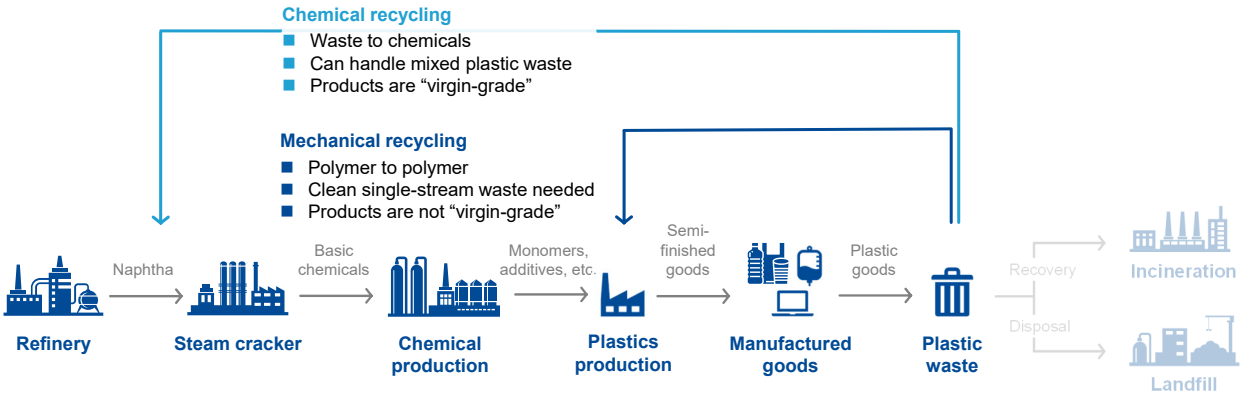

ChemCycling™ is complementary to mechanical recycling.

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Towards a stable and scalable chemical recycling process

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ChemCycling™: technological challenges

The **purification** challenge

How do we achieve the necessary specification of pyrolysis oil for use in the BASF Verbund?

The **scale-up** challenge

How can pyrolysis technology be scaled-up best for commercial use?

BASF addresses these challenges with partner companies.

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ChemCycling™: technological challenges

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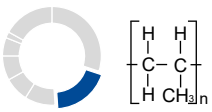
The purification challenge

Plastics demand distribution (51.2 million metric tons)

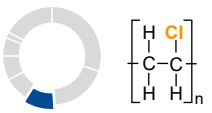
by resin types 2018 in EU28+2

Polyethylene (PE)

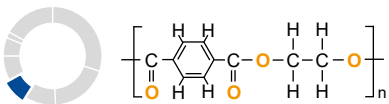
Polypropylene (PP)



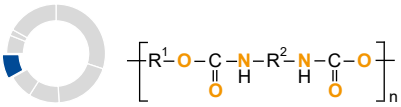
Polyvinyl chloride (PVC)



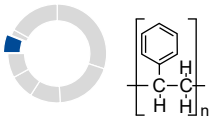
Polyethylene terephthalate (PET)



Polyurethane (PUR)



Polystyrene (PS) + EPS



Polyamide (PA)

Others

Waste plastic feedstock contains a variety of chemical structures and a significant amount of heteroatoms, e.g., chlorine, nitrogen, oxygen.

Source: PlasticsEurope, Plastics – the Facts 2019

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The purification challenge: chemistry matters

Why heteroatoms are undesirable in pyrolysis oil

17 Cl Chlorine 35.453	8 O Oxygen 15.999	7 N Nitrogen 14.007	16 S Sulfur 32.065
↓	↓	↓	↓
Corrosion	“Blue liquids” may be formed, which create explosion risk for steam cracker		Corrosion, catalyst poison

Purification is essential for pyrolysis oil.
The use in existing assets demands narrow specifications.

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Quantafuel and BASF collaborate to supply the BASF Verbund with pyrolysis oil

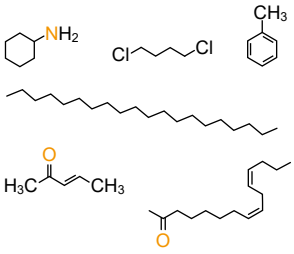
- Unique integrated process of pyrolysis of mixed plastic waste and purification into a secondary raw material
- Catalytic **purification** happens at ambient pressure
- Flexibility in scale enables optimization of the supply chain setup
- 16kt/a plant in Skive, Denmark (world's largest plastic pyrolysis plant) with first-generation catalyst is operating

QUANTAFUEL

In Skive, Quantafuel is realizing its process for the first time at full-scale – with BASF's support.

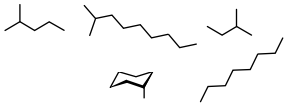
Deep Dive purification: catalytic cracking and hydrogenation of plastic waste

Pyrolysis feed



Purification catalysts

Purified pyrolysis oil



>99.9% carbon, hydrogen

Contaminant Stream

Catalyst performance is key to meet the demanding specifications of chemical industry.

Tackling the purification challenge in collaboration with hte GmbH in Heidelberg

- hte tests catalysts under industrially relevant conditions in high-throughput reactor systems with up to 48 reactors in parallel
- hte supports our partners in optimizing the catalyst by screening
  - chemical composition
  - morphology
- hte enables a fully automated and digitalized testing workflow with efficient data management

Catalyst optimization targets yield, service life and energy consumption.

ChemCycling™: technological challenges

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Tackling the scale-up challenge with our supercomputer Quriosity

Fluid dynamics
- Change of flow regime (turbulent / laminar)
- Performance of mechanical mixing
- 3-phase flow (dust, suspension, coking, bubbles, etc.)
- Internal backflow

Heat transfer
- Area to volume ratio changes
- Dead zones
- Fouling

Kinetics
- Impact from local flow regime and temperature
- Change of limiting step (macroscopic or pore transport)
- Secondary reactions

In silico studies can reduce the upscale-risk and shorten the time to market.

1.75 PetaFLOPs

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Quantafuel and BASF are jointly solving the challenges

- Improving purification reactor performance
  - Catalyst improvement
  - Reactor design
- Successful scale-up
  - BASF provides chemical engineering expertise
  - BASF supports with local, hands-on support in Skive
- Developing next-generation process
  - Pyrolysis reactor
  - Naphtha catalyst

Combining Quantafuel's and BASF's expertise will make the scale-up happen.

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Chemical Recycling
Next steps

2020

Establishing partnerships

- Start up of Quantafuel's plant in Skive/ Denmark. Test second-generation approaches
- Investment into tire pyrolysis specialist Pyrum, Germany
- Agreement for a feasibility study with New Energy, Hungary

2021

Further development of processes

- Test second-generation approaches in pilot scale with Quantafuel
- Start of construction of two additional production lines in Pyrum's existing site in Dillingen
- Trials with mixed plastic waste in New Energy's plant in Dunaharaszti

2022 & beyond

Capacity building

- Start construction of second-generation plant with Quantafuel
- Build-up of additional capacities with Pyrum and further partners

ChemCycling™ is a key contributor to BASF's commitment to use 250,000 metric tons of recycled feedstock annually by 2025.

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