

ChemCycling™: Environmental Evaluation by Life Cycle Assessment (LCA)

Ludwigshafen, September 2020



The role of ChemCycling™ in a Circular Economy

Different loops are necessary for a successful transition towards circularity

■ Polymer loop

By mechanical recycling it is possible to recycle single-stream plastics like PET. The chemical structure of the plastics is not changed

■ Monomer loop

By breaking down plastics into their monomers new virgin-grade plastics can be generated. This is technically feasible for some polymer types only (e.g. PA)

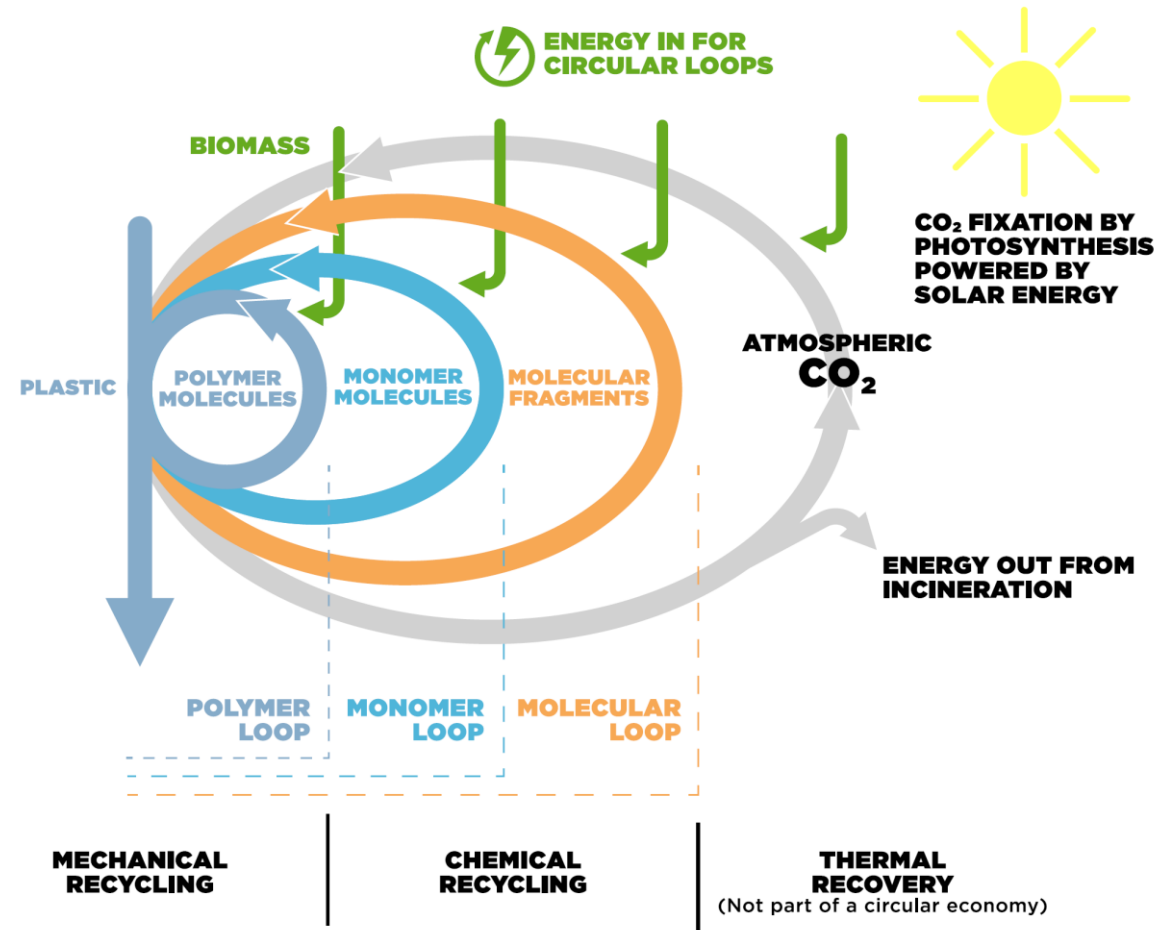
■ Molecular loop

(Focus of BASF's ChemCycling project)

By pyrolysis or gasification technologies plastics can be turned into their basic building blocks and used to produce all types of new virgin-grade plastics

■ CO₂ loop

Bio-based chemicals can be incinerated and plants are growing by uptaking CO₂ from the atmosphere. From plants one can generate bio-based chemicals again. This is technically feasible for some chemicals



Basic LCA

Basic Life Cycle Assessment (LCA) ChemCycling™

Methodological approach

Target: Environmental assessment of chemically recycled products by comparing different end-of-life options for mixed plastic waste* and virgin plastics production



The LCA study comprises **three separate studies** considering waste, product and plastic quality perspectives



The LCA study was **performed by a third party according to ISO 14040/44** and was **reviewed by three independent experts**



Where available, the LCA was **calculated with high-quality data from existing commercial plants**; data for pyrolysis from Plastic Energy

Basic Life Cycle Assessment (LCA) ChemCycling™

Conformity to respective ISO 14040 series

Three separate studies

- **Waste perspective:** Comparison of pyrolysis and incineration of mixed plastic waste
- **Product perspective:** Comparison of plastics based on pyrolysis oil and conventional plastics from primary fossil resources (naphtha)
- **Plastics quality perspective:** Comparison of the life cycle of 1t of virgin plastics with three end-of-life options

Panel decision

- “...the LCA study followed the guidance of and is consistent with the international standards for Life Cycle Assessment (ISO 14040:2006 and ISO 14044:2006).”
- The background report and review statement is available at: www.basf.com

Commissioner / LCA practitioner

Dr. Christian Krüger

Manfred Russ



Critical Review Panel

Prof. Adisa Azapagic
(Panel Chair)



Dr. Florian Antony

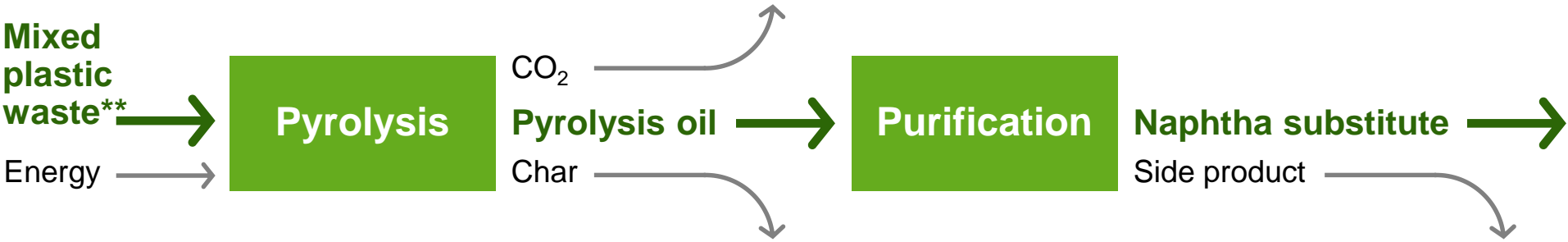
Simon Hann



Excursus: Pyrolysis

An efficient process to convert mixed plastic waste into a secondary raw material for the chemical industry

- About 70% of the mixed plastic waste can be converted into pyrolysis oil
- Almost no external thermal energy used: Pyrolysis gas generates the energy required for the process
- Only a small amount of the input materials are residues and must be incinerated
- Plastics based on pyrolysis oil can achieve 100% identical quality as fossil-based plastics*



→ Suppliers | BASF →

6 * under application of a mass balance approach
** from a sorting plant

Basic LCA ChemCycling™

General results

Chemical recycling is attractive in terms of CO₂ emissions – the most discussed LCA indicator

- 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 (as secondary raw material under a mass balance approach) instead of naphtha (primary fossil raw material). 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 sorted out than with mechanical recycling

Results for additional environmental indicators can be found in the attachment of this slide deck.



