Comparative Environmental Assessment of Plastic Waste Recycling and Energy Recovery (Incineration) Technologies

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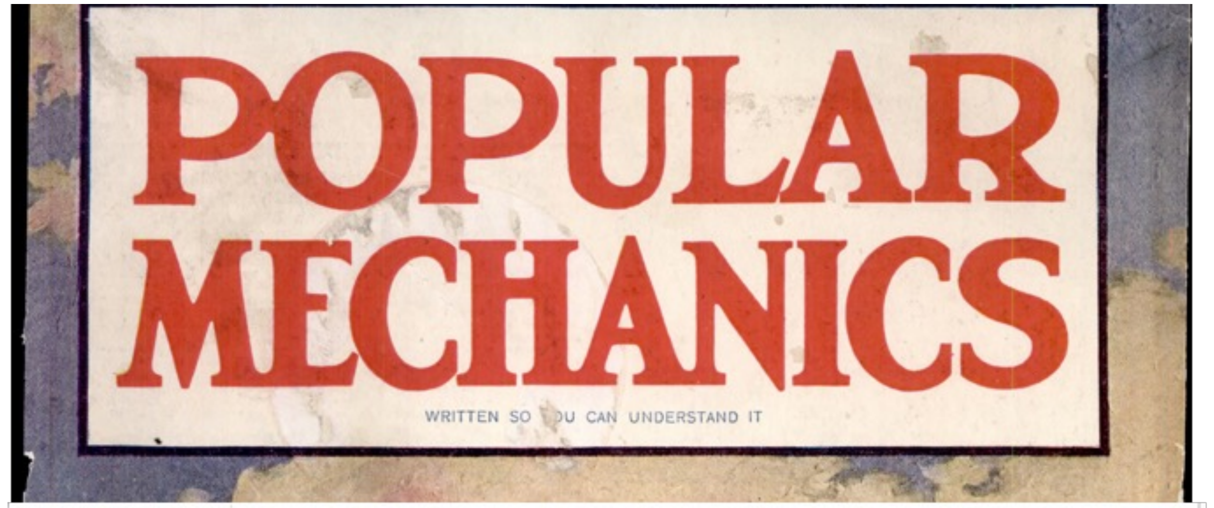
LCT DRIVING CHEMICAL TECHNOLOGY

General introduction

Global warming is NOT NEW



Popular Mechanics Magazine

318 W. Washington Street, Chicago, U. S. A.

EDITED BY H. H. WINDSOR

ISSUED MONTHLY — SUBSCRIPTION: — SINGLE COPY, 15 CENTS

In United States, and its possessions, Cuba and Mexico, per year, postpaid	$1.50
To Canada	1.75
To all other countries in the Postal Union	2.00

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Entered as Second Class Matter Sept. 15, 1903, at the Postoffice at Chicago, Illinois, under Act of March 3rd, 1879.

Published monthly by POPULAR MECHANICS CO. Copyrighted 1912, by H. H. WINDSOR.

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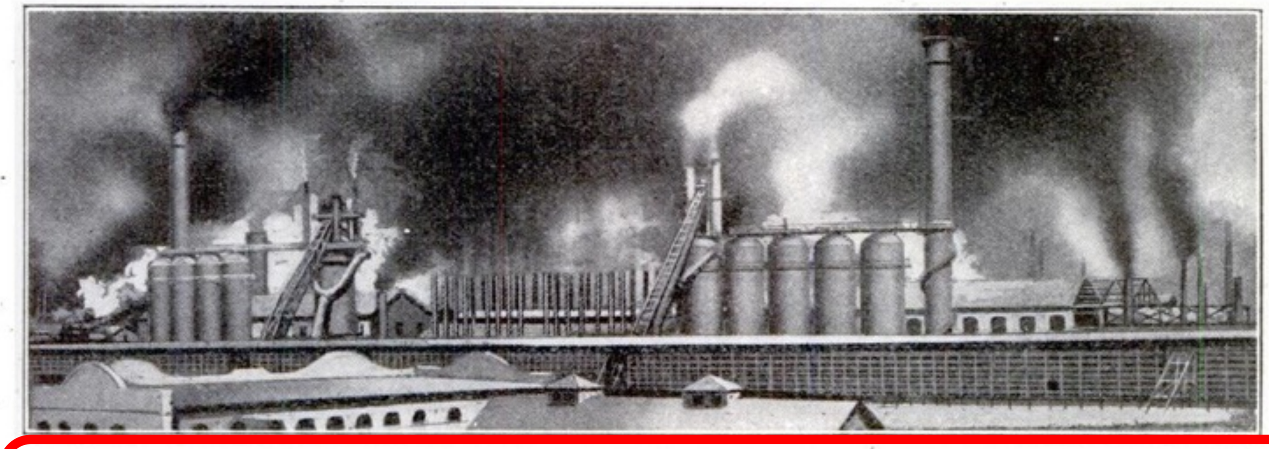
POPULAR MECHANICS 341



The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

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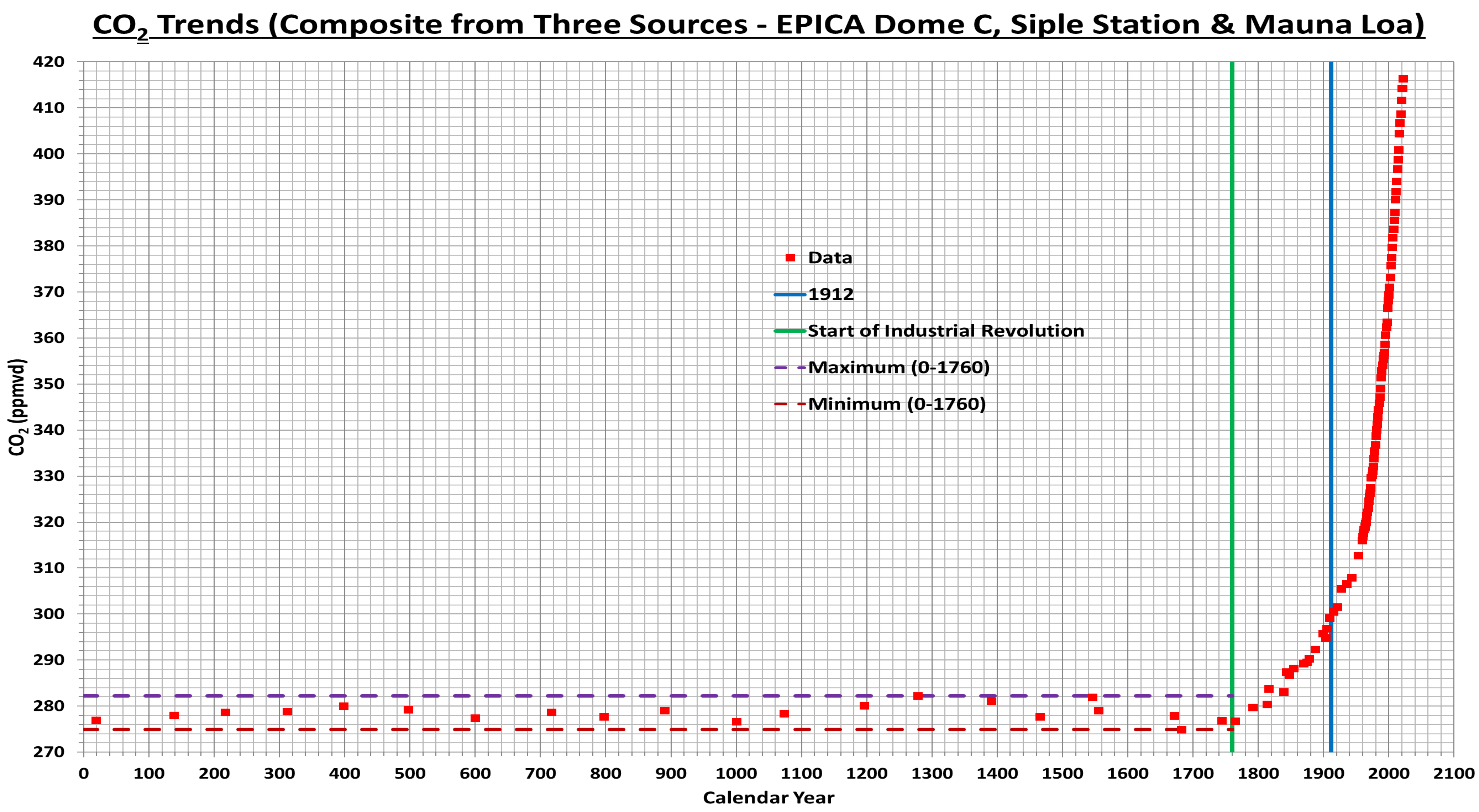
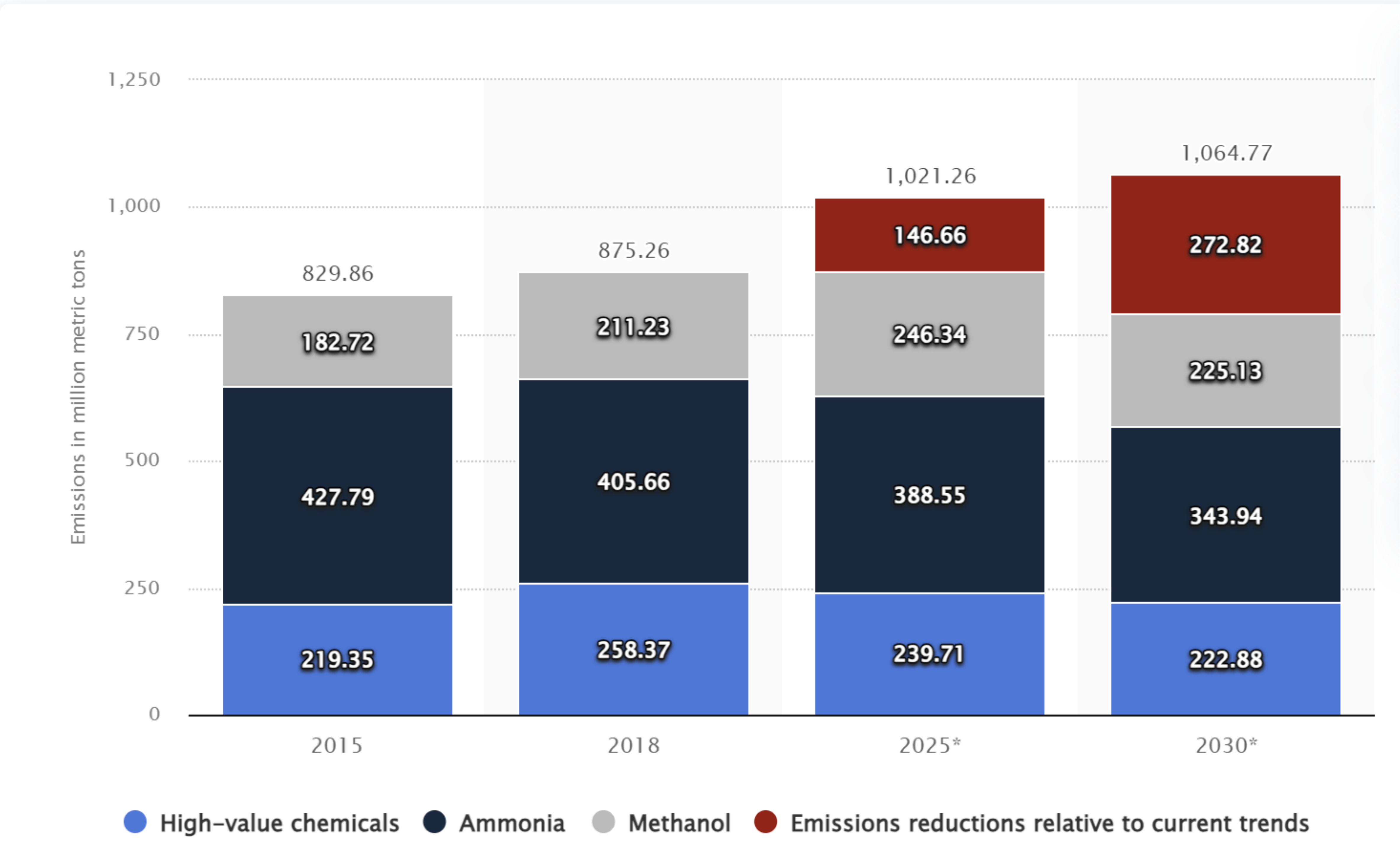
(From https://books.google.be/books?id=Tt4DAAAAMBAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0?%20[sm]#v=onepage&q&f=false)


