LCA ChemCycling™:

CO_2 emissions of pyrolyzed mixed plastic waste and the mass balance approach

Ludwigshafen, October 2020

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The role of ChemCycling™ in a Circular Economy

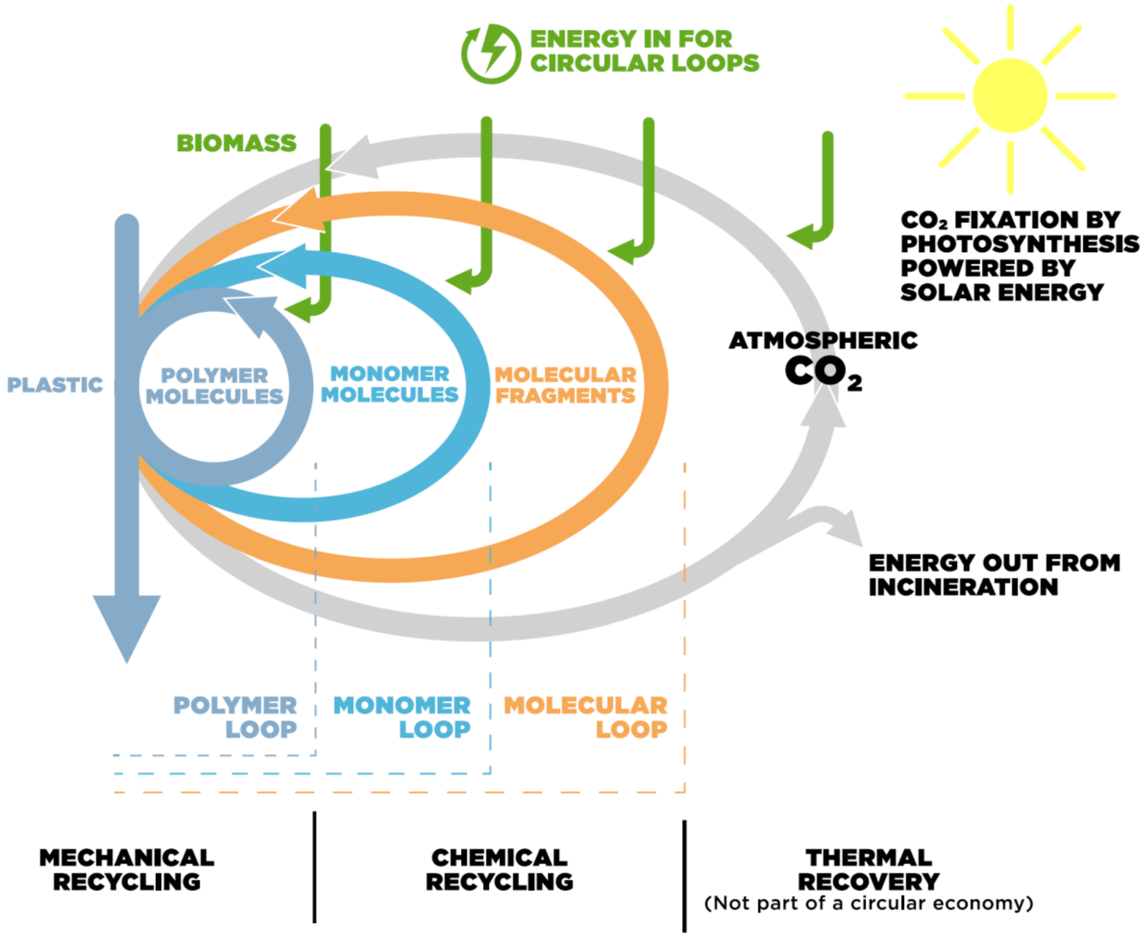
Different loops are necessary for a successful transition towards circularity

- **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

- **CO_2 loop**
  Bio-based chemicals can be incinerated and plants are growing by uptaking CO_2 from the atmosphere. From plants one can generate bio-based chemicals again. This is technically feasible for some chemicals



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

* Mixed plastic waste from German yellow bag (= post-consumer packaging waste)

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

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Manfred Russ

sphera Advancing Operational Excellence™

Critical Review Panel

Prof. Adisa Azapagic
(Panel Chair)

ETHOS Research Environment · Technology · Society

Dr. Florian Antony

Öko-Institut e.V. Institut für angewandte Ökologie Institute for Applied Ecology

Simon Hann

eunomia

Basic LCA – Study 1

Waste perspective

Does pyrolysis of mixed plastic waste save CO_2 emissions compared to incineration?

