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

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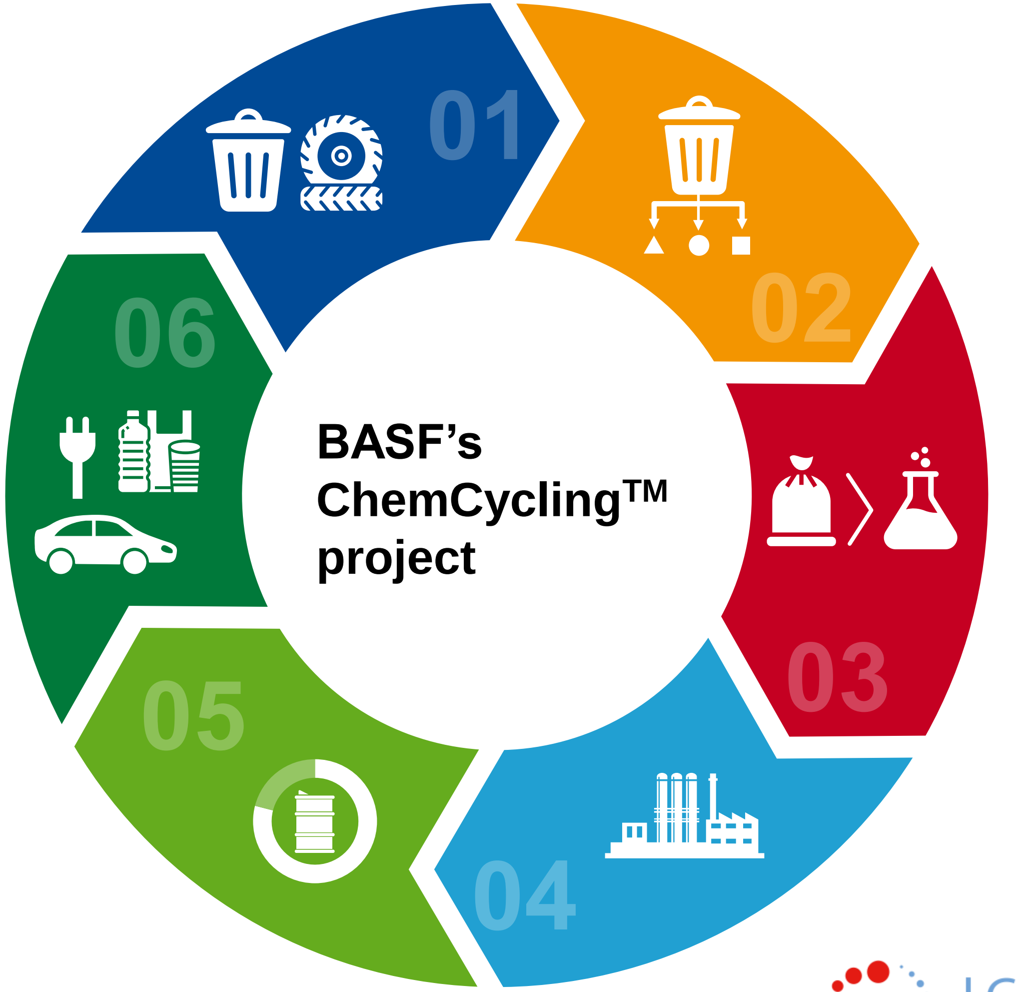