CO2 Trends (Composite from Three Sources - EPICA Dome C, Siple Station & Mauna Loa)
420
410
400
390
380
370
360
350
340
330
320
310
300
290
280
270
CO2 (ppmvd)
Data
1912
Start of Industrial Revolution
Maximum (0-1760)
Minimum (0-1760)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Calendar Year

CO2 emissions of chemical production worldwide from 2015 to 2030, by chemical source

(in million metric tons)



https://www.statista.com/statistics/272474/emissions-of-the-chemical-industry-since-2000/

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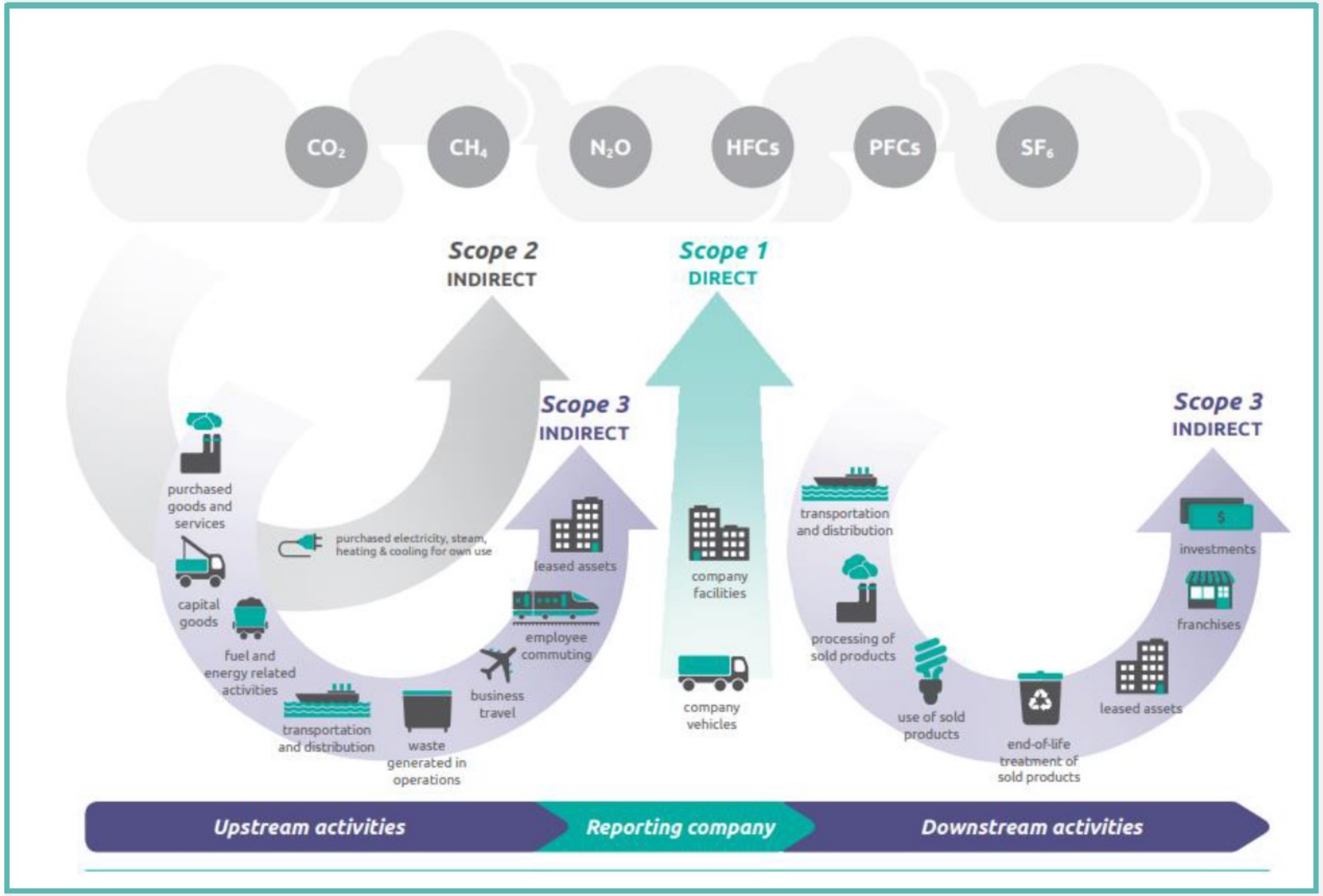
SCOPE definition according GHG protocol



- Scope 1 – All Direct Emissions from the activities of an organization or under their control. Including fuel combustion on site such as gas boilers, fleet vehicles and air-conditioning leaks.
- Scope 2 – Indirect Emissions from electricity purchased and used by the organization. Emissions are created during the production of the energy and eventually used by the organization.
- Scope 3 – All Other Indirect Emissions from activities of the organization, occurring from sources that they do not own or control. These are usually the greatest share of the carbon footprint, covering emissions associated with business travel, procurement, waste and water.