Basic LCA – Study 1

Waste perspective

Does pyrolysis of mixed plastic waste save CO₂ emissions compared to incineration?

Comparison of CO₂ emissions between pyrolysis and incineration of mixed plastic waste

Case study comprises cradle-to-gate life cycle for the different end-of-life options of 1t of mixed plastic waste

Input

- 1t mixed plastic waste from packaging (German yellow bag)

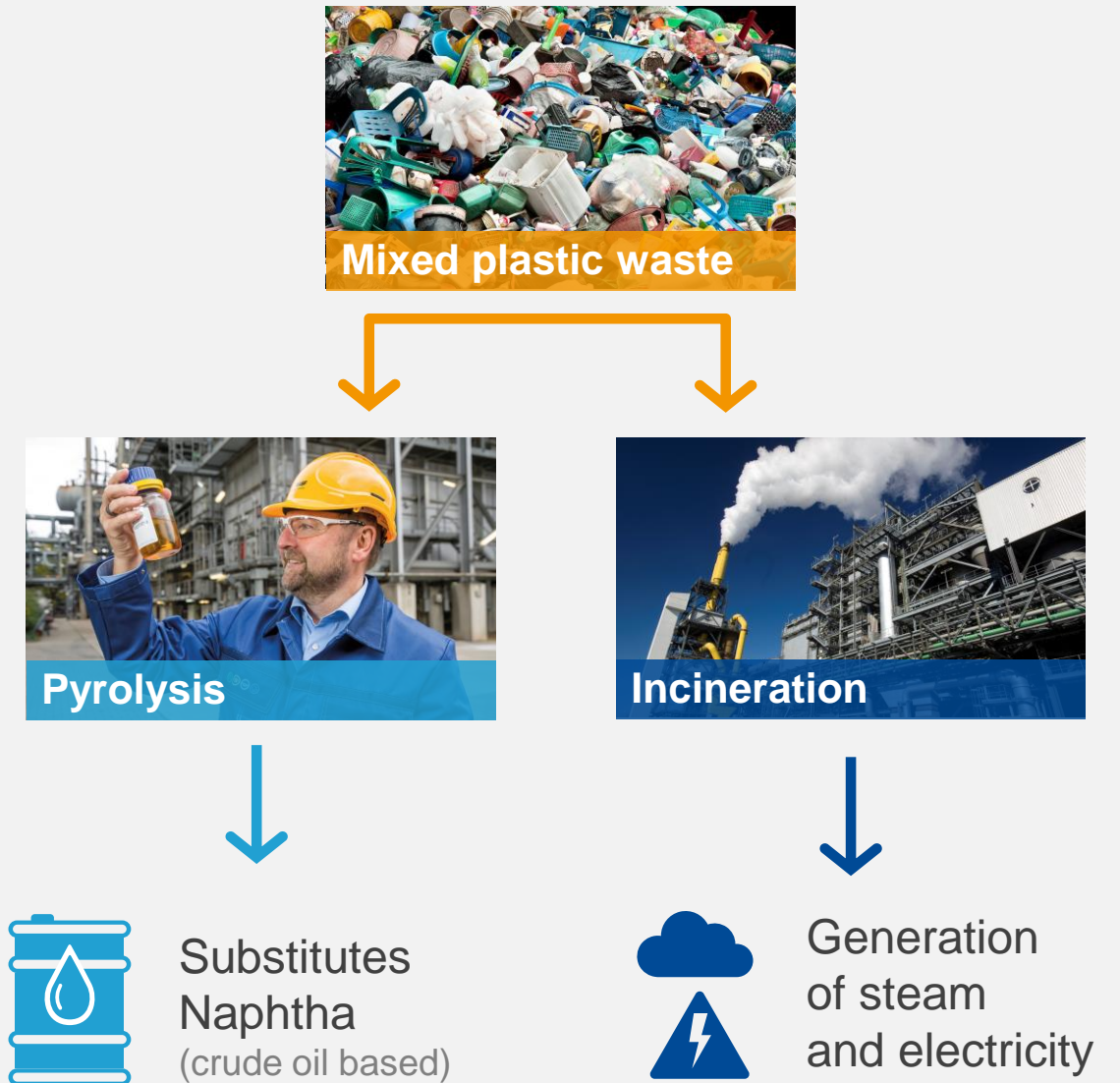
Process alternatives

- Pyrolysis incl. pretreatment and purification
- Incineration (MSWI, RDF)*

Output

- Pyrolysis: Efficient production of oil as feedstock for the chemical industry (material yield: 70%, almost no need of external energy due to internal energy recovery)
- Incineration: Generated electricity and steam substitutes electricity from national grid and steam from national average (light fuel oil and natural gas)

9 * MSWI = municipal solid waste incineration;
RDF = refuse derived fuel (no coal-fired and cement plants)



Comparison of CO₂ emissions between pyrolysis and incineration of mixed plastic waste

Results

- Pyrolysis of mixed plastic waste emits 50 percent less CO₂ than incineration of mixed plastic waste
- Specifically, the study found that pyrolysis emits 1 ton less CO₂ than incineration per 1 ton of mixed plastic waste