10th International Conference on Life Cycle Management, September 2021

The role of ChemCycling™ in a Circular Economy

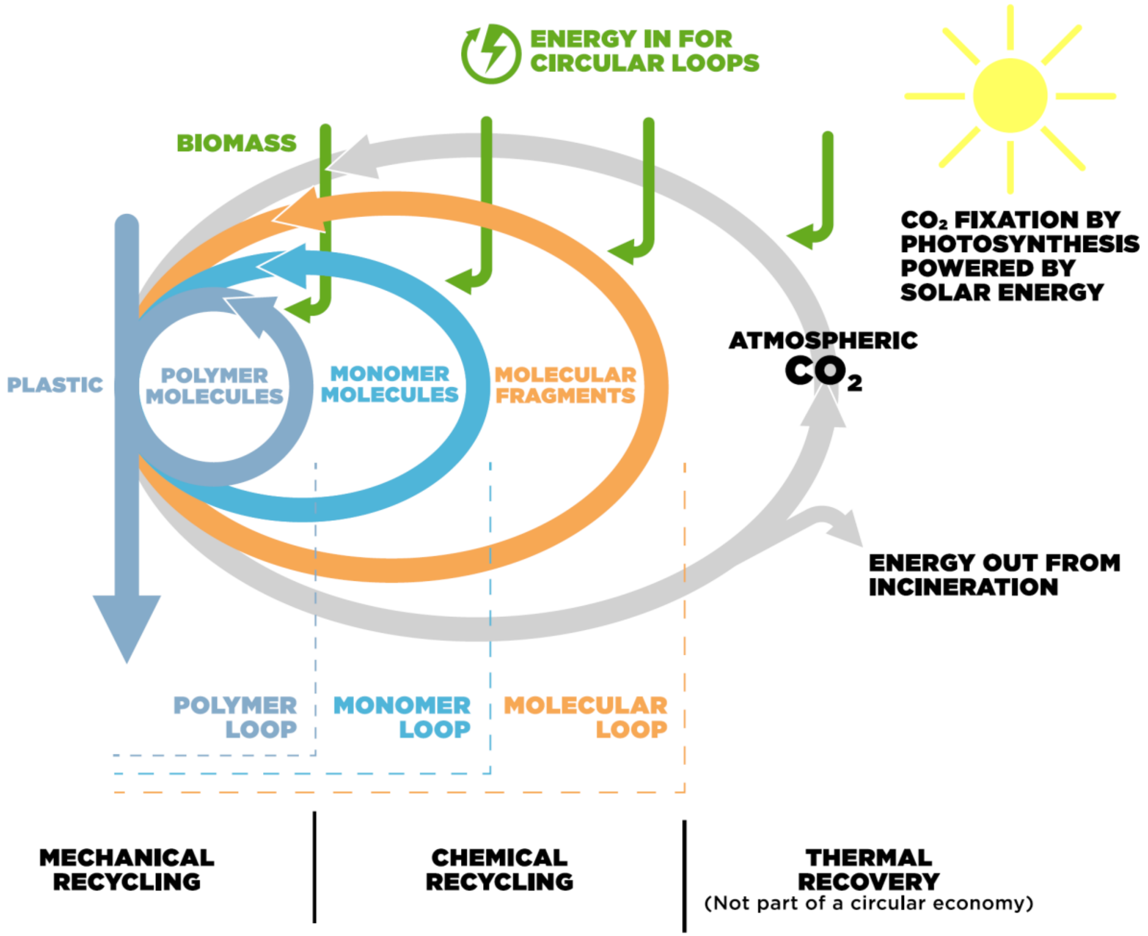
Different loops are necessary for a successful transition towards circularity

- **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 up taking CO_2 from the atmosphere. From plants one can generate bio-based chemicals again. This is technically feasible for some chemicals



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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
- The **scientific publication** is available at: https://doi.org/10.1016/j.scitotenv.2020.144483

Commissioner / LCA practitioner

Dr. Christian Krüger — BASF We create chemistry

Maike Horlacher — sphera

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

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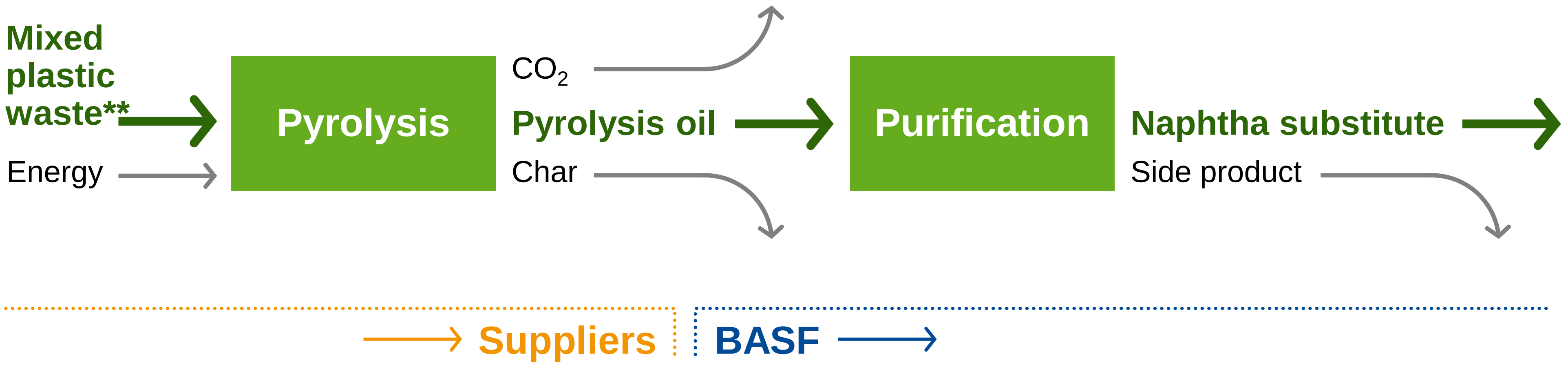
Excursus: Pyrolysis