Unlike LCA, GHG protocol standards estimate the GHG footprint and are based on ISO 14064

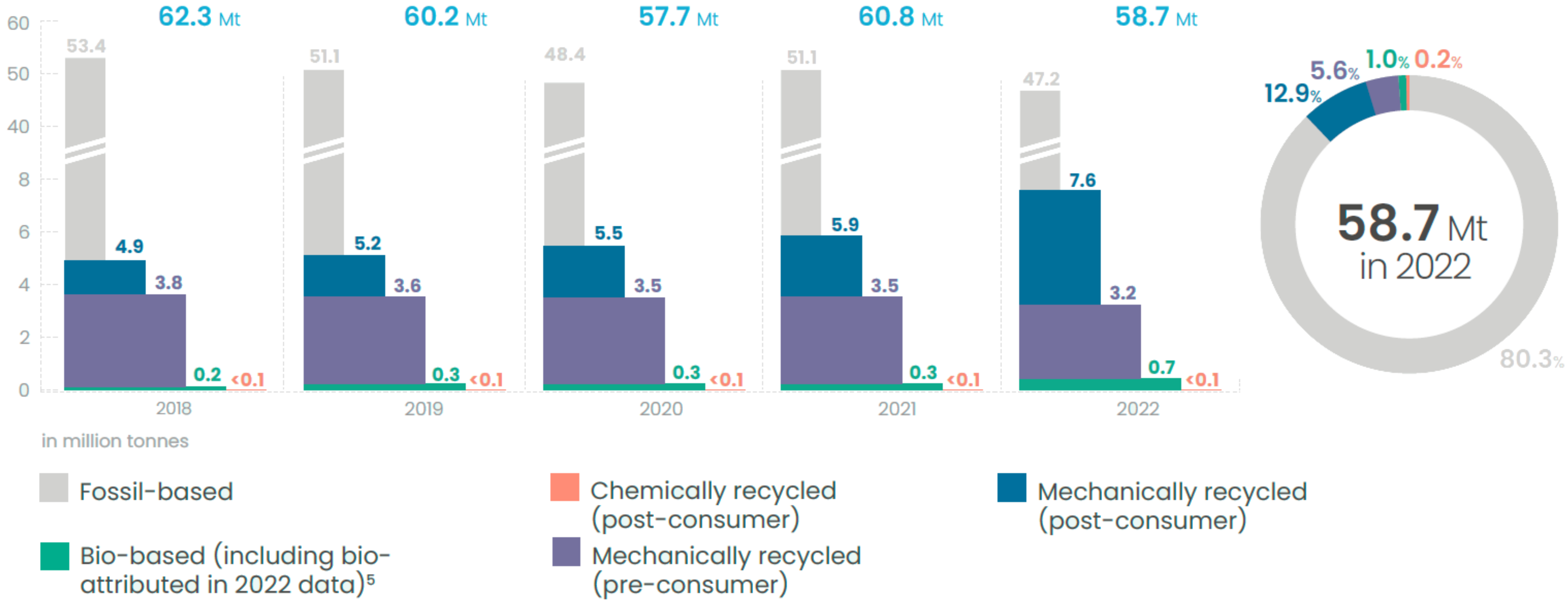
GHG protocol for the chemical industry

- '....I applaud the breadth and depth of this unprecedented report that quantitatively analyzed pathways for **the chemical industry to reach net zero not only in scope 1 & 2, but also scope 3 upstream and downstream**....'
- '.....The production of basic chemical intermediates in-scope for this report has a Scope 1, 2 & 3 emissions of 2.3 Gt CO_{2eq}, representing just under 4% of the 59 Gt global annual emissions and an estimated 72% of all chemical system emissions. Within the 2.3 Gt, Scope 3 represents the majority at 64% (1.5 Gt CO_{2eq}), while Scope 1&2 only represent 36% (0.8 Gt CO_{2eq}). **The magnitude of Scope 3 in the chemical system is driven by its dependence on fossil, leading to high upstream scope 3 emissions from oil and gas extraction (0.5 Gt CO_{2eq}), as well as carbon-dense products such as plastics and urea resulting in high associated downstream Scope 3 emissions (1.0 Gt CO_{2eq}). It is for this reason that focusing on Scope 3 in the chemical system transition to net zero is so essential**.....'
- '....There is growing recognition that the chemical industry needs to address its Scope 1&2 and, **increasingly, end-of-life Scope 3 emissions**....'
- '....**The vast bulk of total in-scope system emissions stem from Scope 3 (~64% today).** Therefore, abating Scope 3 is the biggest driver for system emissions reduction and the driver of the bulk of the technology shifts needed to abate the system...'

From a report commissioned by The Center for Global Commons, The University of Tokyo, Japan. Published September 2022. (Refer https://www.systemiq.earth/planet-positive-chemicals/)

The problem of plastic waste

Plastic production in EU-27 (PlasticsEurope, 2023)



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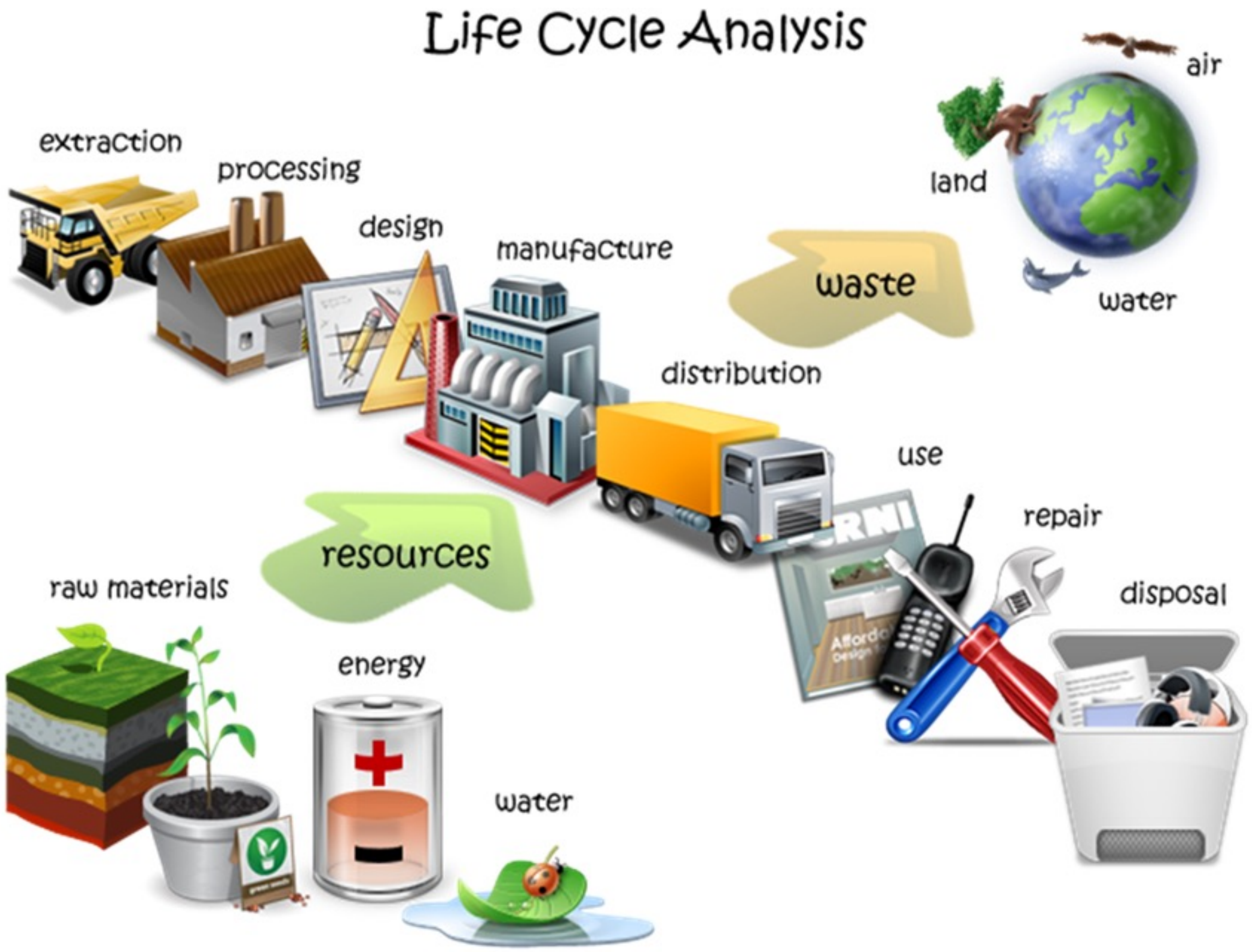
✓ 40% used for packaging

✓ 40% of packaging plastic in incinerated (Kusenberg et al., 2022)

Life cycle assessment

Definition

- Is a **quantitative method** in which the energy and raw material consumption, different types of emissions and other important factors related to a specific product are being measured, analyzed and summoned over the product's entire life cycle from an environmental point of view.
- Is considered to be the most comprehensive approach to assessing environmental impact.
- Is governed by two standards: **ISO 14040** and **14044**