Comparison of CO_2 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

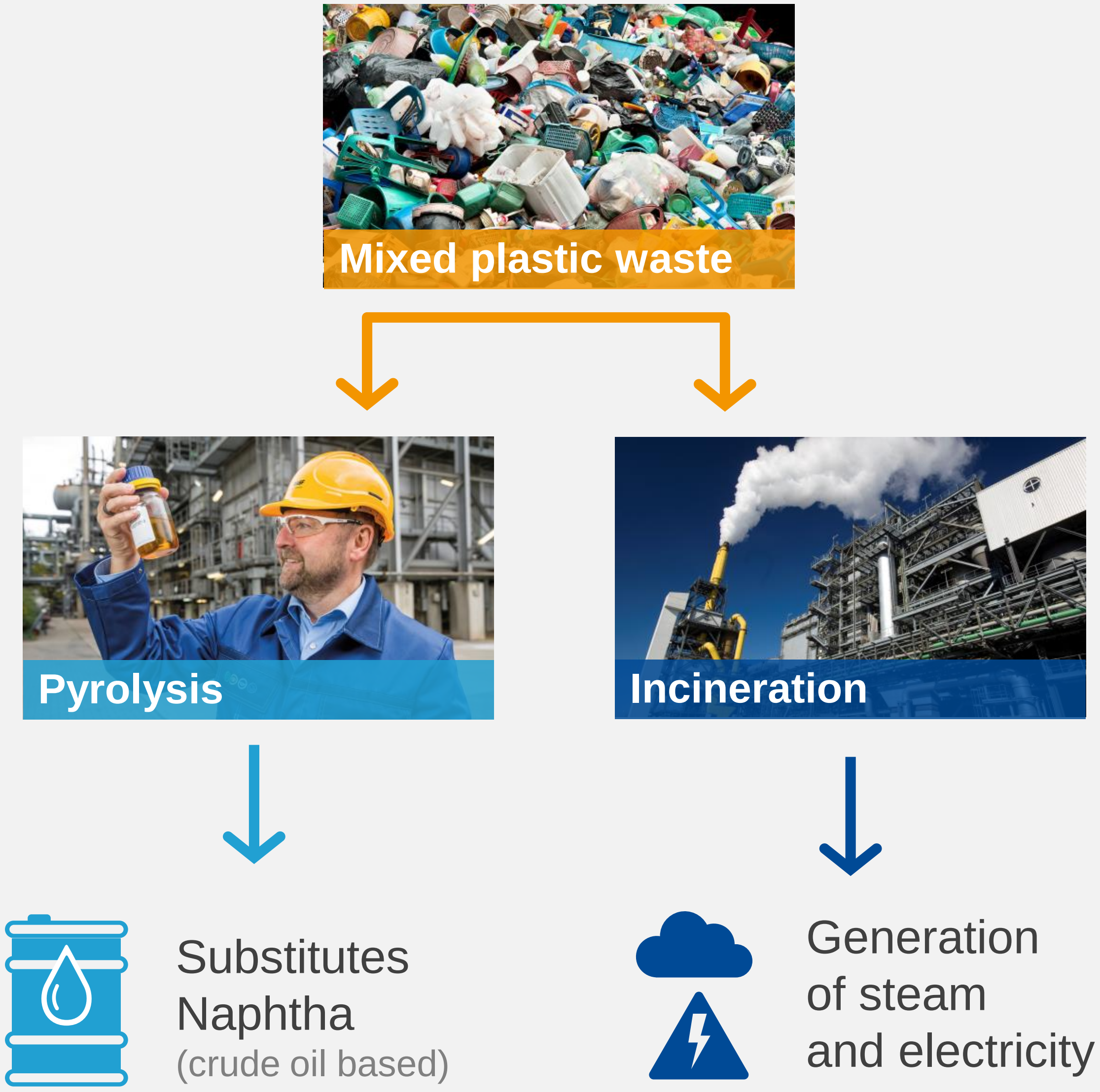
- 1t mixed plastic waste from packaging (German yellow bag)

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)



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

Comparison of CO_2 emissions between pyrolysis and incineration of mixed plastic waste

Explanations

- Pyrolysis emits less direct emissions than incineration (light green bars)
- If all CO_2 emissions and savings are taken into account, both alternatives receive credits (dark green bars):
  - Pyrolysis: CO_2 savings credited as pyrolysis oil is replacing fossil feedstock in chemical production
  - Incineration: CO_2 savings credited as the energy generated by incineration replaces the average energy sourced from the national grid

CO_2 emissions [kg CO_2e/t plastic waste]