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

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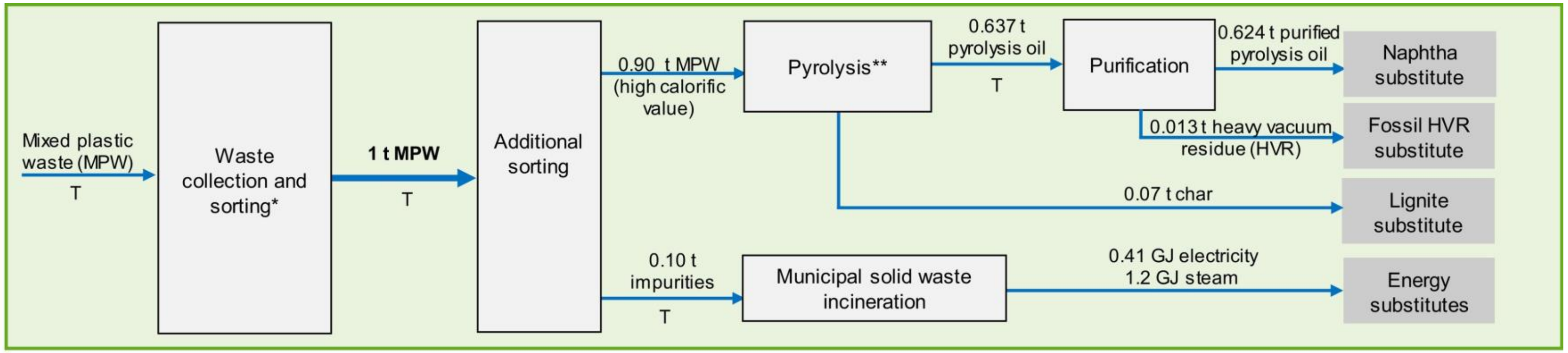
Case study 1

Waste perspective

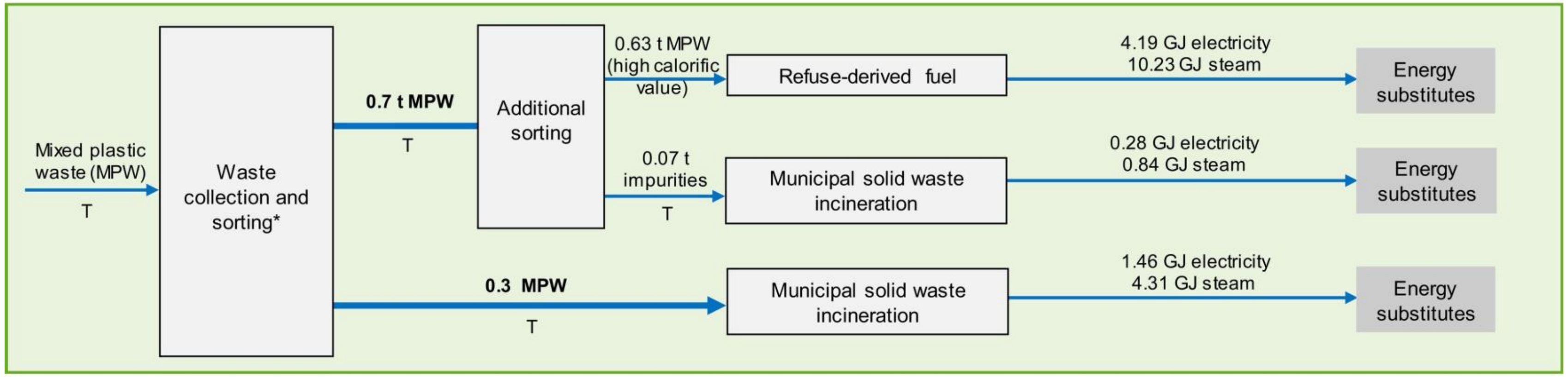
Does pyrolysis of mixed plastic waste save CO_2 emissions compared to incineration?