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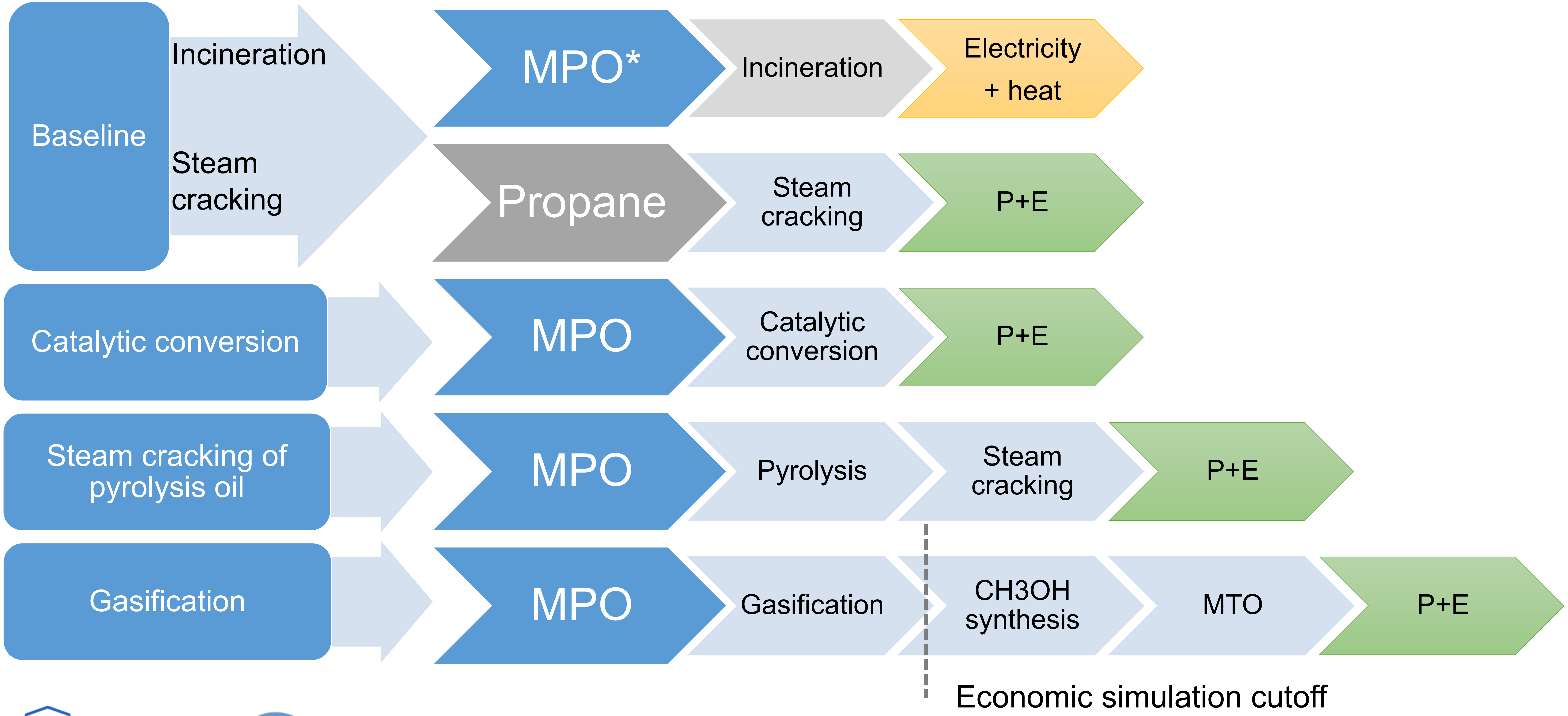
Case study



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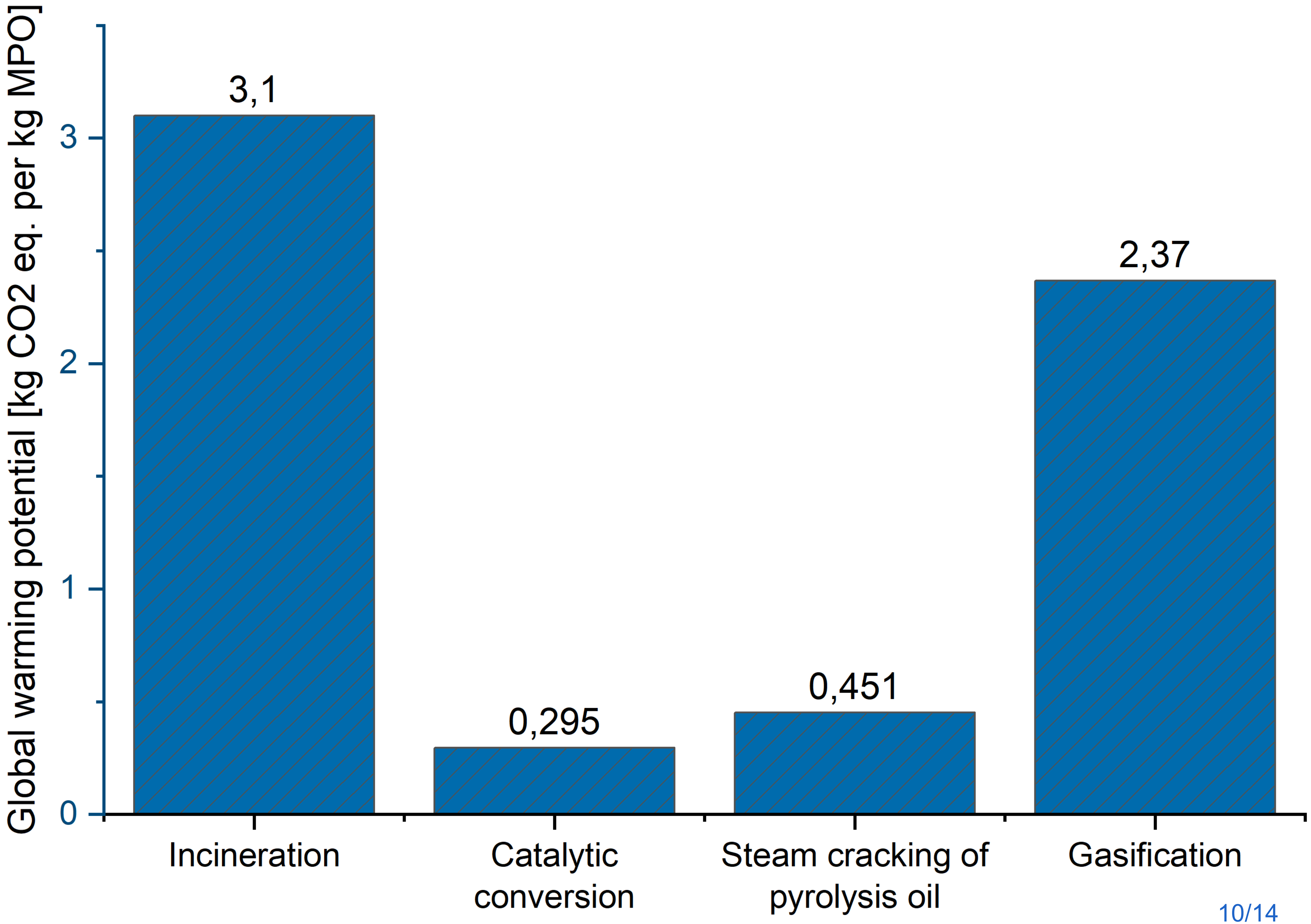
*MPO = mixed polyolefin waste

Chemical recycling as waste management strategy

MTO route (case 3) shows highest greenhouse gas emissions due to significant utility consumption.



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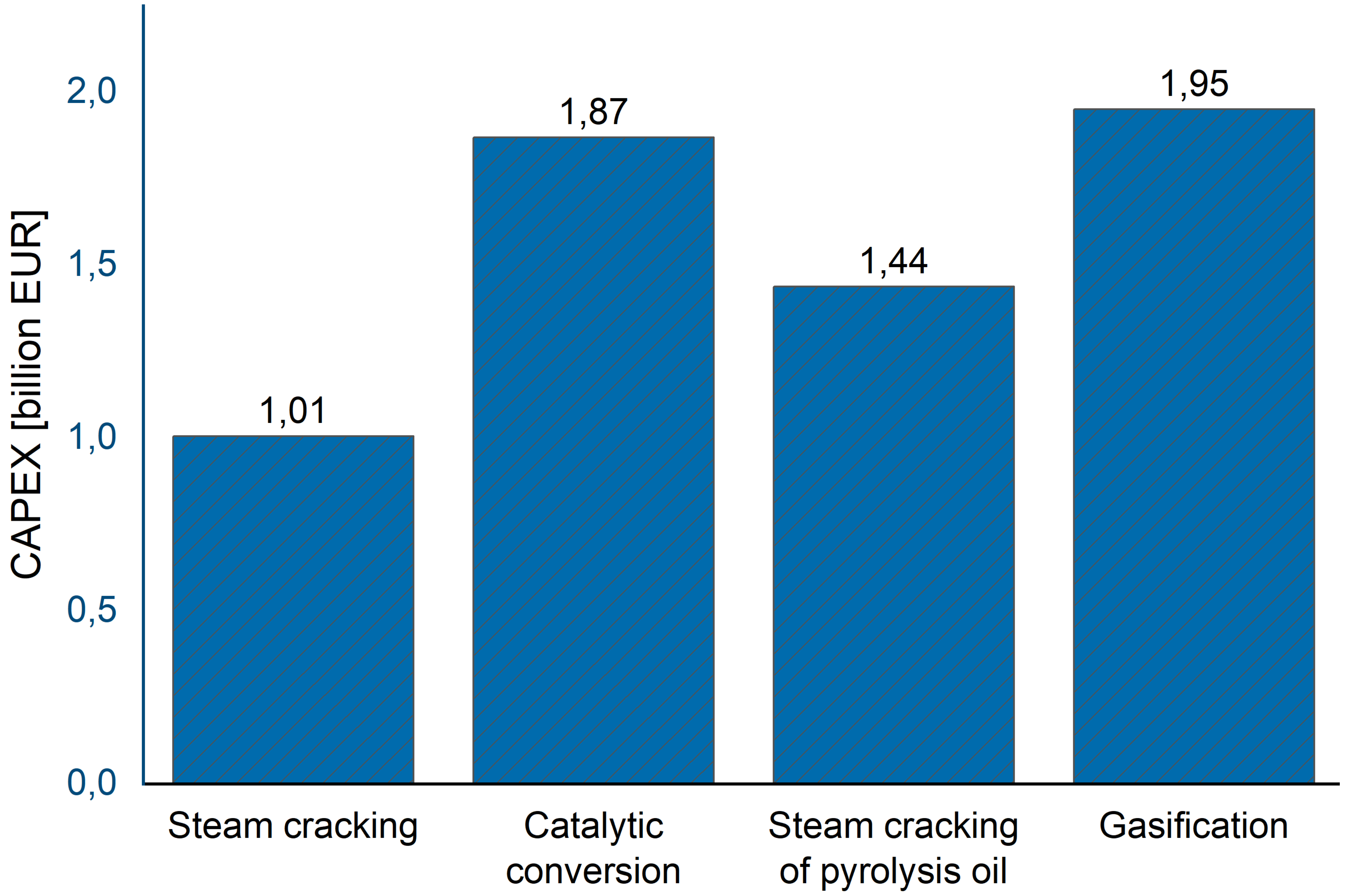
Economical aspects: capital expenditure

Target capacity:
1000 KTA of plastic

Steam cracking (Baseline B and Case 2) benefit from mature technology.