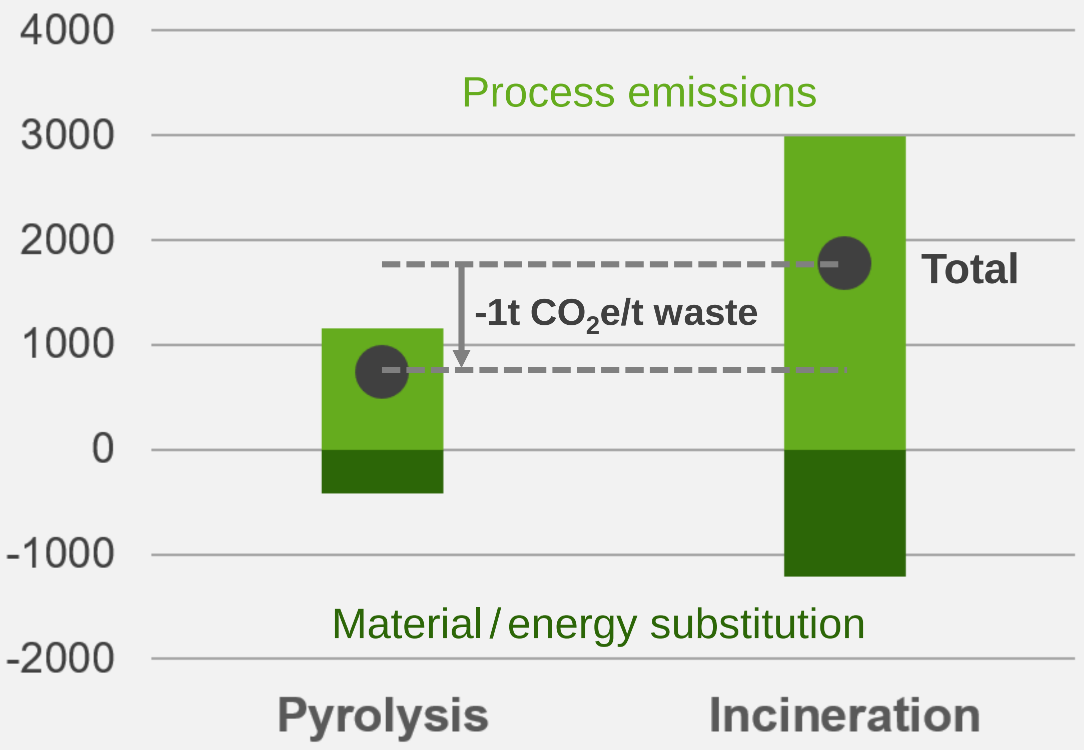


Fig. 1: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO_2e.
Incineration of 1t mixed plastic waste emits, in total, 1777 kg CO_2e.

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Basic LCA – Study 2

Product perspective

Does plastic material based on waste pyrolysis oil cause lower CO_2 emissions than plastic material produced with fossil naphtha?

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Excursus: Mass Balance Approach

The key for a successful transition to Circular Economy

Feedstock

Fossil

Circular: Renewable / Recycled

Use of circular feed-stock 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 renewable feedstock to selected products

Mass Balance Approach

Replacing fossil resources in the current Production Verbund **delivering products with the same performance** as conventional products

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Comparison of CO_2 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

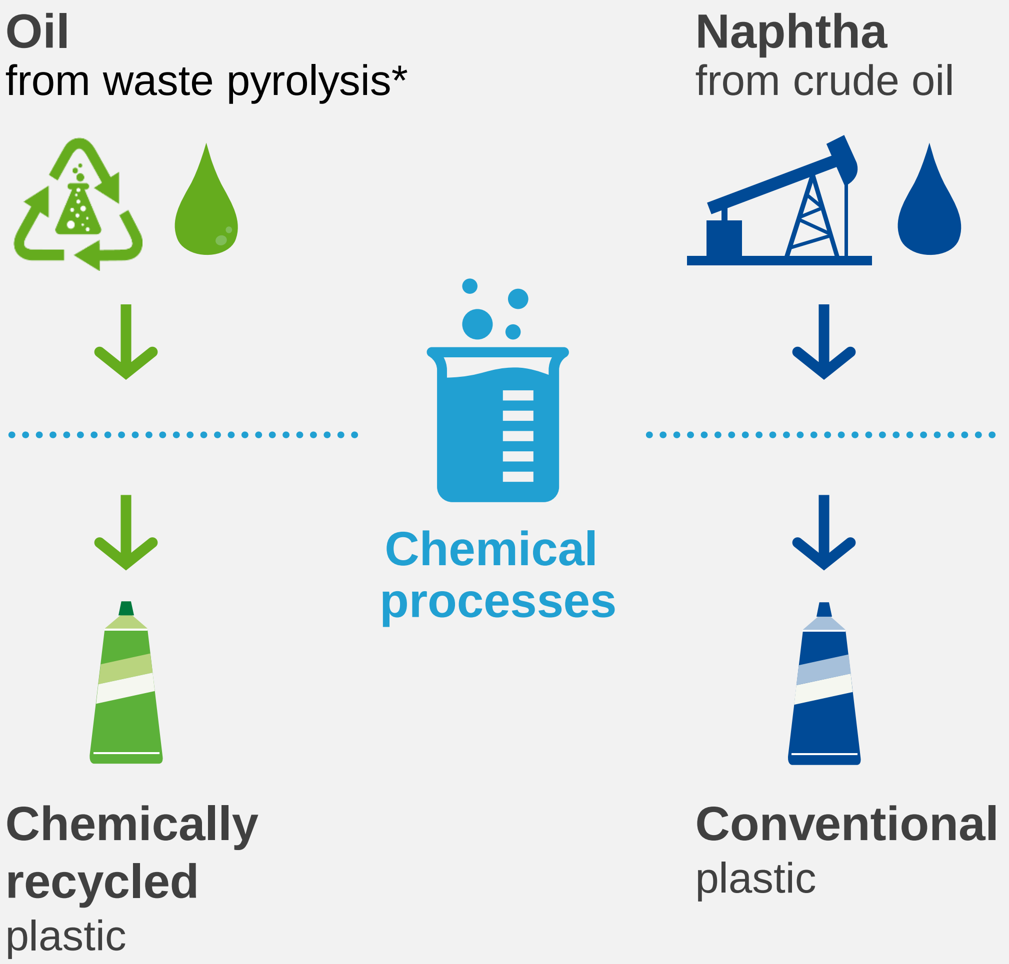
- Oil from pyrolysis of mixed plastic waste (German yellow bag)
- Naphtha from crude oil