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 in Germany in 2030



a) Chemical recycling of mixed plastic waste via pyrolysis



b) Energy recovery via incineration of municipal solid waste (30% wt) and combustion of refuse-derived fuel (70% wt)

Fig. 1: System boundaries for the study considering the waste perspective. (T: transport. Substitutes: system credits. *Economic allocation for waste fractions in the sorting plant. **Mass losses due to the process inefficiencies.) (Jeswani et al. 2021, p. 3)

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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
- For EU, the most relevant indicators are climate change and resource consumption. For these indicators pyrolysis shows significant benefits versus incineration. 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.

CO_2 emissions [kg CO_2e/t plastic waste]

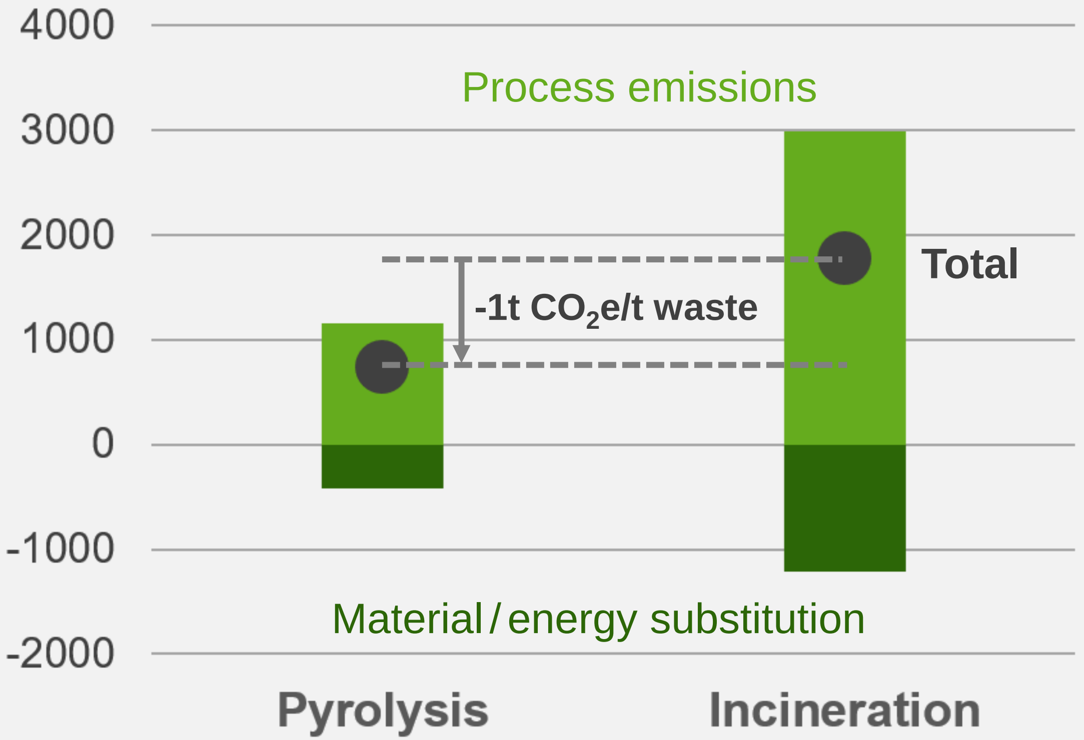

Fig. 2: Pyrolysis of 1t mixed plastic waste emits, in total, 739 kg CO_2e. Incineration of 1t mixed plastic waste emits, in total, 1777 kg CO_2e.