Economical aspects: sensitivity study

Feed costs (**FC**) assumed at gate [EUR/ton]:

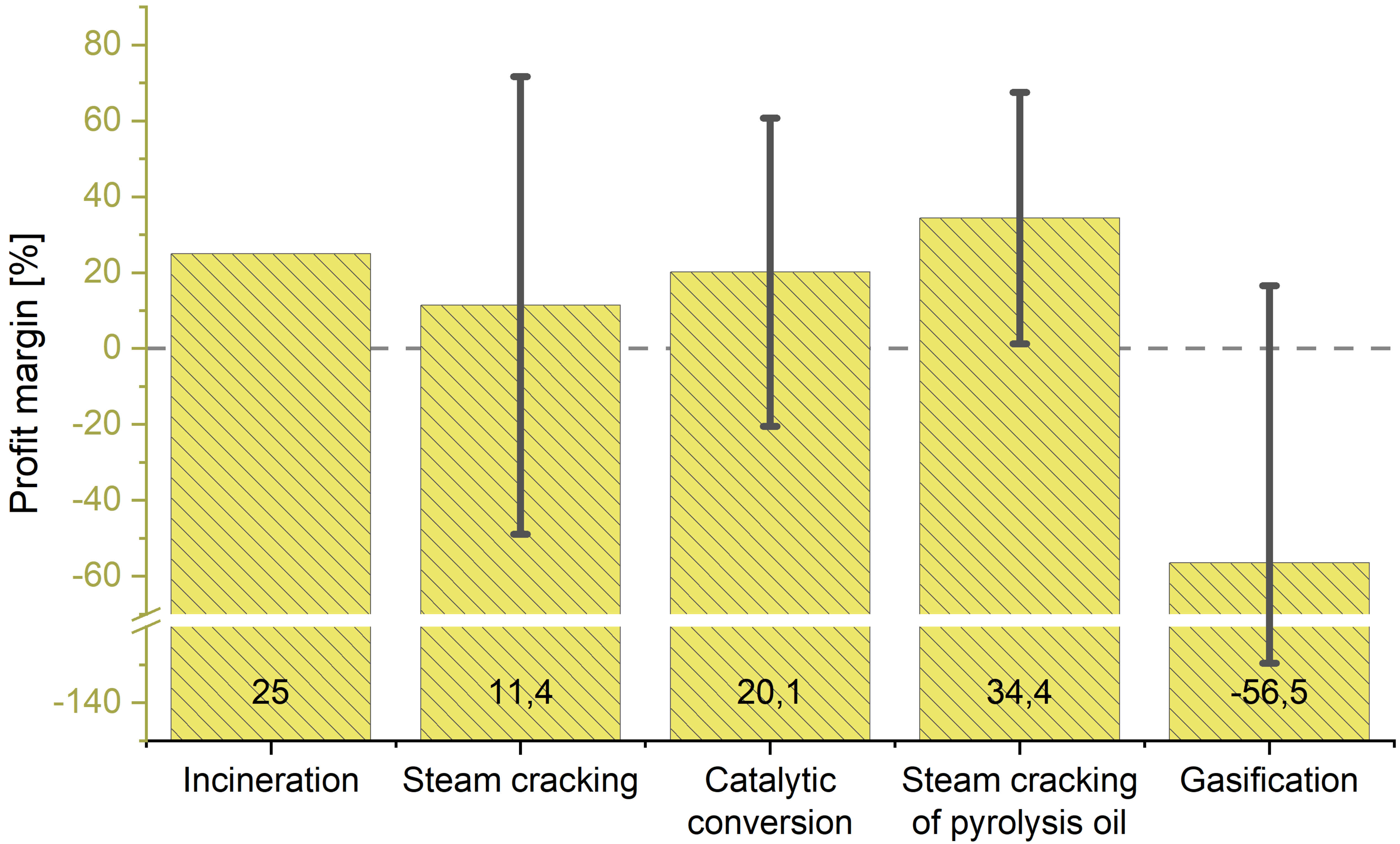
MPO: 325

Propane: 310

Sensitivity

Lower bound: FC*0

Upper bound: FC*2



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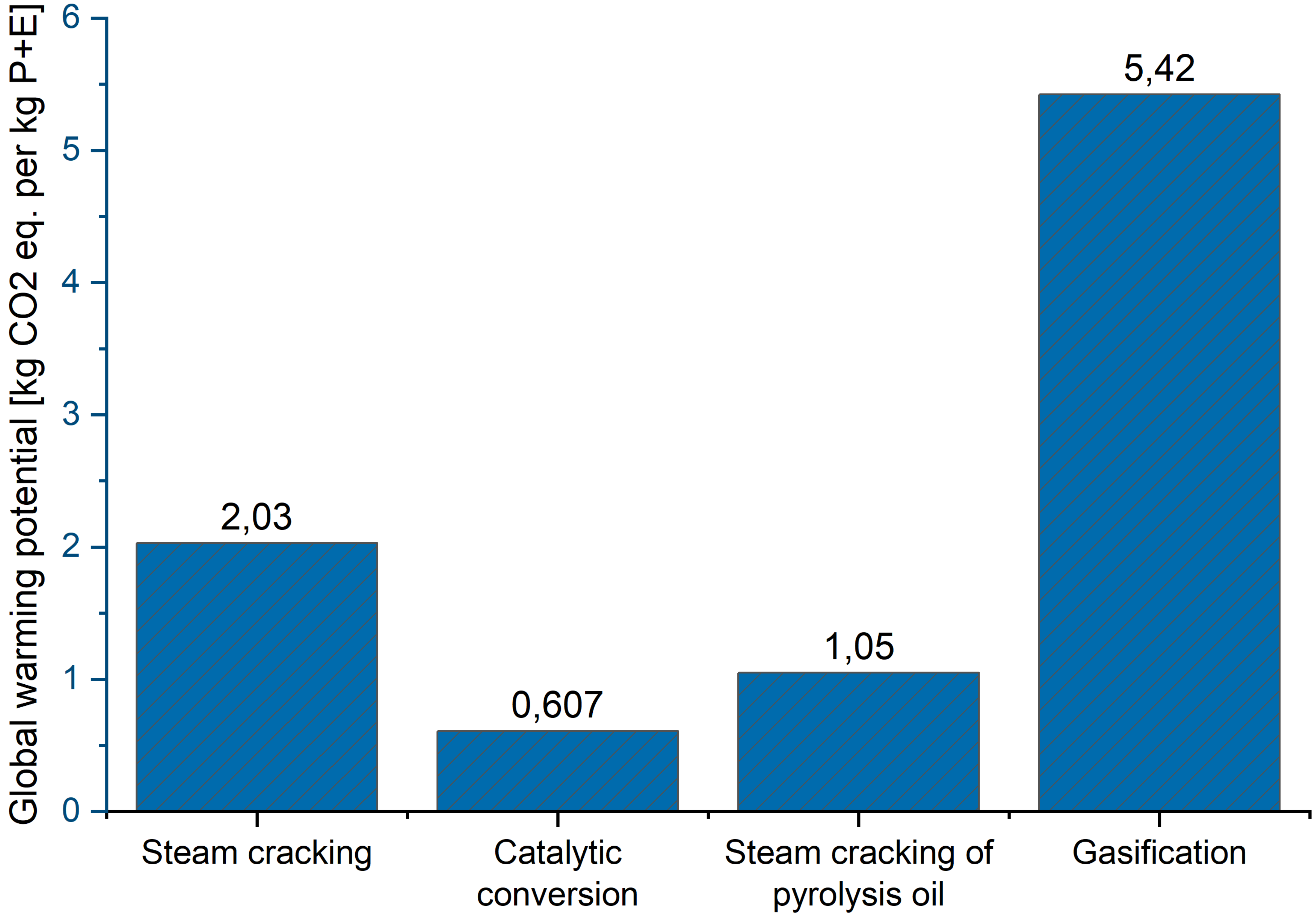
MPO as olefin feedstock