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)



* Including the life cycle steps of study 1

Comparison of CO_2 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, CO_2 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

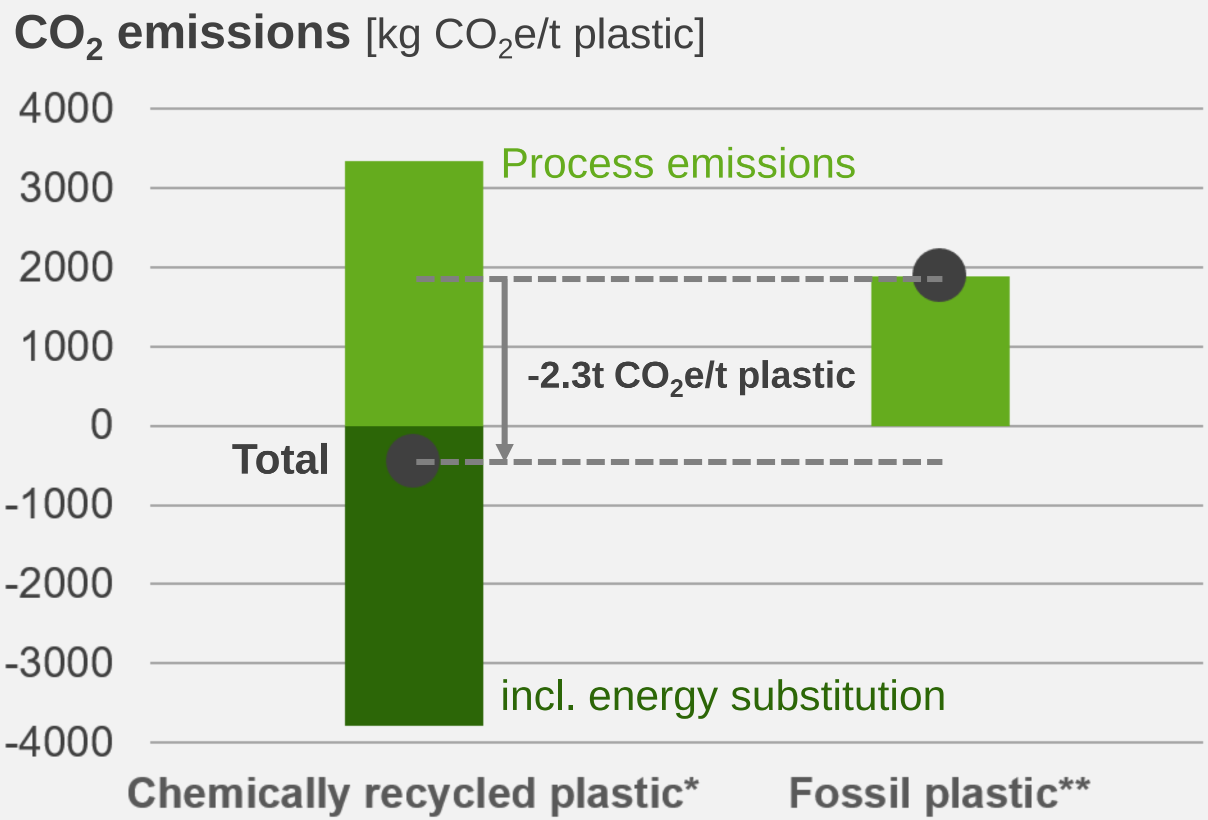


Fig. 2: Conventional production of 1t LDPE emits, in total, 1894 kg CO2e. For the production of 1t LDPE via pyrolysis a negative number of -477 can be accounted for the overall CO_2 emissions.

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

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Basic LCA – Study 3

Plastic quality perspective

Does plastic material produced via chemical recycling cause lower CO_2 emissions than plastic material produced via mechanical recycling?

