ChemCycling™
From plastic waste to chemically recycled products

Standard presentation | January 2020
Heading towards a sustainable future
We are heading towards a sustainable future

In the 21st century, sustainability has become a worldwide megatrend

Modern life is great. But it is also taking a heavy toll on our planet. If we want to keep nature intact, we need to be more efficient with our resources.

That is why the concept of sustainability has become a megatrend – in politics as well as in business sectors as diverse as the chemical industry.
More and more customers are making environmentally conscious purchasing decisions

- Purchasing decisions are based on **values**
- **Price and quality** remain important
- Transparency is key: customer prefer brands that they perceive as **authentic and trustworthy**
- **Consumers are critical** and question producers’ promises
Closing the loop for plastics with the ChemCycling™ project
Plastics in the environment is a major global challenge and additional recycling solutions need to be established.
Chemical Recycling

A missing link to close the loop

Chemical recycling
- can handle mixed plastic waste
- produces virgin-grade high-performance materials

Mechanical recycling

Recovery – utilize the energy

Waste to fuel
Incineration

Linear economy

Landfill
Littering

7
Chemical Recycling
Learning from trees

Nutrients

Wilted leaves

Destructors
BASF’s ChemCycling™ project
Breaking new ground in plastics waste recycling

Consumers use and dispose plastic products (e.g. packaging, tyres)

Waste companies collect and sort the waste and supply BASF’s technology partners with it

Our customers use these chemicals to make their own products

Our partners convert the plastic waste into pyrolysis oil through a thermochemical process

Pyrolysis oil is purified to be used as feedstock at the beginning of BASF’s Verbund production

BASF can allocate the recycled feedstock to all chemicals produced in this Verbund via a certified mass balance approach.

BASF’s ChemCycling™ project
Status of BASF’s ChemCycling™ project (June 2020)

Project start

Network and partnerships along the value chain developed

2018
- First batches of pyrolysis oil fed into the Verbund
- Certification system for recycled products developed together with ecocycle

2019
- First certified ChemCycling™ product prototypes realized with customers
- Presentation of customer prototypes at K press conference and K fair
- Investment into Quantafuel to jointly drive chemical recycling of mixed plastic waste

2020
- First commercial applications of high-performance plastics from recycled feedstock in demanding applications
BASF’s partnership with Quantafuel
The partnership is part of BASF’s efforts to develop chemical recycling as a business

- Together we aim to **further develop Quantafuel’s integrated process of pyrolysis and purification** towards optimizing the output for the use as feedstock in chemical production.

- After start up of Quantafuel’s plant in Skive, Denmark, BASF will **have a right of first refusal to all pyrolysis oil and purified hydrocarbons** from this plant for a minimum of four years.

- BASF will use these secondary raw materials to **develop the market for chemically recycled plastics with selected customers**.

- Once the Quantafuel plant reaches full capacity, BASF aims to **deliver first commercial supply volumes of Cycled™ products to selected customers**.

BASF is further investigating various options for supplying the company’s Production Verbund with greater volumes of pyrolysis oil.
Benefits of ChemCycling™
With ChemCycling™ we are contributing to a circular economy and are saving resources and emissions

- More plastic waste is recycled as the project focusses on plastic waste for which no high-value recycling processes are established yet.
- Plastic waste is turned into virgin-grade high-performance materials for demanding applications via a mass balance approach.
- Using recycled feedstock from plastic waste in chemical production helps to save fossil resources.
- CO₂ emissions are saved against conventional plastic production and incineration of plastic waste.
With ChemCycling™ more plastic waste will be recycled

- We contribute to the recycling of plastic waste for which no high value recycling processes are established yet

- Examples of waste plastics which are difficult to recycle mechanically or which are incinerated include:
  - Plastics with adhering food residues
  - Multi-layer food packaging
  - Tires

ChemCycling™ does not compete but complement mechanical recycling
With ChemCycling™ we turn plastic waste into virgin-grade high-performance materials

- Products manufactured with chemically recycled plastic waste under a mass balance approach achieve the same level of quality and purity as virgin plastics.

- This makes it possible to manufacture products with recycled content that have to meet high quality and hygiene standards, for example food packaging.