In conventional steam crackers the fossil feedstock is the dominant contributor to GWP that accounts for ~65% according to (Mynko et al., 2022)



Product recovery rates

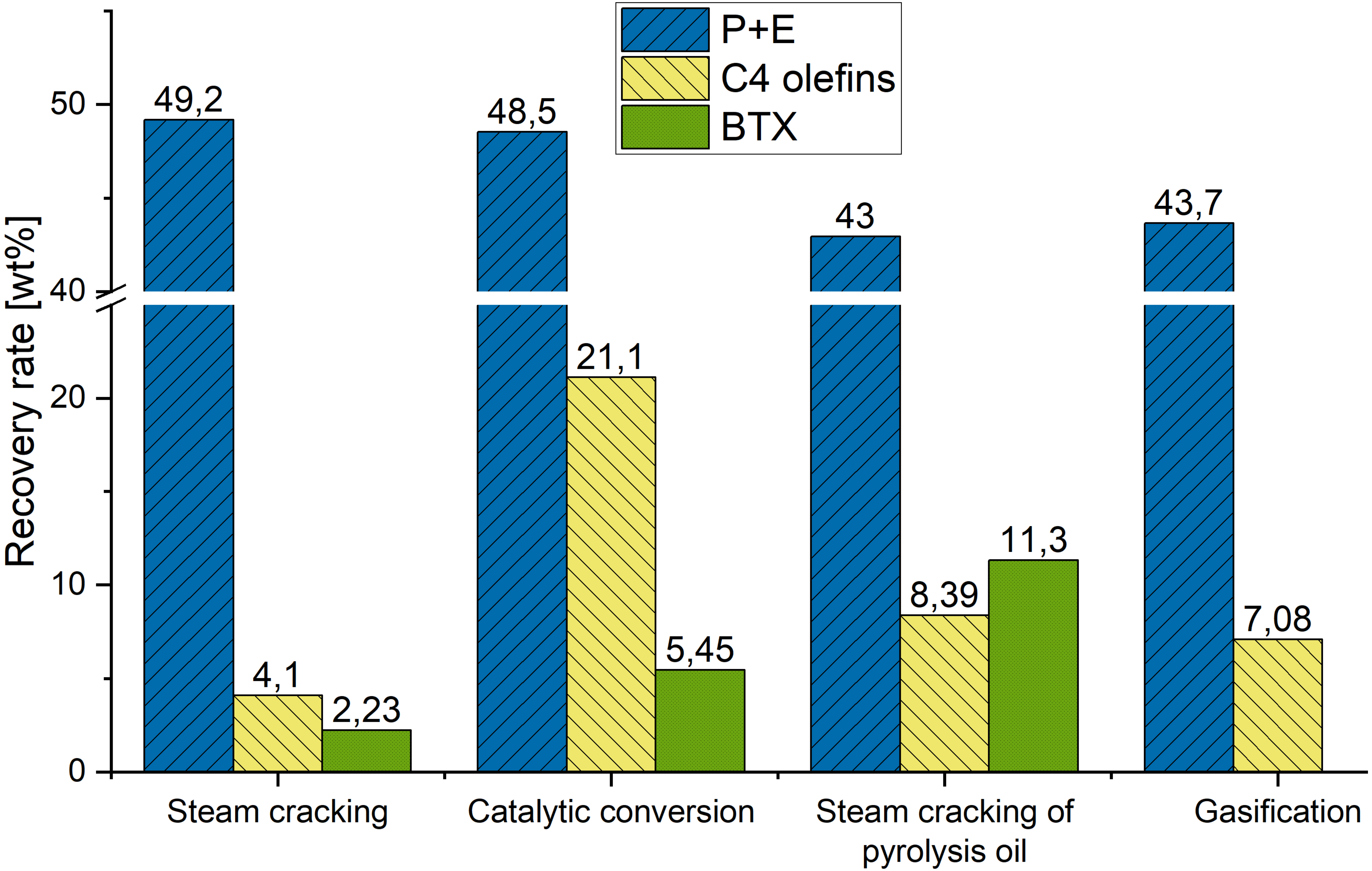
Recovery rate

$$\frac{m(Product)}{m(Feed)} \times 100\%$$

Feed:

C3H8 for steam cracking

MPO for other cases



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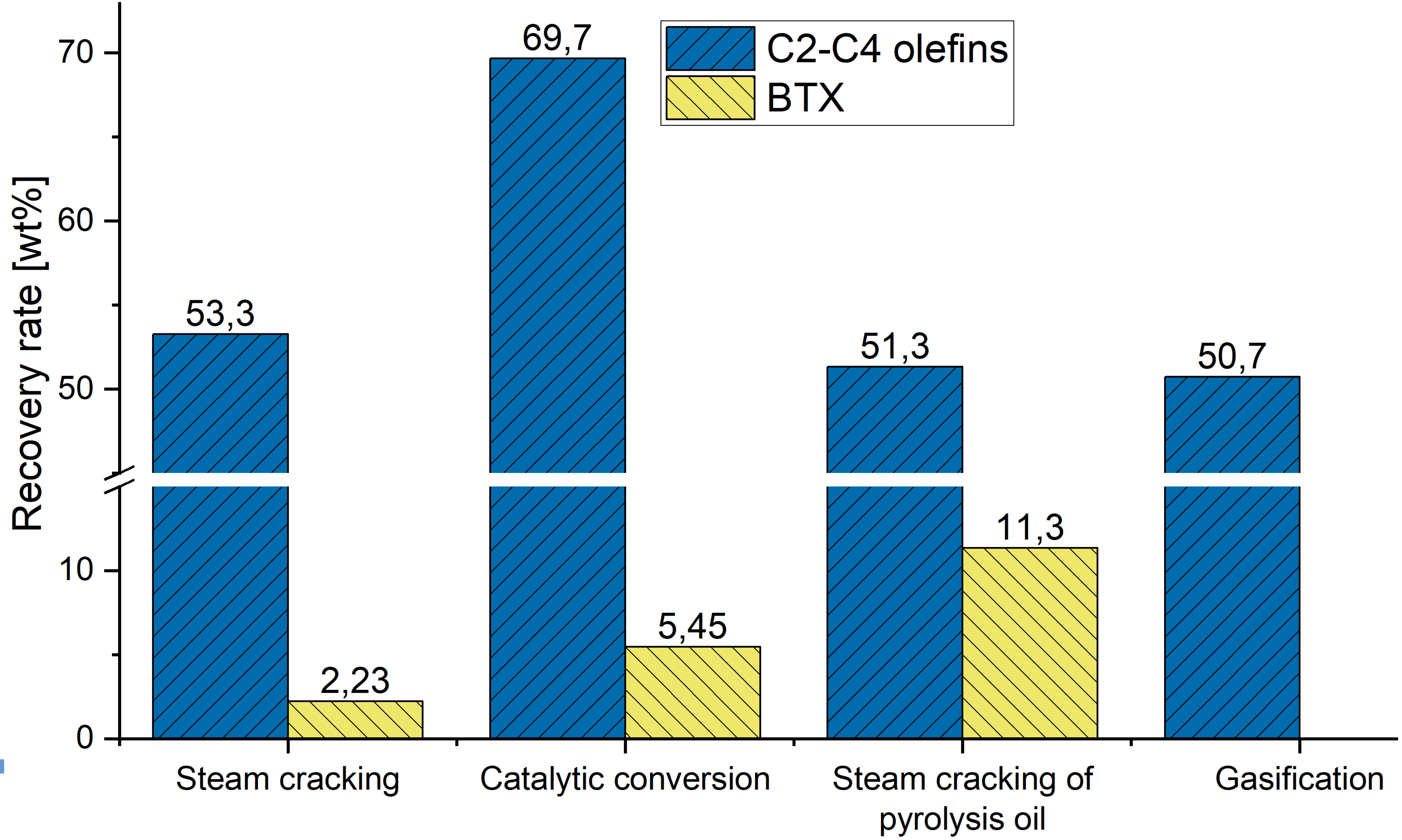
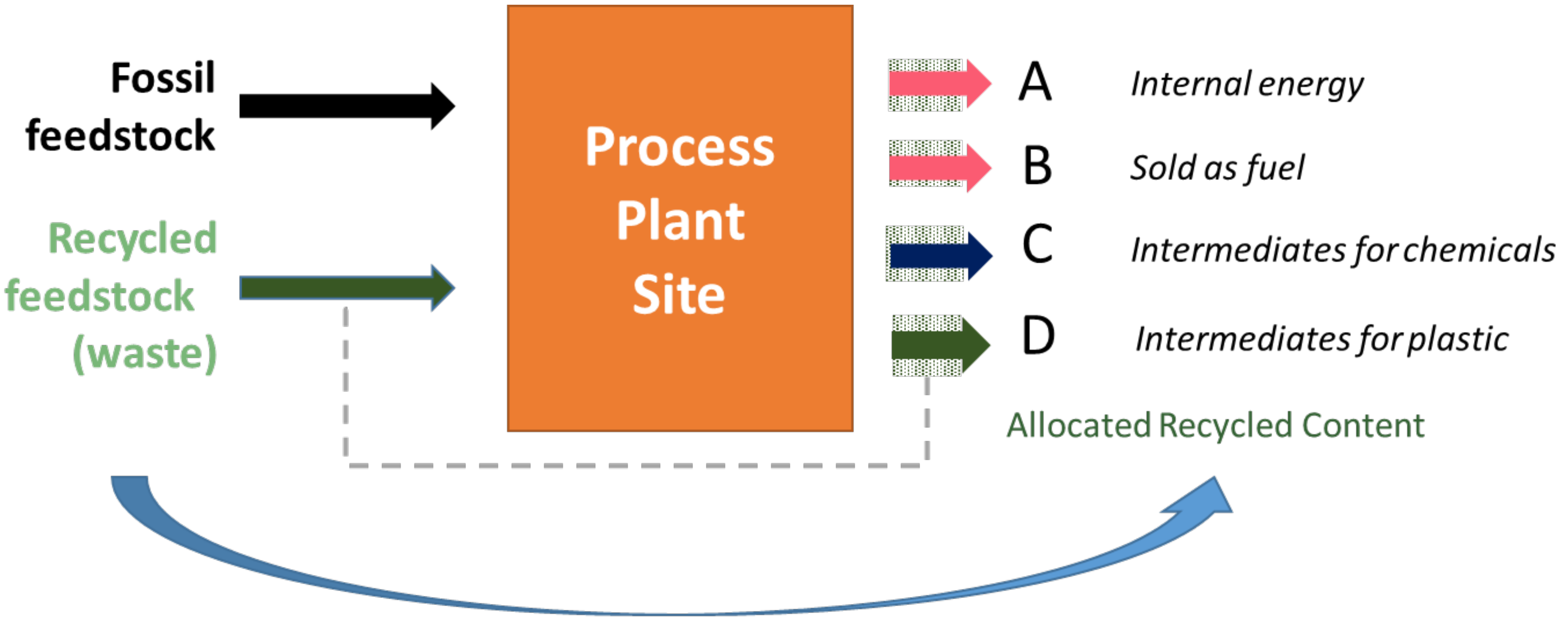