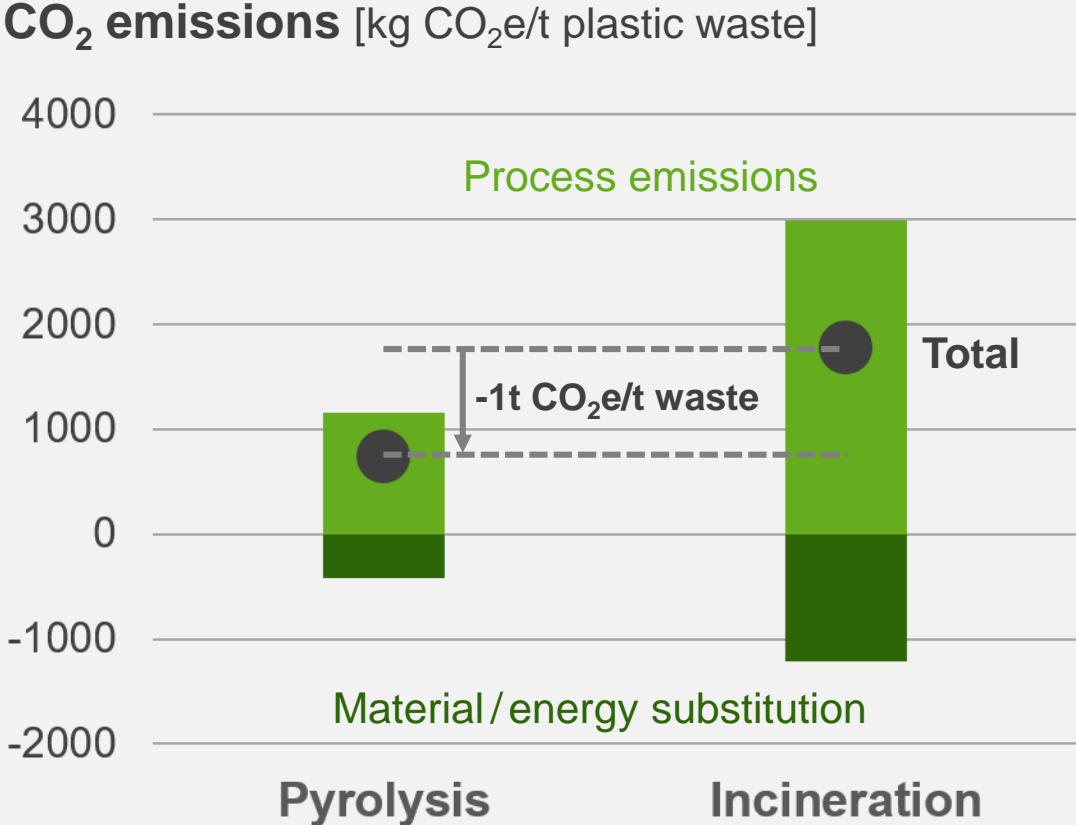


Fig. 1: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO₂e. Incineration of 1t mixed plastic waste emits, in total, 1777 kg CO₂e.

Comparison of CO₂ emissions between pyrolysis and incineration of mixed plastic waste

Explanations

- Pyrolysis emits less direct emissions than incineration (light green bars)
- If all CO₂ emissions and savings are taken into account, both alternatives receive credits (dark green bars):
 - ▶ Pyrolysis: CO₂ savings credited as pyrolysis oil is replacing fossil feedstock in chemical production
 - ▶ Incineration: CO₂ savings credited as the energy generated by incineration replaces the average energy sourced from the national grid

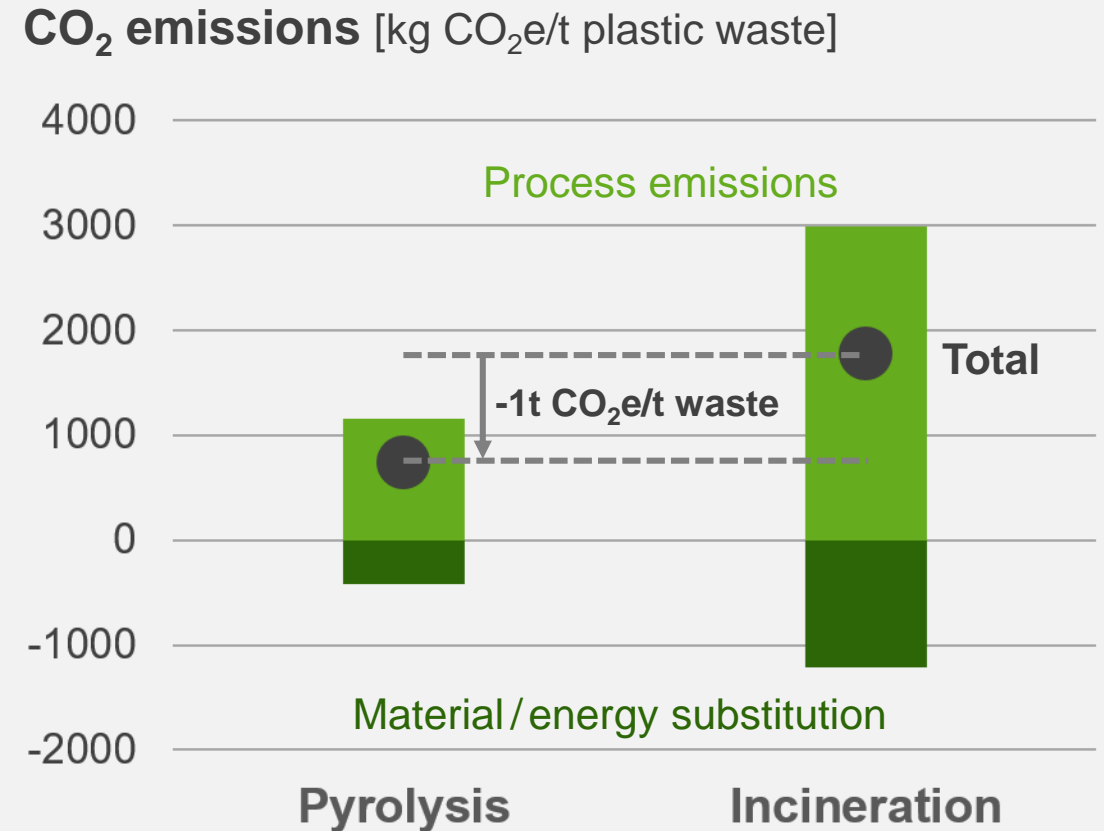


Fig. 1: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO₂e.
Incineration of 1t mixed plastic waste emits, in total, 1777 kg CO₂e.

Basic LCA – Study 2

Product perspective

Does plastic material based on waste pyrolysis oil cause lower CO₂ emissions than plastic material produced with fossil naphtha?

Comparison of CO₂ emissions between plastics production from pyrolysis oil and naphtha

Case study comprises cradle-to-gate life cycle for the production of 1t of plastic product

Input

- Oil from pyrolysis of mixed plastic waste (German yellow bag)
- Naphtha from crude oil

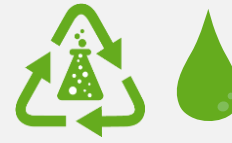
Processes

- Production of ethylene in steam cracker and polymerization to LDPE (low-density polyethylene)

Output

- Chemically recycled: LDPE (from pyrolysis oil applying the mass balance approach)
- Conventional: LDPE virgin (from naphtha)

Oil from waste pyrolysis*



Chemically recycled plastic

Naphtha from crude oil



Conventional plastic



Chemical processes

Comparison of CO₂ emissions between plastics production from pyrolysis oil and naphtha

Results

- 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
- In particular, the study could show this for the production of a reference plastic (LDPE):
1 ton of LDPE produced from pyrolysis oil under a mass balance approach, emits 2.3 t less CO₂ than 1 ton LDPE produced from fossil naphtha