With ChemCycling™ we can increase recycled content in efficient materials for demanding applications and offer customers opportunities for innovative business models.
ChemCycling™ is attractive in terms of CO₂ emissions

Conclusions of an external, critically-reviewed life-cycle assessment (LCA) for ChemCycling™:

- Pyrolysis of mixed plastic waste emits 50 percent less CO₂ than incineration of mixed plastic waste
- CO₂ emissions are saved when manufacturing plastics based on pyrolysis oil under a mass balance approach instead of naphtha. The lower emissions result from avoiding the incineration of mixed plastic waste
- Manufacturing of plastics via either chemical recycling (pyrolysis) or mechanical recycling of mixed plastic waste results in comparable CO₂ emissions. It was taken into account that the quality of chemically recycled products is similar to that of virgin material and that usually less input material is out than with mechanical recycling
LCA Deep Dive: Comparison of CO$_2$ emissions between pyrolysis and incineration of mixed plastic waste

Explanations

- Pyrolysis emits less direct emissions than incineration (light blue bars)

- If all CO$_2$ emissions and savings are taken into account, both alternatives receive credits (dark blue bars):
  - Pyrolysis: CO$_2$ savings credited as pyrolysis oil is replacing fossil feedstock in chemical production
  - Incineration: CO$_2$ savings credited the energy generated by incineration which replaces the average energy sourced from the national grid

Fig. 1: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO$_2$e. Incineration of 1t mixed plastic waste emits, in total, 1777 kg CO$_2$e.
LCA Deep Dive: Comparison of CO₂ emissions between plastics production from pyrolysis oil and naphtha

Explanations

- Direct emissions of chemically recycled plastics are higher than for virgin plastics due to the extremely efficient fossil naphtha supply chains (light blue bars).
- However, CO₂ savings that originate from not incinerating the plastic waste can be credited to the chemically recycled plastic (dark blue bars).
- In total, a net overall advantage of chemically recycled plastic compared to fossil.

Fig. 2: Conventional production of 1t LDPE emits, in total, 1894 kg CO₂e. For the production of 1t LDPE via pyrolysis a negative number of -477 can be accounted for the overall CO₂ emissions.

* pyrolysis used as chemical recycling technology
** from primary fossil resources
LCA Deep Dive: Comparison of CO₂ emissions of 1t of virgin plastics with three end-of-life options

Explanations

- Manufacturing of products with chemically recycled feedstock and with mechanically recycled feedstock emits significantly less CO₂ than virgin fossil products that are incinerated.

- To consider the different product qualities for chemical and mechanical recycling the **Circular Footprint Formula** was applied: With chemical recycling original product quality (quality factor = 1) can be achieved. Mechanical recycling of mixed plastic waste results in non-virgin-grade quality; according to economic considerations a quality factor of 0.5 is used.

- For pyrolysis the yield is 70%, the material losses for mechanical recycling are up to 55%*.

* The error bar reflects the different scenarios by changing the quality factor and the material loss rates after sorting of waste.

** The error bar reflects the different scenarios by changing the quality factor and the material loss rates after sorting of waste.

Fig. 3: Production and end-of-life treatment of 1t of plastics via pyrolysis emit 2,100 kg CO₂e, whereas production and end-of-life treatment of 1t of plastics via mechanical recycling emits 1,973 kg CO₂e. Production and incineration of 1t of plastics emits 3,700 kg CO₂e.
Regulatory requirements
Regulatory support for ChemCycling™ is needed to reach market maturity

BASF calls for technology-neutral regulations

- Chemical recycling needs to count towards recycling targets
- Mass balanced recycled content should be supported to the same extent as single sourced recycled content
- Incentives for recycled content should apply to all kinds of recycling
The mass balance approach
Allocation of recycled feedstock with the mass balance approach

How it works

Feedstock

- Fossil
- Recycled

Use of recycled feedstock in very first steps of chemical production (e.g., steam cracker)

BASF Production Verbund

Utilization of existing Production Verbund for all production steps

Products

- Conventional product
- Mass balance product

Allocation of recycled feedstock to selected products
Challenge: Recycled materials cannot be directed to one specific product

Therefore, an external certification system is needed.
Our solution: Certification and standardization

Ecoloop ensures the correct allocation of recycled resources in BASF’s value chain.

Feedstock
- Fossil
- Recycled

BASF Production Verbund

Products
- Conventional
- Allocated
BASF Verbund
BASF Verbund Site in Ludwigshafen/Germany

The world’s largest integrated chemical complex owned by a single company

Headquarters

<table>
<thead>
<tr>
<th>Employees BASF SE</th>
<th>35,316*</th>
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<tbody>
<tr>
<td>Site area</td>
<td>10 km²</td>
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<tr>
<td>Sales products**</td>
<td>~ 8.5 million metric tons p.a.</td>
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<tr>
<td>Road</td>
<td>~ 106 km</td>
</tr>
<tr>
<td>Rail</td>
<td>~ 230 km</td>
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Logistics

| ~ 2,100 trucks daily |
| ~ 400 railcars daily |
| ~ 20 ships daily     |

Pipeline system

| ~ 2,850 km |

Production facilities

| ~110 production facilities with around 200 production plants |

* as of 31 Dec 2018
Petrochemicals are the starting point for a broad range of products
The „chemis-tree“
From raw materials to chemical products
Recycled raw materials replace fossil feedstock
We create chemistry