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Case 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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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 virgin grade LDPE granulate in Germany in 2030

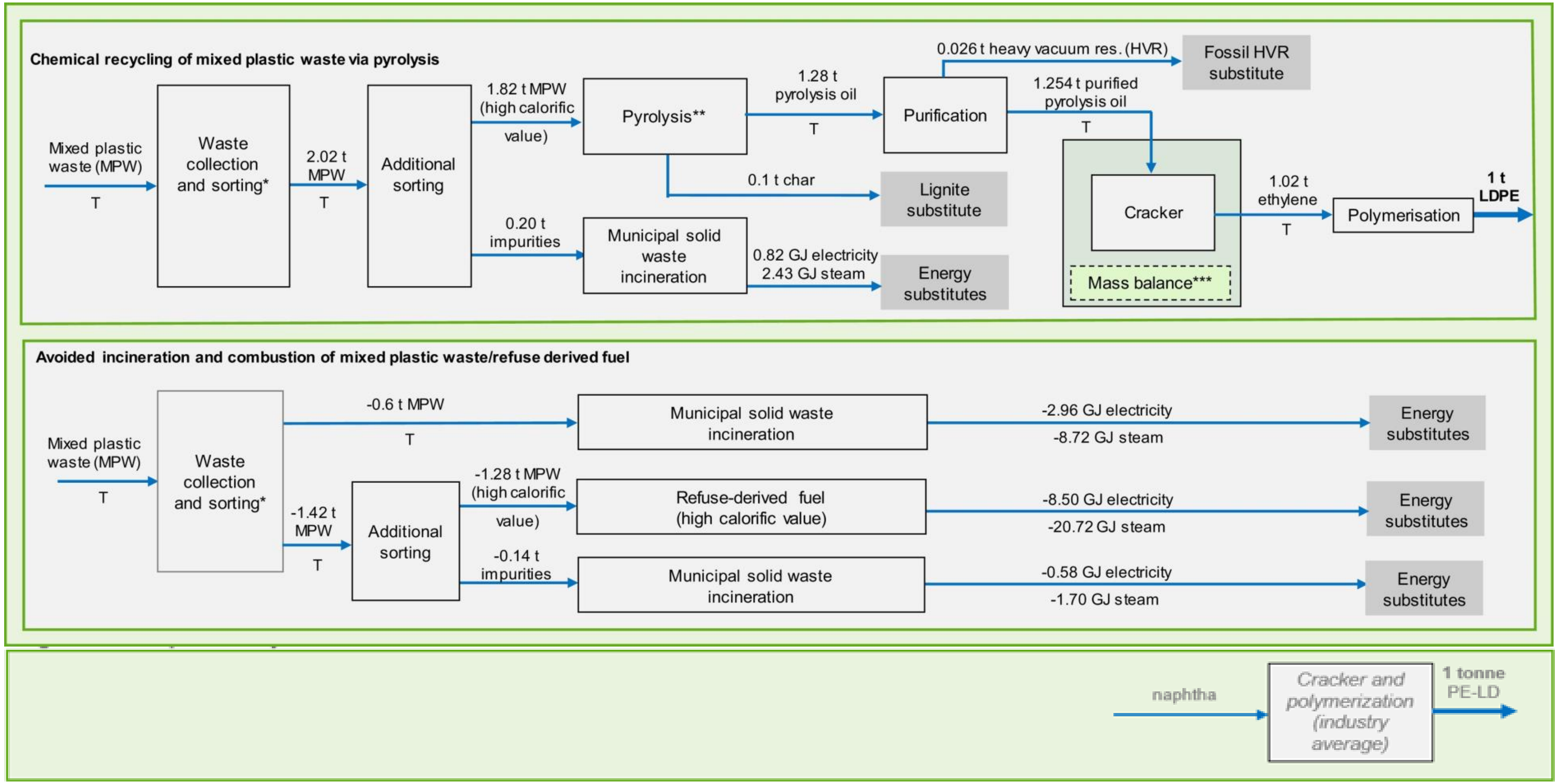

Fig. 3: System boundaries for the study considering the product perspective: production of virgin-grade quality of recycled plastic. (The avoided incineration of mixed waste plastics and combustion of refuse-derived fuel is included within the system boundaries. T: transport. *Economic allocation for waste fractions in the sorting plant. **Mass losses due to the process inefficiencies. ***Substitution of naphtha by waste-derived feedstock.) (Jeswani et al. 2021, p. 4)