Mass balance with a Fuel Use Exempt model

"Fuel Use Exempt" Model

Deduction of process losses + auto-consumed energy, output used as fuels



Chain of Custody: Mass Balance

Replacing Fossil Feedstock

+ third-party certification: credible and transparent claims

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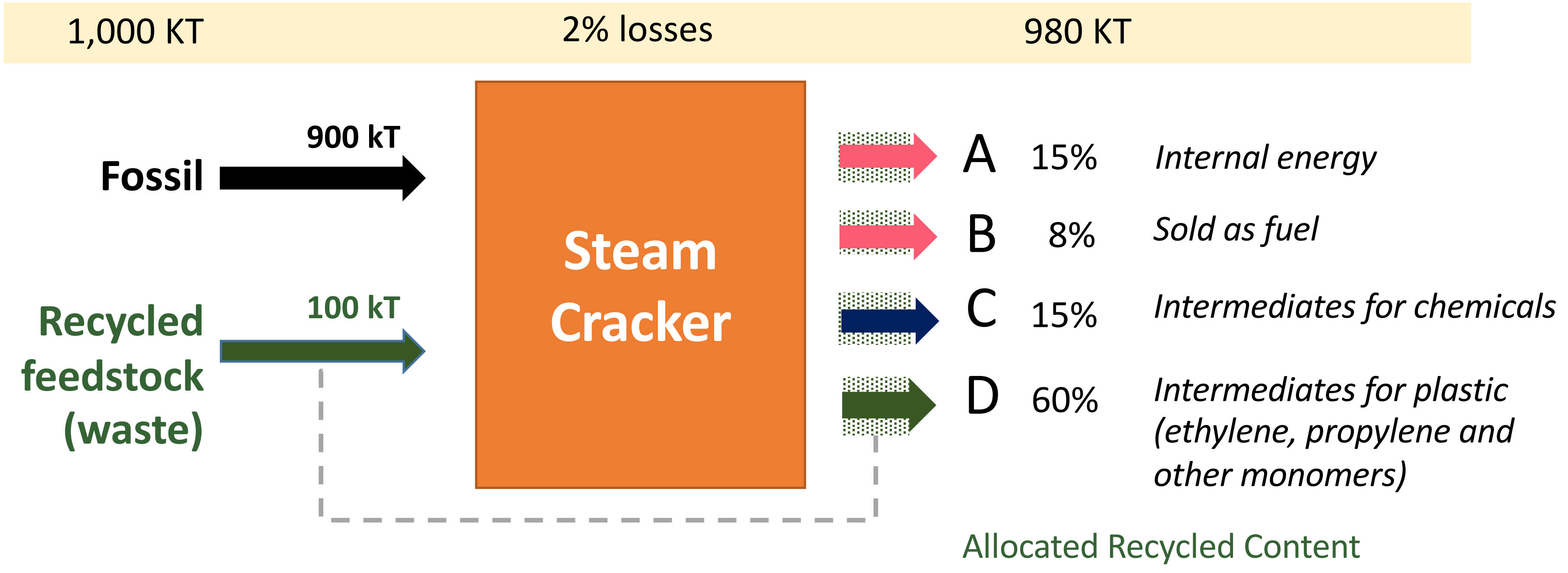
MEERSCHMAN Annick <ame@cefic.be>

Mass balance – a practical example of a steam cracker



"Free attribution" Model — **98 kT**

Deduction of process losses (2%)

"Fuel Use Exempt" Model — **75 kT**

Deduction of process losses + energy/fuel (25%)

"Polymers only" Model — **60 kT**

Deduction of process losses (2%), auto-consumed energy (15%), output used as fuels (8%), non-polymer outputs (15%)

"Proportional " Model

Deduction of process losses (2%), auto-consumed energy (15%), output used as fuels (8%), proportionally split over different output materials

30 kT ethylene
15 kT propylene
15 kT other monomers

Chain of Custody: Mass Balance

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Source for steam-cracker: Technoeconomics – Energy & Chemicals TECH 2018-1 Ethylene program (Nexant)

Brussels we have a problem…

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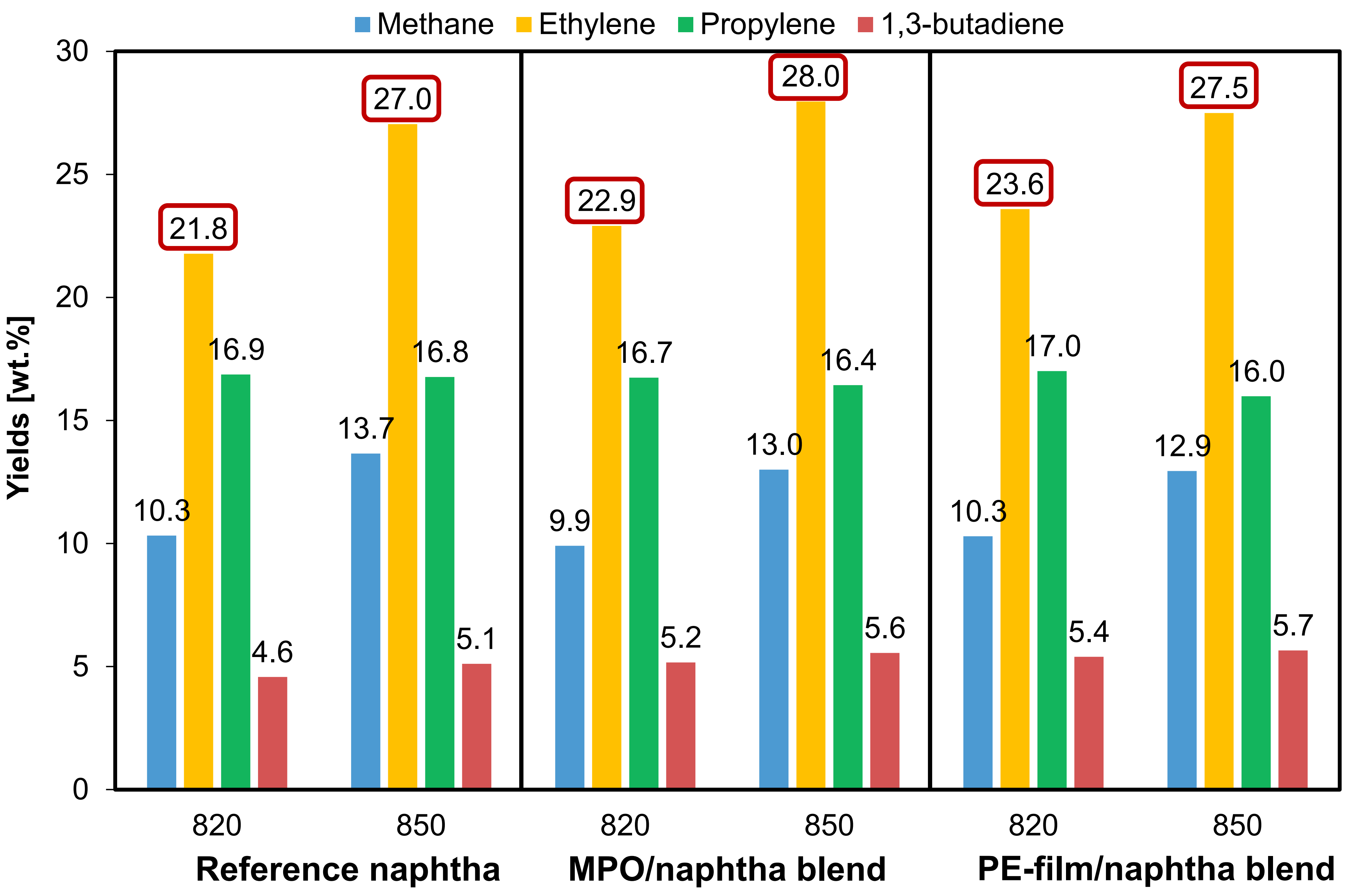
Yields are actually higher than fossil!