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Comparison of CO_2 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

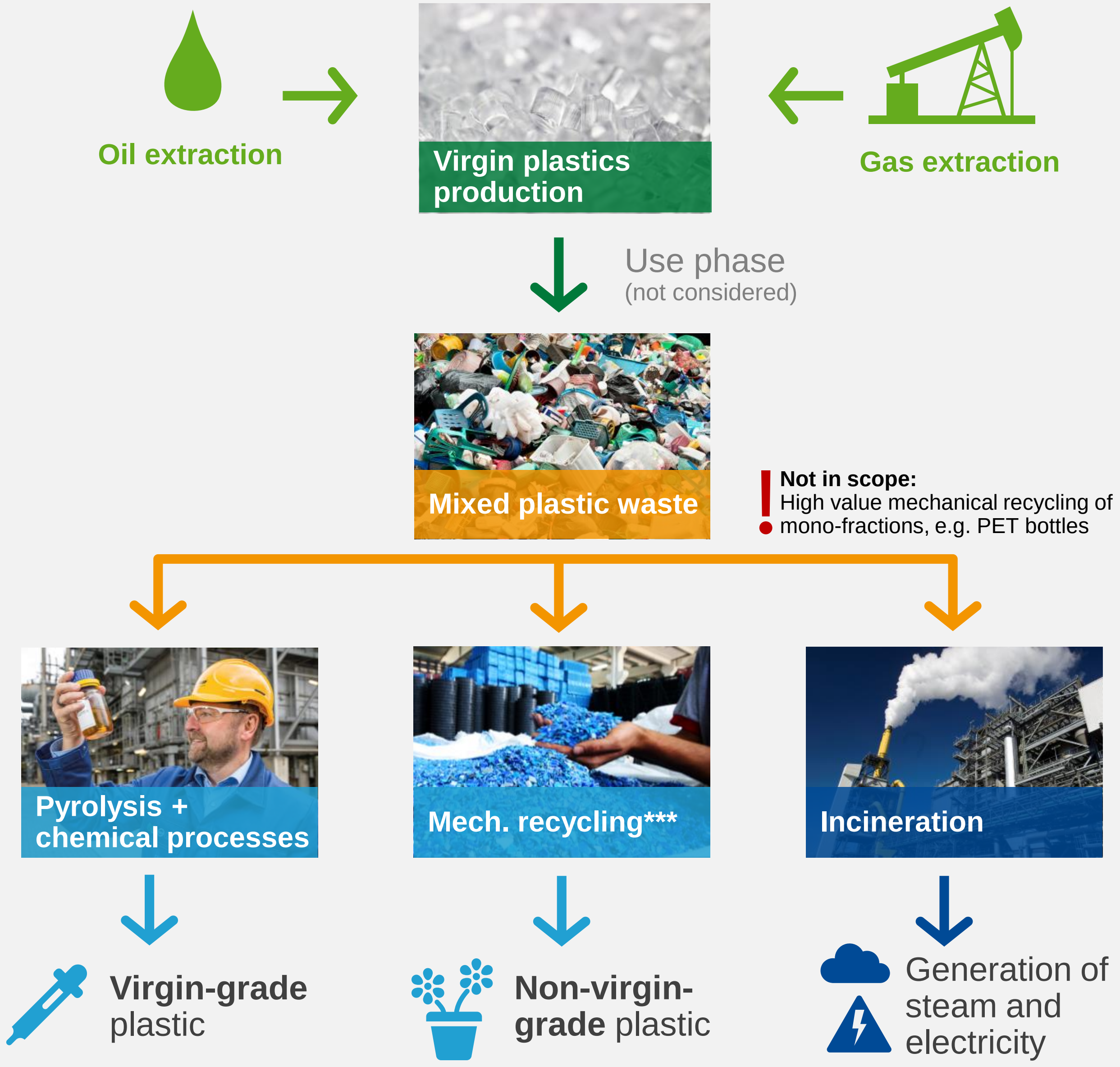
- Virgin plastics production based on oil & gas turned into mixed plastic waste

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

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Comparison of CO_2 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 CO_2 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 / Insitute for Applied Ecology (2016): Umweltpotenziale der getrennten Erfassung und des Recyclings von Wertstoffen im Dualen System

CO_2 emissions [kg CO_2e/t product]