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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

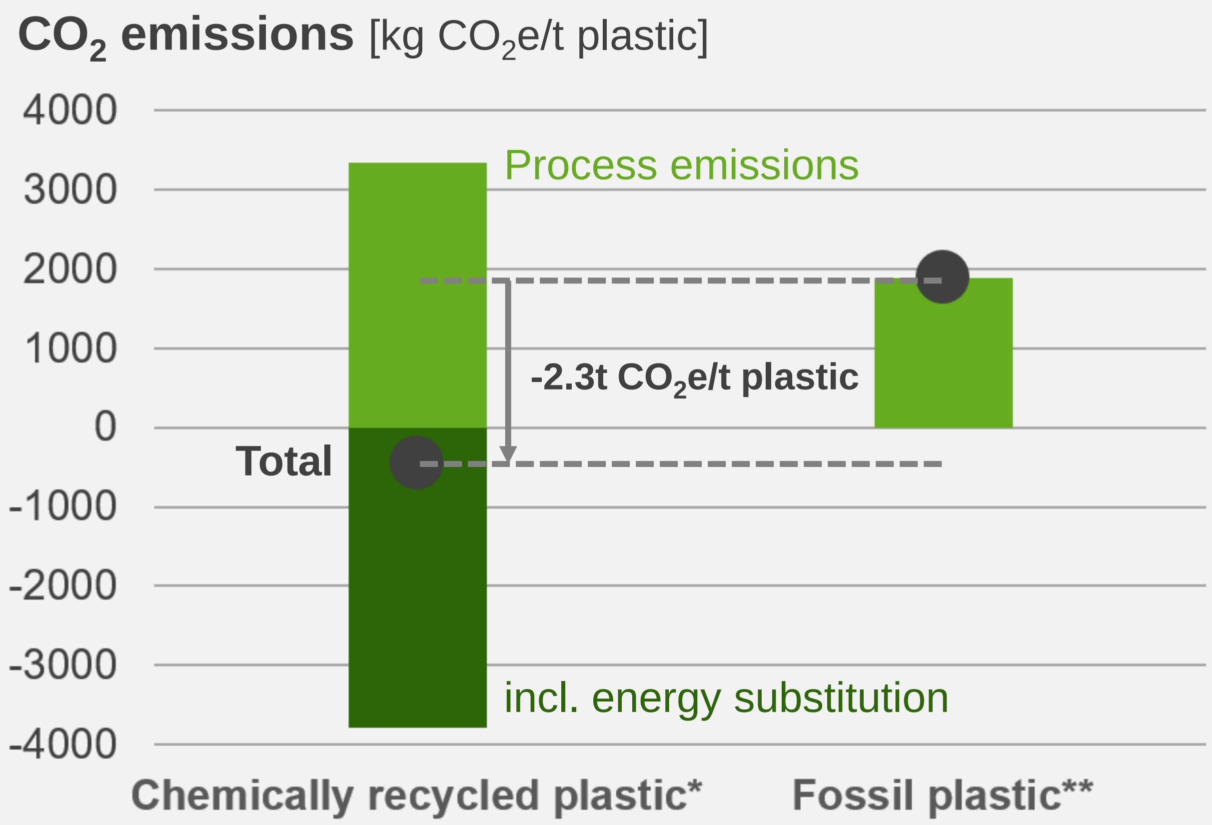

Fig. 4: Conventional production of 1t LDPE emits, in total, 1894 kg CO2e. For the production of 1t LDPE via pyrolysis a negative number of -477 can be accounted for the overall CO_2 emissions.

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

Case 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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PEF Circular Footprint Formula

- The circular footprint formula was developed to find a fair way to mathematically share the burdens and credits between suppliers and users of products that are recycled.