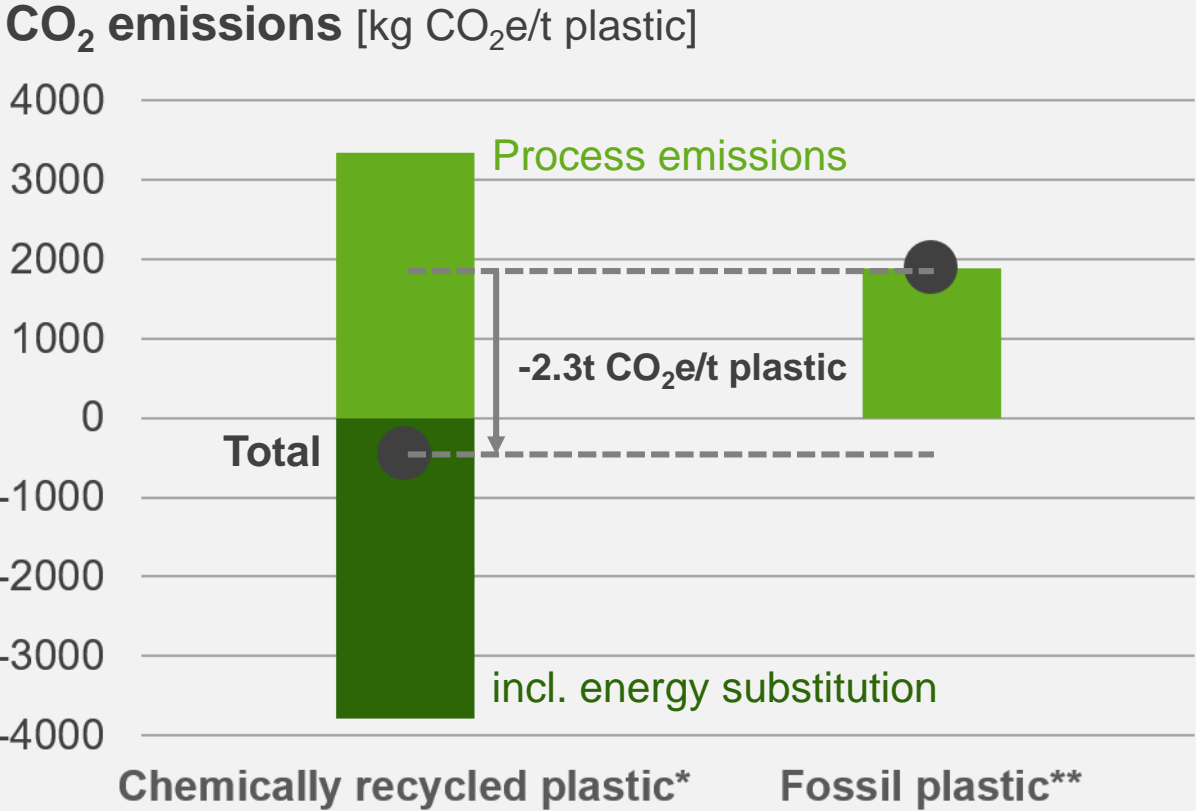


Fig. 2: Conventional production of 1t LDPE emits, in total, 1894 kg CO₂e. For the production of 1t LDPE via pyrolysis a negative number of -477 can be accounted for the overall CO₂ emissions.

* pyrolysis used as chemical recycling technology
** from primary fossil resources

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 green bars)
- However, CO₂ savings that originate from not incinerating the plastic waste can be credited to the chemically recycled plastic (dark green bars)
- In total, a net overall advantage of chemically recycled plastic compared to fossil

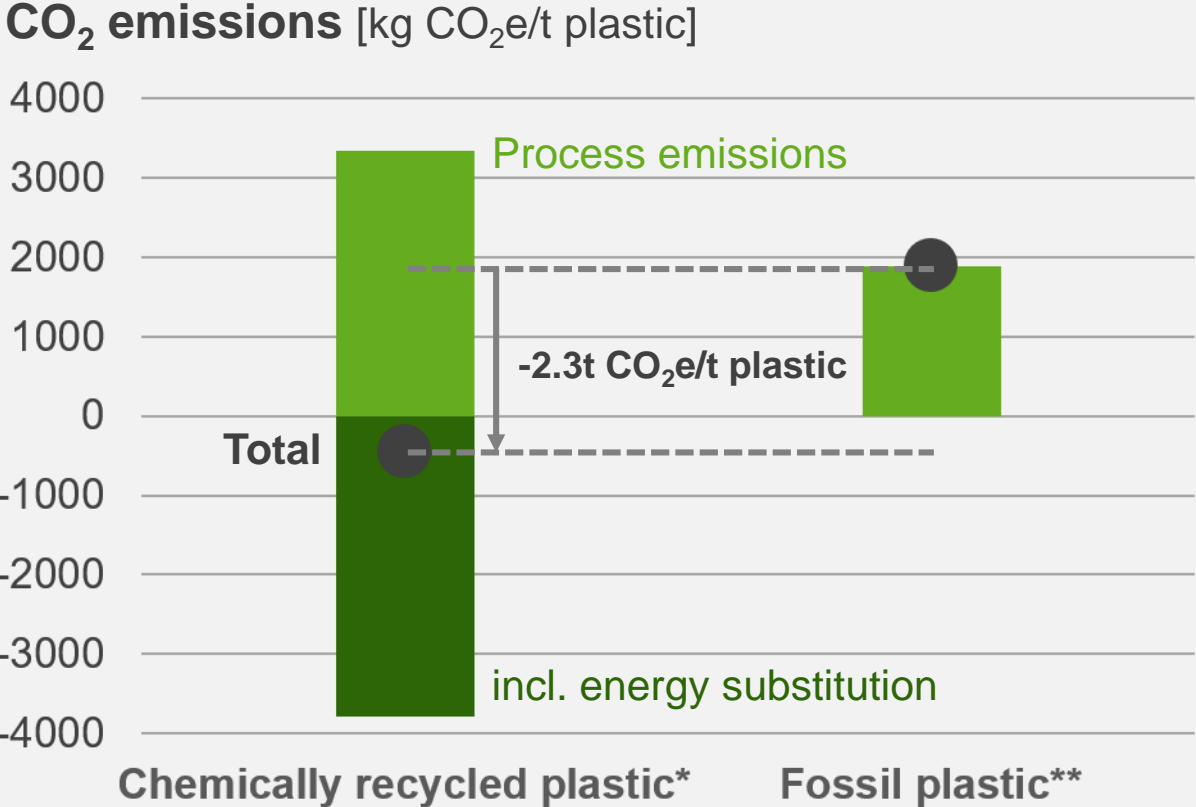


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* pyrolysis used as chemical recycling technology
 ** from primary fossil resources

Basic LCA – Study 3

Plastic quality perspective

Does plastic material produced via chemical recycling cause lower CO₂ emissions than plastic material produced via mechanical recycling?

Comparison of CO₂ emissions of 1t of virgin plastics with three end-of-life options

Case study comprises life cycle from 1t of fossil plastic and three different end-of-life options incl. production of secondary material (reflecting composition of the German yellow bag)