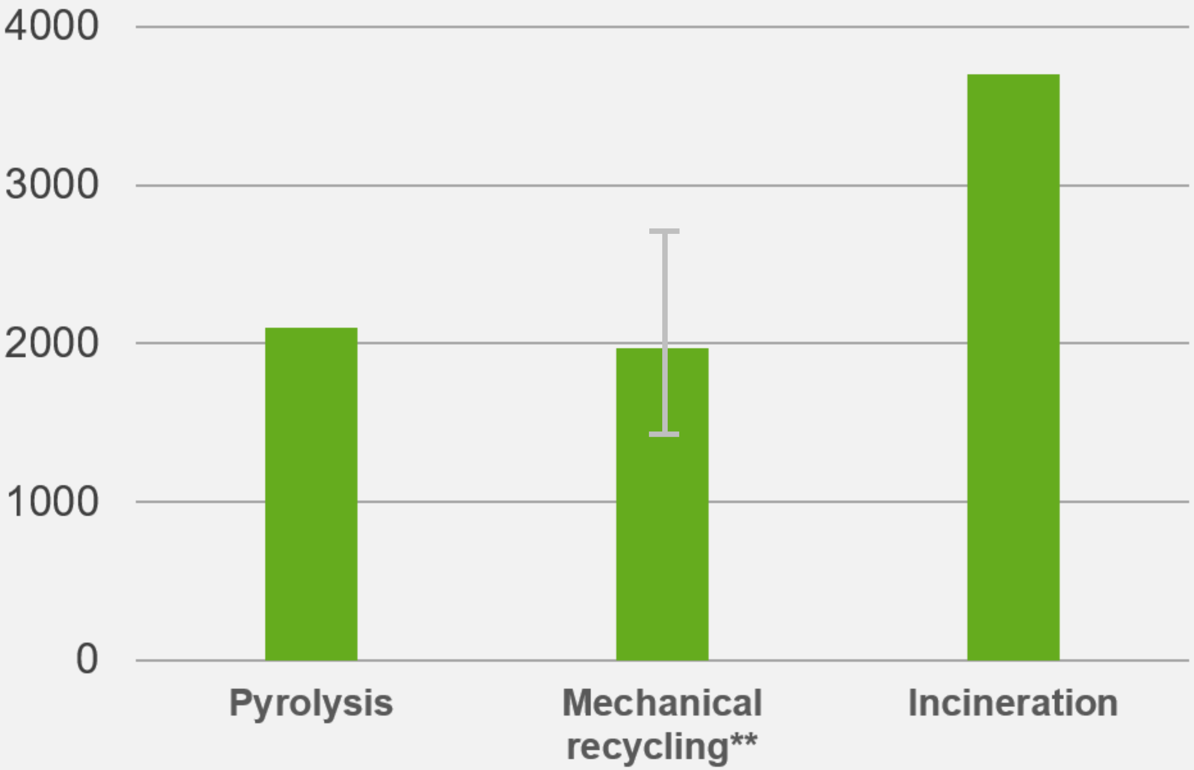

Fig. 3: Production and end-of-life treatment of 1t of plastics via pyrolysis emit 2,100 kg CO2e, whereas production and end-of-life treatment of 1t of plastics via mechanical recycling emits 1,973kg CO2e. Production and incineration of 1t of plastics emits 3,700 kg CO2e.

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

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Main Conclusions

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Basic LCA ChemCycling™

General results

Chemical recycling is attractive in terms of CO_2 emissions – the most discussed LCA indicator

- Pyrolysis of mixed plastic waste emits 50 percent less CO_2 than incineration of mixed plastic waste
- CO_2 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 CO_2 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.

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Excursus: Pyrolysis

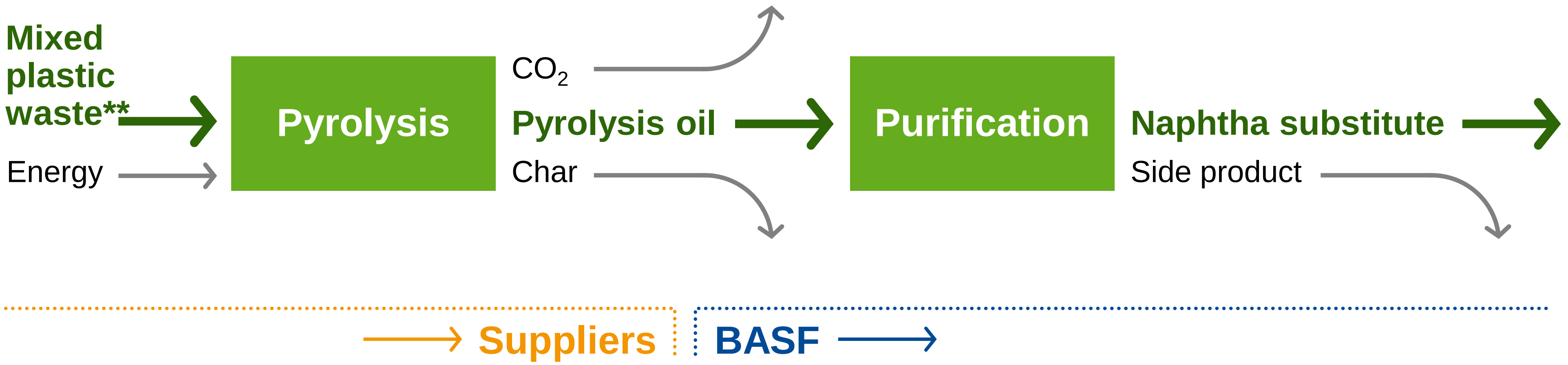
An efficient process to convert mixed plastic waste into a secondary raw material for the chemical industry