- In the past, burdens and credits were usually shared 50/50
  - Instead of the fixed sharing, the formula accounts for the market situation (demand versus offer) for recycling material of a certain product → factor A
  - Energy recovery, e.g. with waste incineration is currently favored by the formula: B=0 as default setting. Always full credits for recovered energy. Unsymmetrical element in formula compared to material in- and output.

material

$$(1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_P}\right) + (1-A)R_2 \times \left(E_{recyclingEoL} - E^*_V \times \frac{Q_{Sout}}{Q_P}\right)$$

energy

$$(1-B)R_3 \times \left(E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}\right)$$

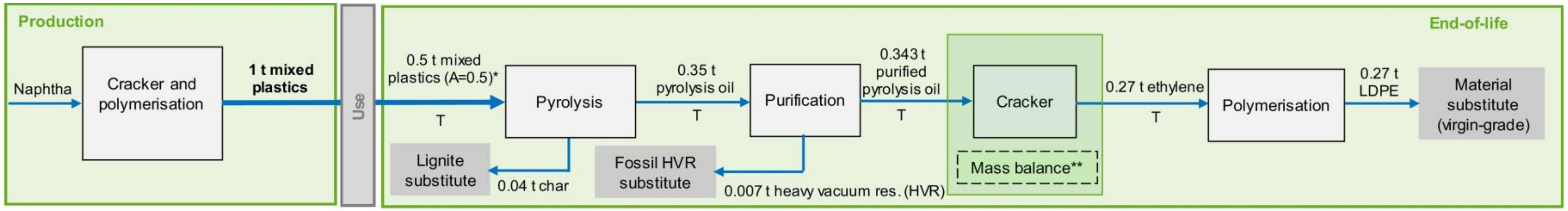
disposal

$$(1-R_2-R_3) \times E_D$$

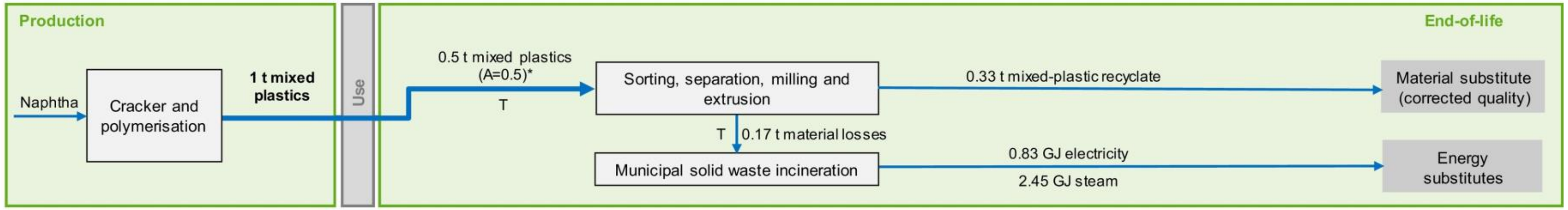
Zampori, L. and Pant, R., Suggestions for updating the Product Environmental Footprint (PEF) method, EUR 29682 EN, Publications Office of the European Union, Luxembourg, 2019,

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

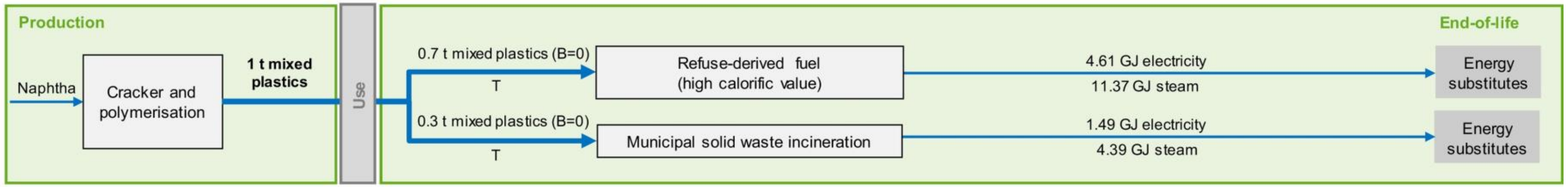
Case study comprises life cycle from 1t of fossil plastic and three different end-of-life options incl. production of secondary material in Germany in 2030



a) Production of virgin mixed plastics and end-of-life chemical recycling of mixed plastic waste via pyrolysis to produce virgin-grade plastic (low density polyethylene)



b) Production of virgin mixed plastics and end-of-life mechanical recycling of mixed plastic waste to produce mixed plastic recyclate



c) Production of virgin mixed plastics and end-of-life energy recovery from mixed waste plastics via incineration of municipal solid waste (30% wt) and combustion of refuse-derived fuel (70% wt)

Fig. 5: System boundaries for the study combining the product and waste perspectives: production of mixed virgin plastics and its end-of-life treatment by chemical recycling via pyrolysis (a), mechanical recycling (b) and energy recovery (c). (T: transport. *Due to the application of the "A" factor in the circular footprint formula, only 50% of the mass is allocated to this life cycle. **Substitution of naphtha by waste-derived feedstock.) (Jeswani et al. 2021, p. 5)

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 or a combination of both of mixed plastic waste result in similar CO_2 emissions.** All recycling pathways emit significantly less CO_2 than virgin fossil products that are incinerated.