Input

- Virgin plastics production based on oil & gas turned into mixed plastic waste

Process alternatives

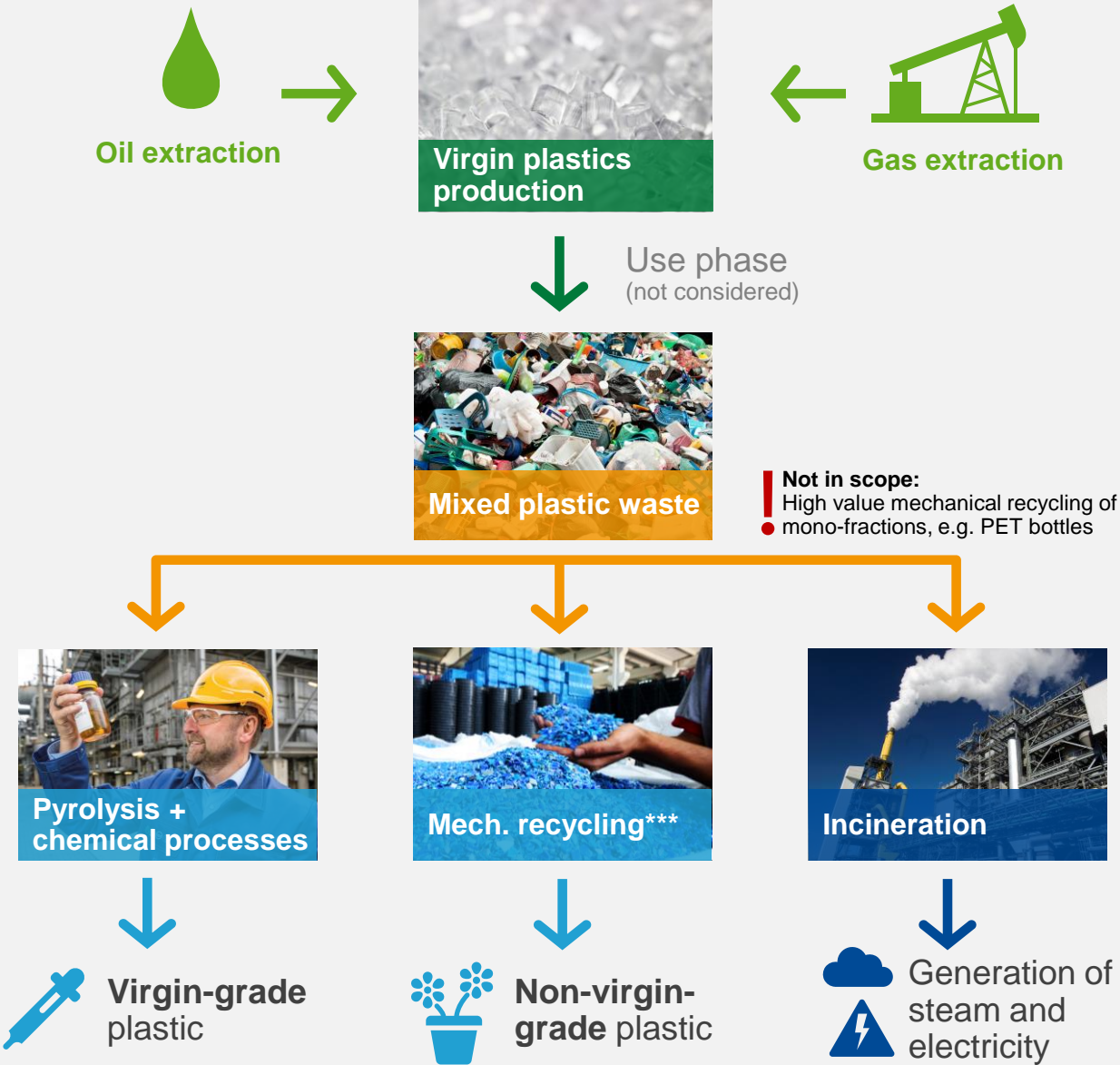
- Pyrolysis (incl. pretreatment, purification and incineration of sorting losses) + chemical processes; applying mass balance approach
- Mechanical recycling (incl. pretreatment, extrusion and sorting losses)
- Incineration (MSWI, RDF)*

Output

- Pyrolysis produces high-performance virgin-like plastics applying a mass balance approach
- Mechanical recycling produces non-virgin-grade plastics**
- Incineration: Generated electricity and steam substitutes electricity and steam from national grid/average

* MSWI = municipal solid waste incineration; RDF = incineration of refuse derived fuel (no coal-fired and cement plants)

** Product quality factor: 0.5 (from Circular Footprint Formula by EU Commission)



*** Material losses are incinerated

Comparison of CO₂ emissions of 1t of virgin plastics with three end-of-life options

Results

- Manufacturing of plastics via either chemical recycling (pyrolysis) or mechanical recycling of mixed plastic waste result in similar 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 sorted out than in mechanical recycling



CO₂ emissions [kg CO₂e/t product]

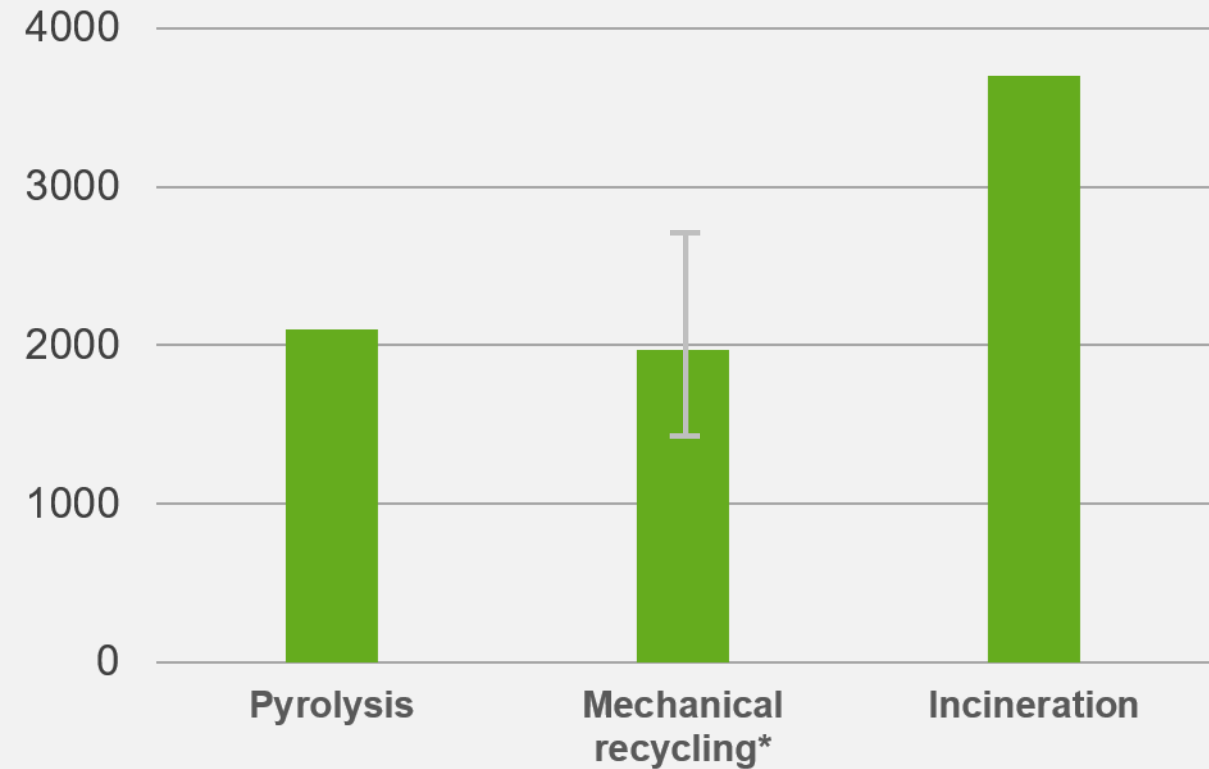


Fig. 3: Production and end-of-life treatment of 1t of plastics via pyrolysis emit 2,100 kg CO₂e, whereas production and end-of-life treatment of 1t of plastics via mechanical recycling emits 1,973kg CO₂e. Production and incineration of 1t of plastics emits 3,700 kg CO₂e.