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*



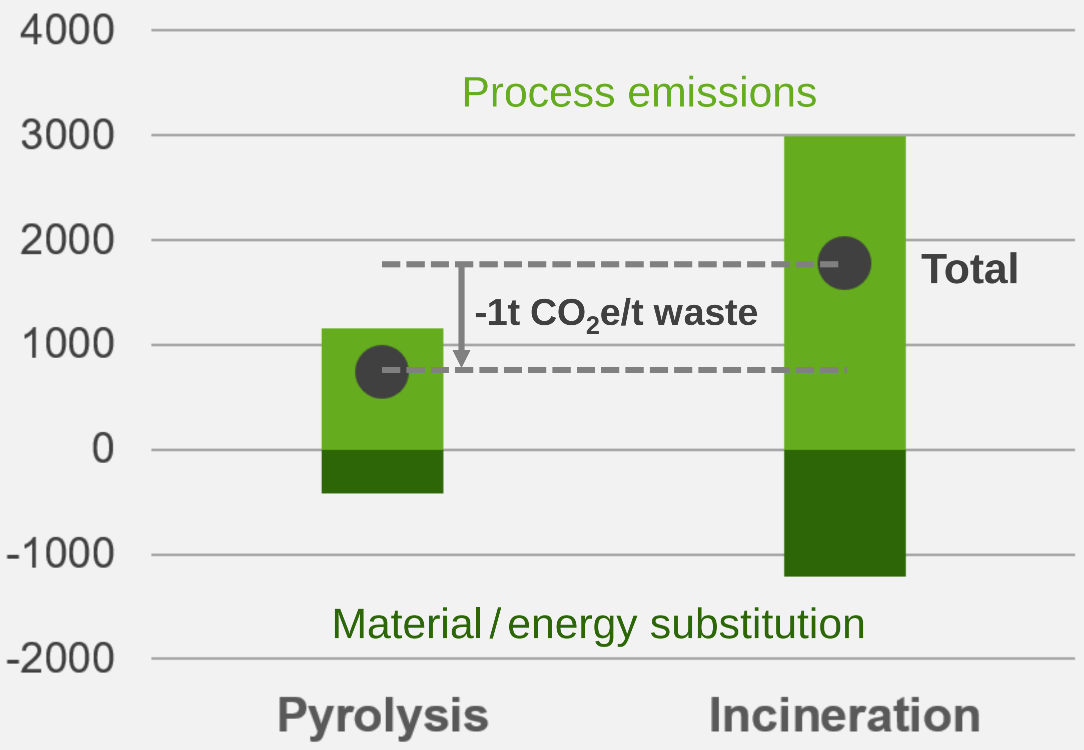
* under application of a mass balance approach
** from a sorting plant

Comparison of CO_2 emissions between pyrolysis and incineration of mixed plastic waste

Results

- **Pyrolysis of mixed plastic waste emits 50 percent less CO_2 than incineration of mixed plastic waste**
- Specifically, the study found that pyrolysis emits 1 ton less CO_2 than incineration per 1 ton of mixed plastic waste

CO_2 emissions [kg CO_2e/t plastic waste]



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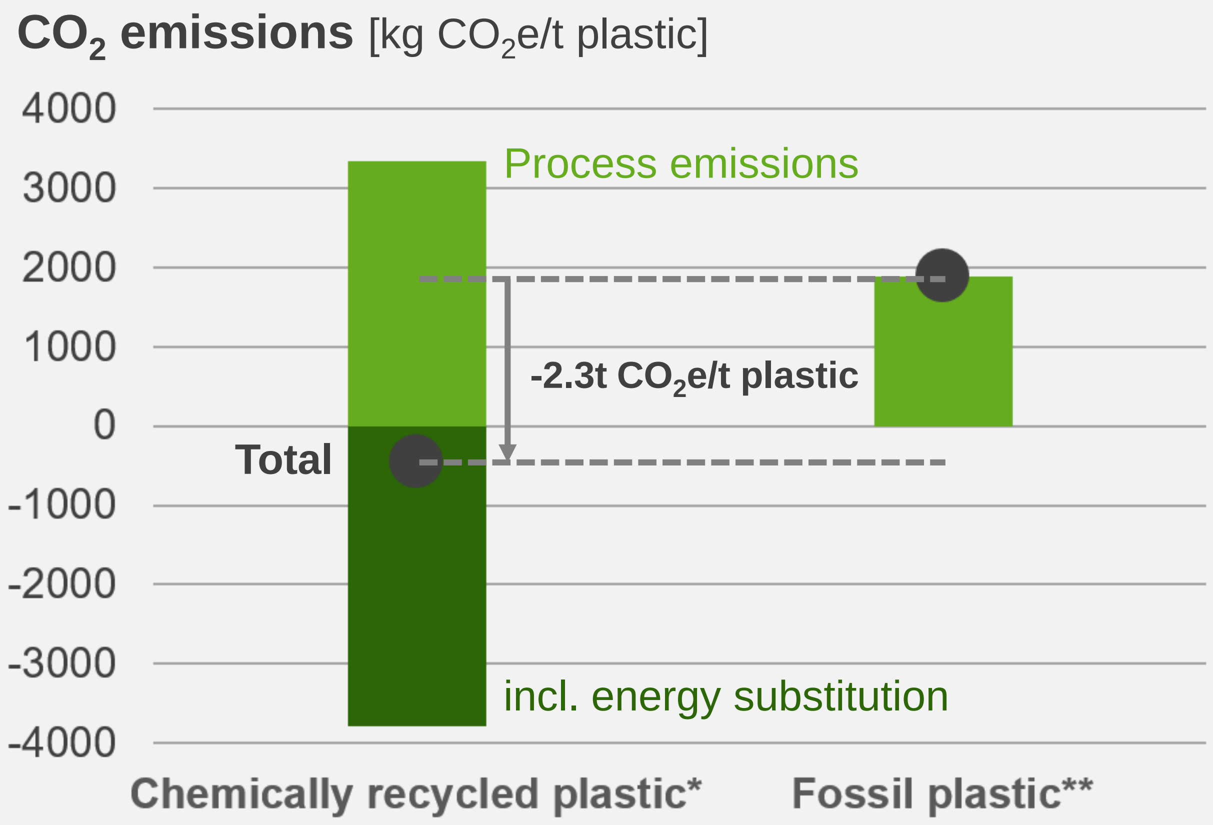
Comparison of CO_2 emissions between plastics production from pyrolysis oil and naphtha