- **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**

- **For mechanical recycling and pyrolysis material waste is partly energetically recovered:** For pyrolysis the yield is 70%; the material losses for mechanical recycling are up to 55%.

CO_2 emissions [kg CO_2e/t product]

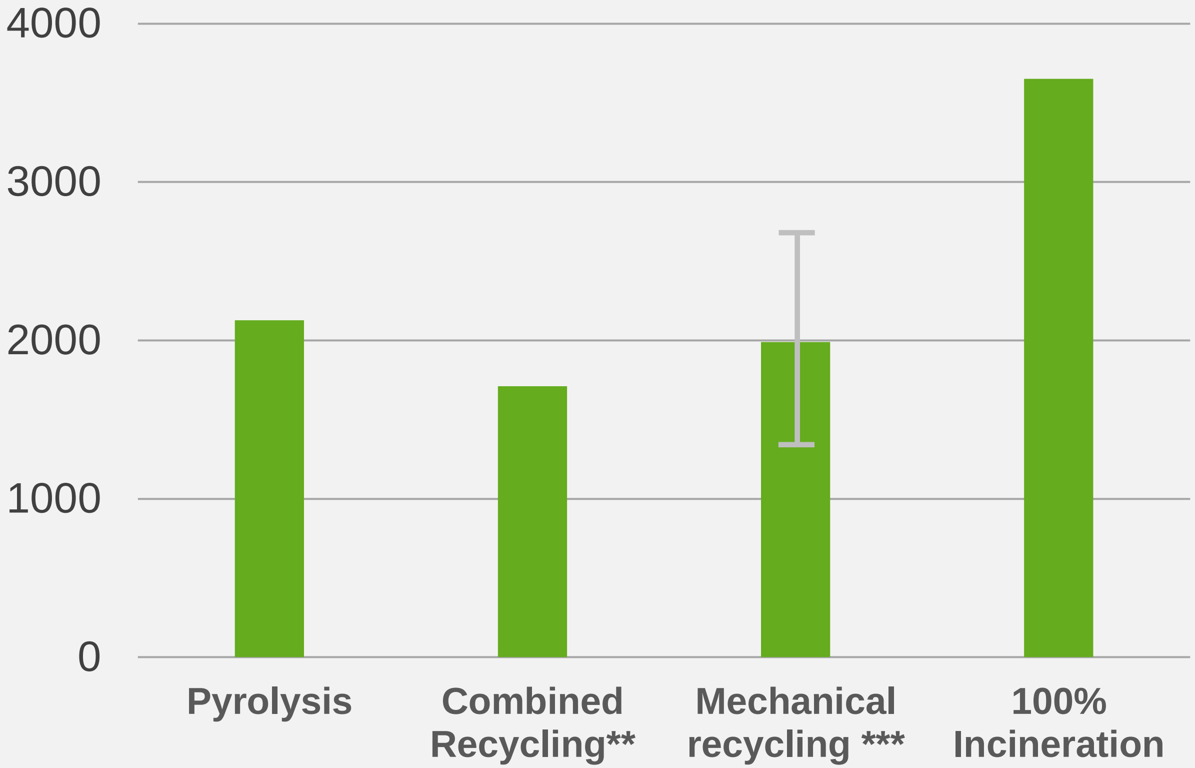


Fig. 6: Production and end-of-life treatment of 1t of plastics via pyrolysis emit 2,100 kg CO2e, whereas production and end-of-life treatment of 1t of plastics via mechanical recycling emits 2,000 kg CO2e. A combined recycling approach, emits 1,700 kg CO2e. Production and incineration of 1t of plastics emits 3,700 kg CO2e.

** This post-study scenario has not been part of the critical review process.
*** 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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