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

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%*

* starting from sorting plant. Source: Öko-Institut / Institute for Applied Ecology (2016): Umweltpotenziale der getrennten Erfassung und des Recyclings von Wertstoffen im Dualen System

CO₂ emissions [kg CO₂e/t product]

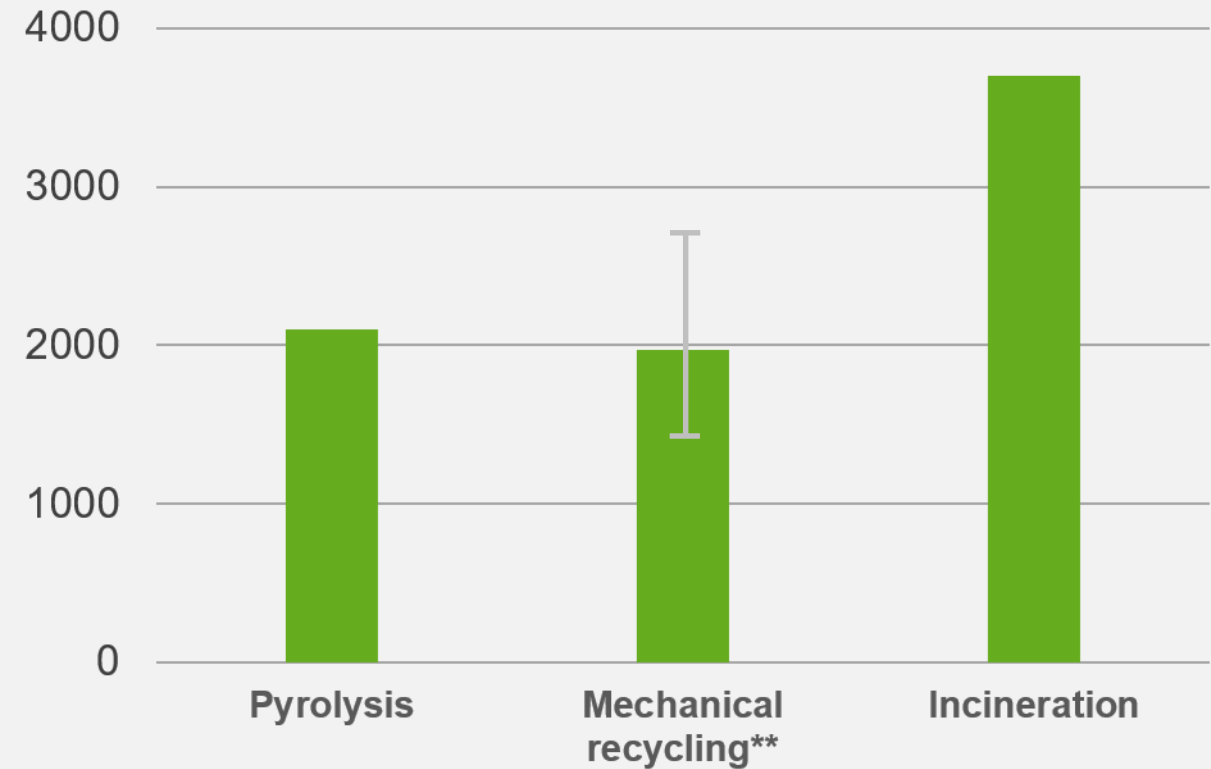


Fig. 3: Production and end-of-life treatment of 1t of plastics via pyrolysis emit 2,100 kg CO₂e, whereas production and end-of-life treatment of 1t of plastics via mechanical recycling emits 1,973kg CO₂e. Production and incineration of 1t of plastics emits 3,700 kg CO₂e.

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

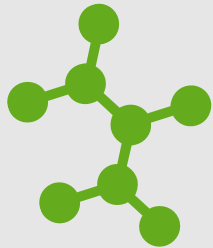
Specific LCAs

for various BASF products

Specific Life Cycle Assessment (LCA) ChemCycling™

Methodological approach

Target: Environmental assessment of chemically recycled BASF products by comparing their production based on pyrolysis oil derived from either mixed plastic waste or end-of-life tires to their production with primary fossil resources (e.g. naphtha)



The specific LCA studies focus on a **product perspective**



The results were **calculated based on a third-party reviewed methodology according to ISO 14040/44**



Data for pyrolysis of mixed plastic waste provided by our partner Quantafuel



Data for pyrolysis of end-of-life-tires provide by our partner Pyrum

Ultramid[®] (Base Polymer)

Product perspective

Does Ultramid[®] base polymer based on pyrolysis oil from end-of-life tires cause lower CO₂ emissions than Ultramid[®] base polymer produced with fossil naphtha?

Comparison of CO₂ emissions between Ultramid[®] production from ELT pyrolysis oil and naphtha

Case study comprises cradle-to-gate life cycle for the production of 1t of Ultramid[®] base polymer

Input

- Oil from pyrolysis of End-of-life tires (ELT)
- Naphtha from crude oil

Processes

- Production of Ultramid[®] base polymer (PA6)

Output

- Chemically recycled: Ultramid[®] Ccycled[™] base polymer (PA6) (from pyrolysis oil applying a mass balance approach)
- Conventional: Ultramid[®] base polymer virgin (from naphtha)

Oil from tire pyrolysis



Ultramid[®] Ccycled[™] (PA6)

Naphtha from crude oil



Conventional Ultramid[®]



Chemical processes

Comparison of CO₂ emissions between Ultramid[®] B base polymer production from ELT pyrolysis oil and naphtha

Results

- CO₂ emissions are saved when manufacturing PA6 based on pyrolysis oil under a mass balance approach. The lower emissions result from avoiding the incineration of end-of-life tires (ELT).
- 1 ton of PA6 produced from pyrolysis oil under a mass balance approach, emits 1.3 ton less CO₂ than 1 ton PA6 produced from fossil feedstock.

Feedstock
from Germany



Produced Product
PA

Relevant Industry

CO₂ emissions [kg CO₂e/t product]