Results

- **CO_2 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 CO_2 than 1 ton LDPE produced from fossil naphtha



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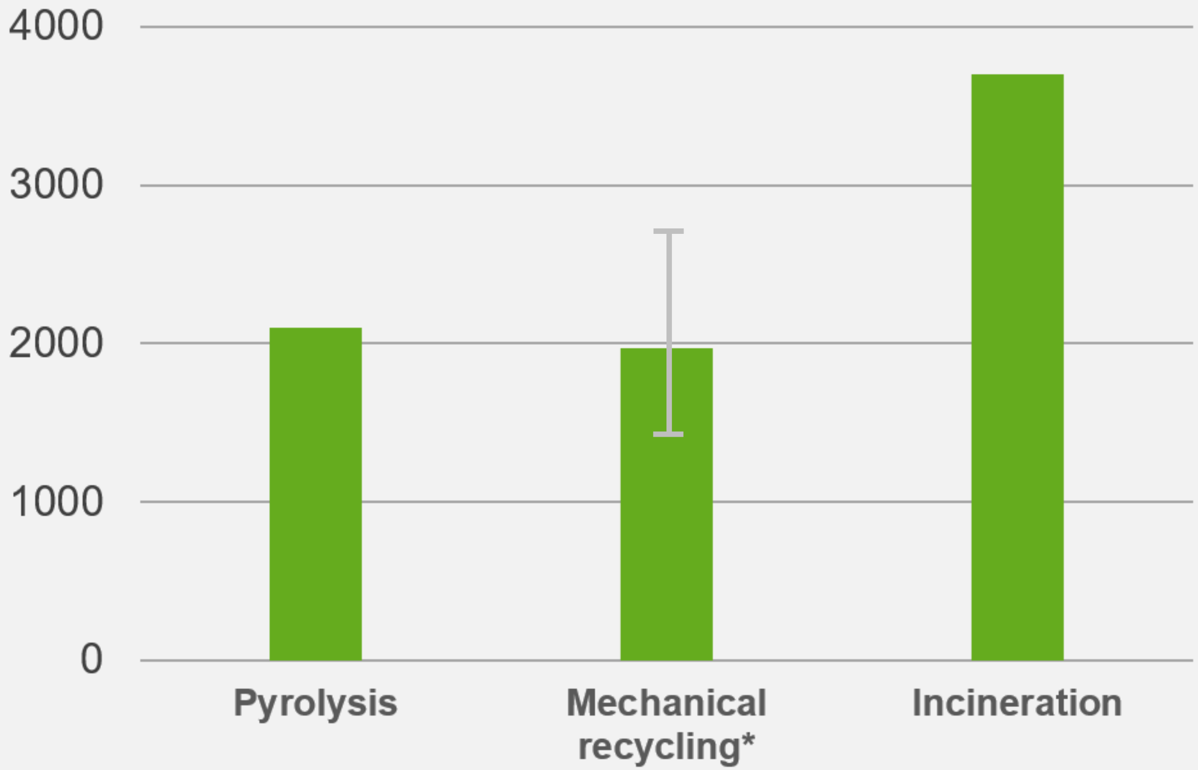
Comparison of CO_2 emissions of 1t of virgin plastics with three end-of-life options

Results

- Manufacturing of plastics via either chemical recycling (pyrolysis) or mechanical recycling of mixed plastic waste result in similar CO_2 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

CO_2 emissions [kg CO_2e/t product]



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