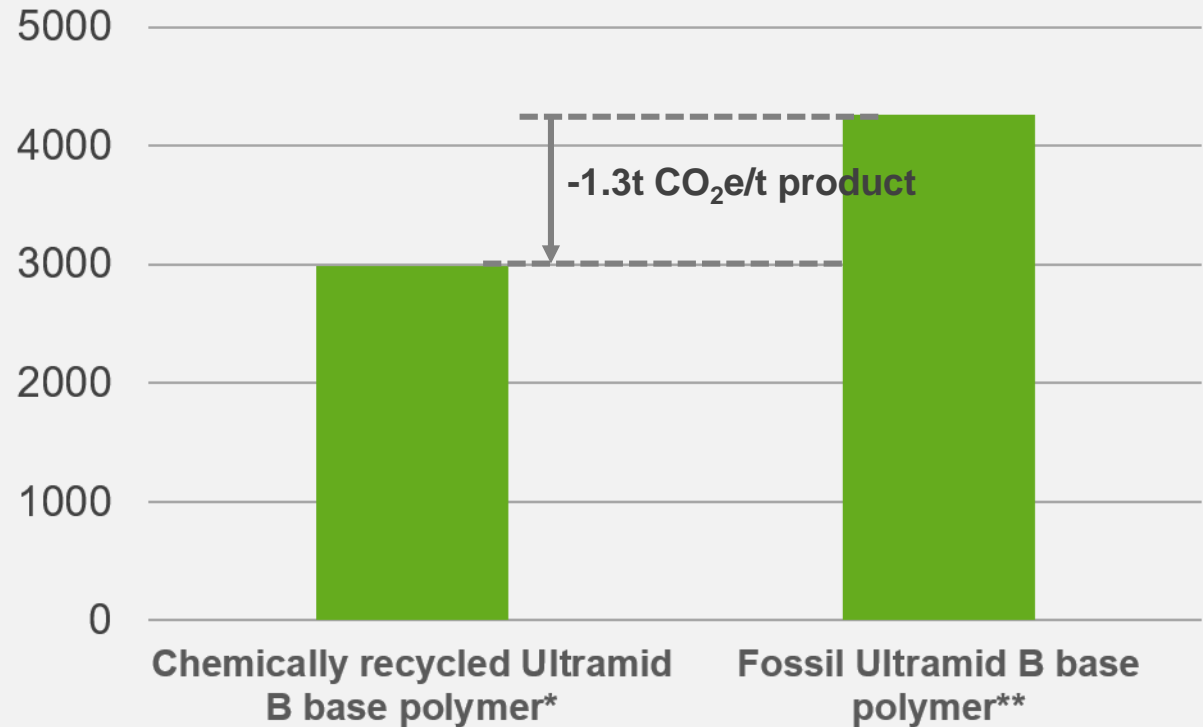


Fig. 4: Conventional production of 1t PA6 emits, in total, 4300 kg CO₂e. For the production of 1t PA6 via pyrolysis, in total, 3000 kg CO₂e.

* pyrolysis used as chemical recycling technology

** from primary fossil resources

Comparison of CO₂ emissions between Ultramid[®] B base polymer production from ELT pyrolysis oil and naphtha

Results

- CO₂ emissions are saved when manufacturing PA6 based on pyrolysis oil under a mass balance approach. The lower emissions result from avoiding the incineration of end-of-life tires (ELT).
- 1 ton of PA6 produced from pyrolysis oil under a mass balance approach, emits 1.3 ton less CO₂ than 1 ton PA6 produced from fossil feedstock.

Feedstock
from Germany



Produced Product
PA

Relevant Industry


CO₂ emissions [kg CO₂e/t product]

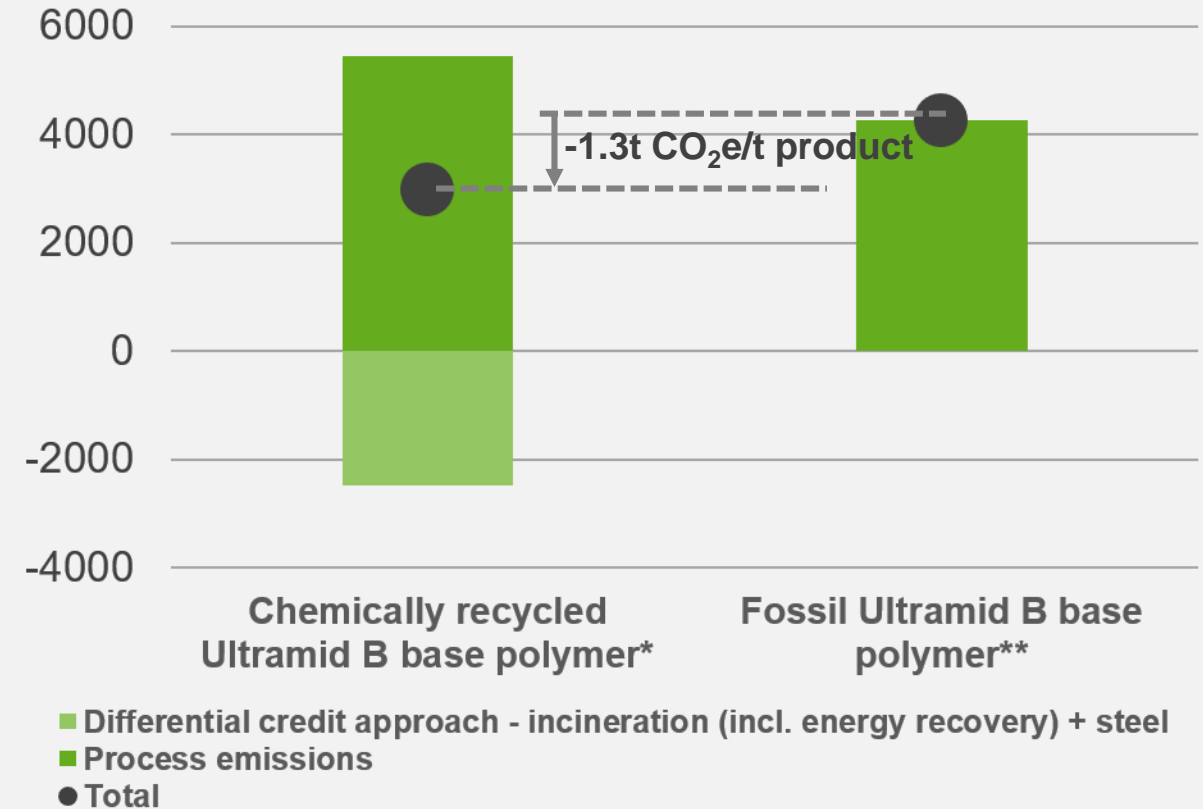


Fig. 5: Conventional production of 1t PA6 emits, in total, 4300 kg CO₂e.
For the production of 1t PA6 via pyrolysis, in total, 3000 kg CO₂e.

* pyrolysis used as chemical recycling technology

** from primary fossil resources

Styropor®

Product perspective

Does Styropor® based on pyrolysis oil from mixed plastic waste cause lower CO₂ emissions than Styropor® produced with fossil naphtha?

Comparison of CO₂ emissions between Styropor[®] production from MPW pyrolysis oil and naphtha

Case study comprises cradle-to-gate life cycle for the production of 1t of Styropor[®] base polymer

Input

- Mixed plastic waste (MPW) pyrolysis oil
- Naphtha from crude oil

Processes

- Production of Styropor[®] (EPS) via steam cracker

Output

- Chemically recycled: Styropor[®] Ccycled[™] (from pyrolysis oil applying a mass balance approach)
- Conventional: Styropor[®] virgin (from naphtha)

Oil from mixed plastic waste



Styropor[®] Ccycled[™]

Naphtha from crude oil



Conventional Styropor[®]



Chemical processes

Comparison of CO₂ emissions between Styropor[®] P 326 production from MPW pyrolysis oil and naphtha

Results

- CO₂ emissions are saved when manufacturing EPS based on pyrolysis oil under a mass balance approach. The lower emissions result from avoiding the incineration of mixed plastic waste.
- 1 ton of EPS produced from pyrolysis oil under a mass balance approach, emits 2.0 ton less CO₂ than 1 ton EPS produced from fossil feedstock.

Feedstock



from Denmark

Produced Product
EPS

Relevant Industry

CO₂ emissions [kg CO₂e/t product]

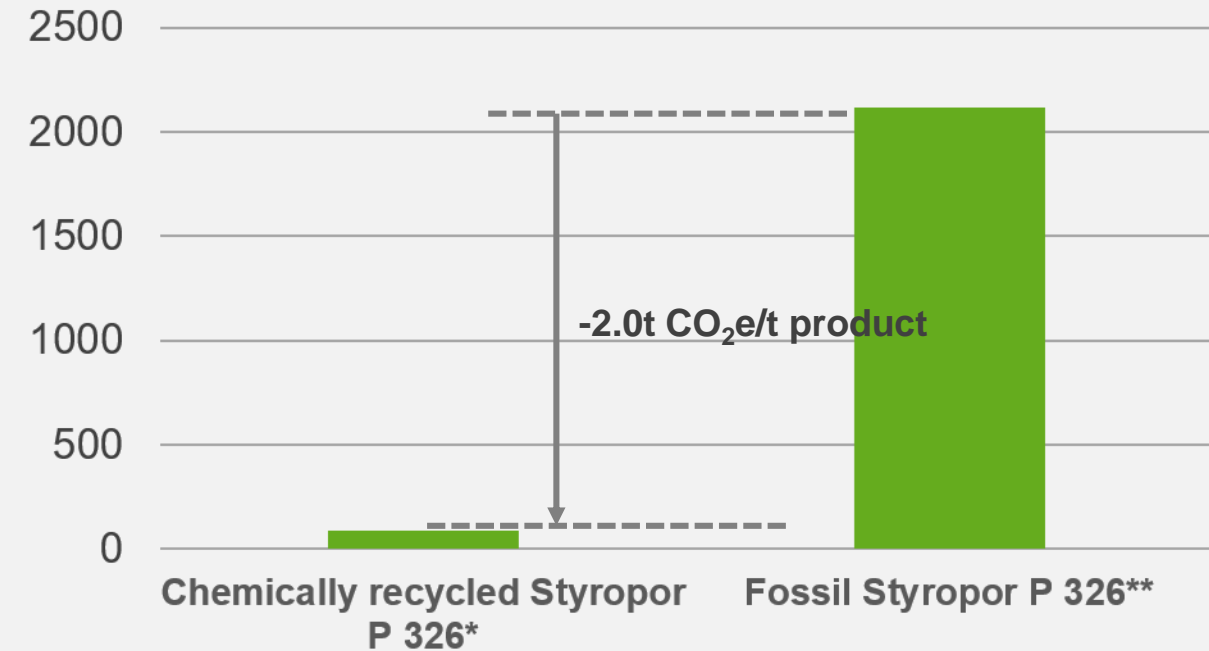


Fig. 10: Conventional production of 1t EPS emits, in total, 2100 kg CO₂e.
For the production of 1t EPS via MPW pyrolysis, in total, 86 kg CO₂e.

* pyrolysis used as chemical recycling technology

** from primary fossil resources

Comparison of CO₂ emissions between Styropor[®] P 326 production from MPW pyrolysis oil and naphtha

Results

- CO₂ emissions are saved when manufacturing EPS based on pyrolysis oil under a mass balance approach. The lower emissions result from avoiding the incineration of mixed plastic waste.
- 1 ton of EPS produced from pyrolysis oil under a mass balance approach, emits 2.0 ton less CO₂ than 1 ton EPS produced from fossil feedstock.

Feedstock



from Denmark

Produced Product
EPS

Relevant Industry

CO₂ emissions [kg CO₂e/t product]

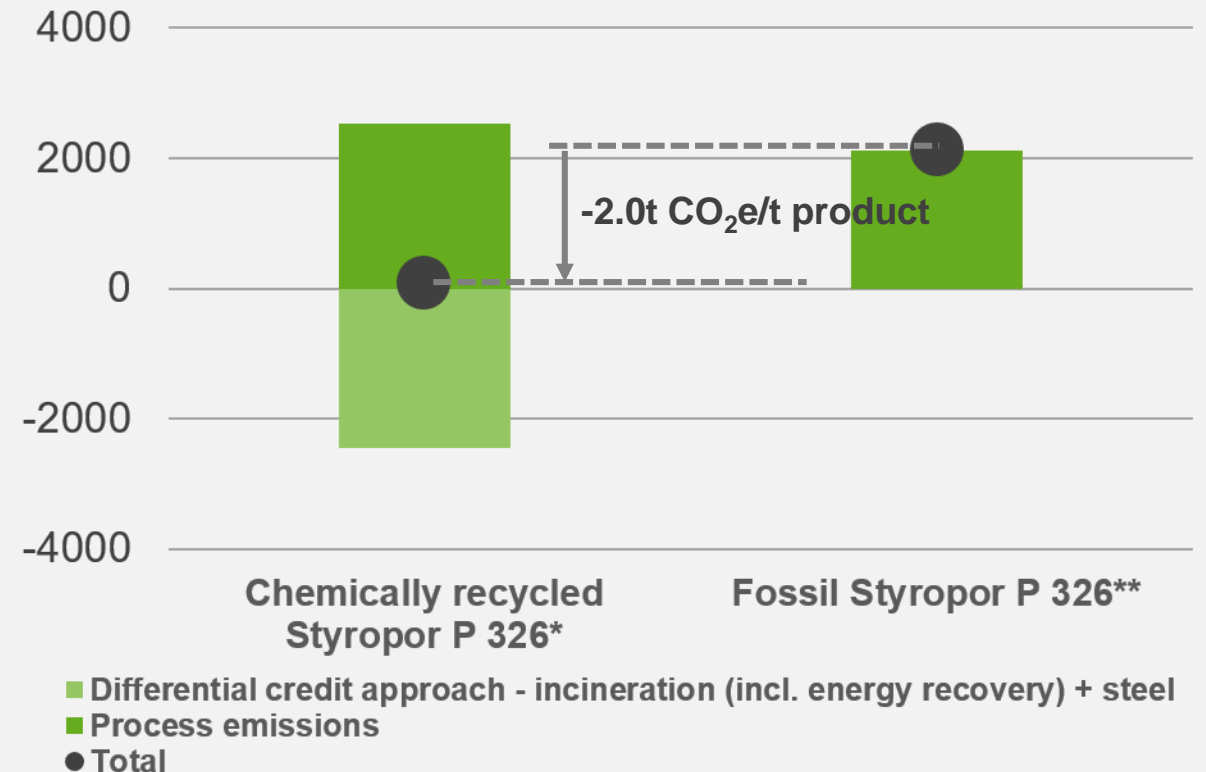


Fig. 11: Conventional production of 1t EPS emits, in total, 2100 kg CO₂e.
For the production of 1t EPS via MPW pyrolysis, in total, 86 kg CO₂e.

* pyrolysis used as chemical recycling technology

** from primary fossil resources



We create chemistry

Basic LCA ChemCycling™

Additional results

Other environmental indicators

- LCA indicator methods like PEF* or ReCiPe** have more than 15 environmental indicators, which can show a more holistic picture
- For EU the most relevant indicators are CO₂ emissions and resource consumption. For these indicators pyrolysis shows significant benefits versus incineration and the production of primary plastics and is similar to mechanical recycling of mixed plastic waste. Other indicators show an indifferent picture: E.g. acidification and summer smog are higher for pyrolysis due to the different credits of electricity production. The different (eco)toxicity potential indicators are dominated by secondary and tertiary processes (e.g. electricity production and credits), so it is not possible to derive clear conclusions.

Further details can be found in the LCA background report.

* PEF = Product Environmental Footprint, developed by Joint Research Center (EU COM)

** ReCiPe was developed by RIVM, Radboud University Nijmegen, Leiden University and PRé