Blending ratio: 1 part pyrolysis oil, 3 parts naphtha



Feedstock	Reference naphtha		MPO / naphtha		PE-film / naphtha	
COT [°C]	820	850	820	850	820	850
P/E	0.77	0.62	0.73	0.59	0.72	0.58
Product yields [wt.%]						
C_1-C_4 [wt.%]	67.9	75.8	68.5	75.9	70.1	74.9
PyGas (C_5-C_9)	31.4	23.3	28.2	18.1	28.0	21.7
PFO (C_{10+})	0.7	1.0	3.3	6.0	2.0	3.4

Ethylene yields of pyrolysis oil/naphtha blends > pure

Opportunity for pyrolysis oils as steam cracker feedstock

High olefin content → more secondary reactions → heavy products in C_{10+} range

→ Higher coke formation and transfer line exchanger fouling

https://doi.org/10.1016/j.wasman.2022.01.033

Insights

- Catalytic conversion (Case 1) shows the most promising outcomes for achieving circularity, although it requires additional R&D.
- Steam cracking (Case 2) is most profitable due to higher ethylene yield.
- Gasification (Case 3) is economically unviable given current cost of MPO. To ensure economic viability, either subsidies or increased carbon pricing are required.
- **Mass balance can result in an underestimation of recycled content**

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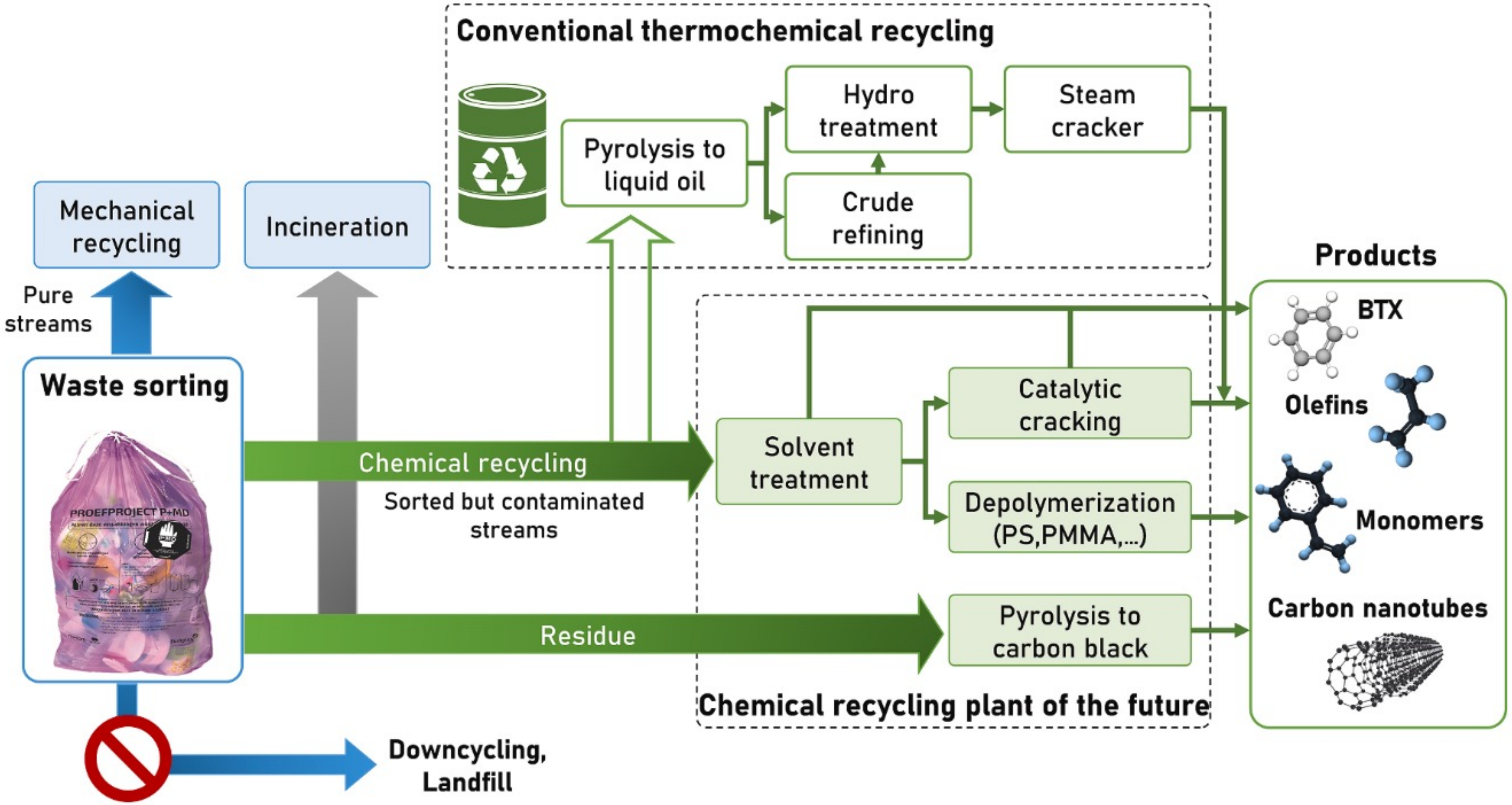
Agenda

- ✓ The problem of plastic waste
- ✓ Methodology
- ✓ Chemical recycling
- ✓ Disposal of plastic waste
- ✓ Key findings



Plastic waste recycling scheme proposed by LCT (Kusenberg et al., 2022)

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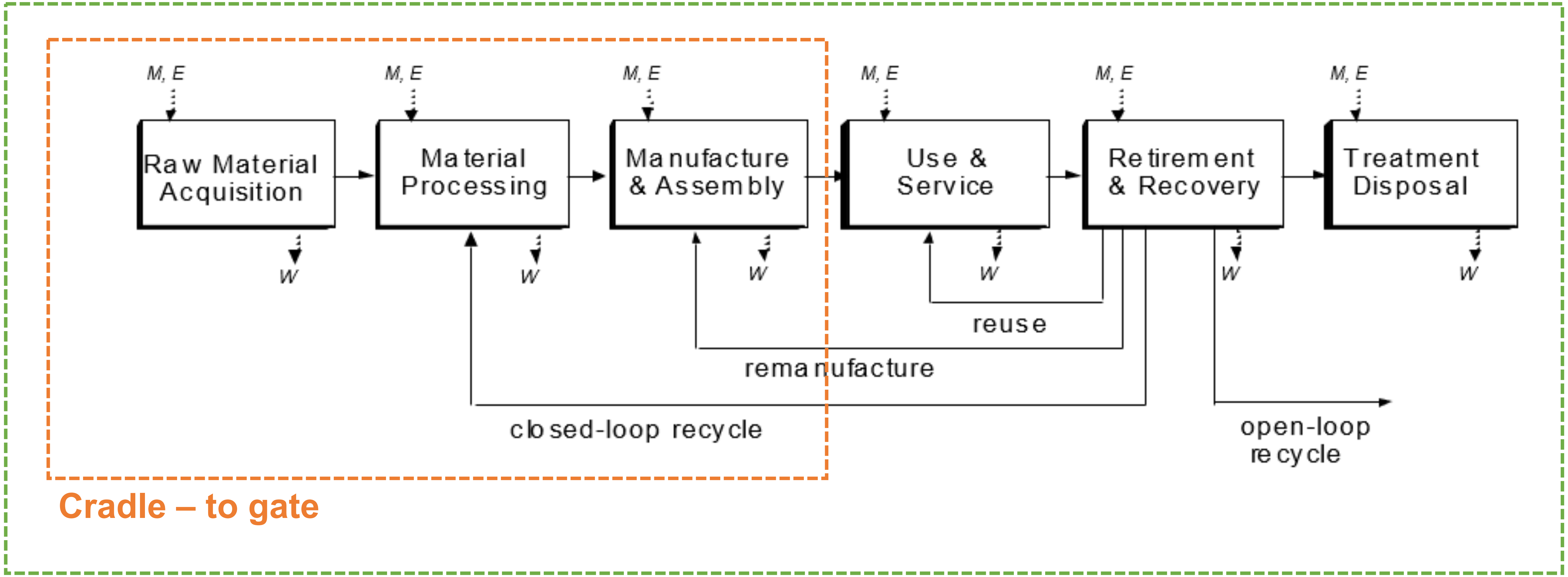
System boundaries



M, E = Material and Energy inputs to process and distribution
W = Waste (gas, liquid, or solid) output from product, process, or distribution

Material flow of product component

Cradle – to gate approach has been selected due to high uncertainty of further life cycle stage (since the products are base chemicals), in line with (WBCSD, 2014)

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Case 1. Catalytic conversion of MPO

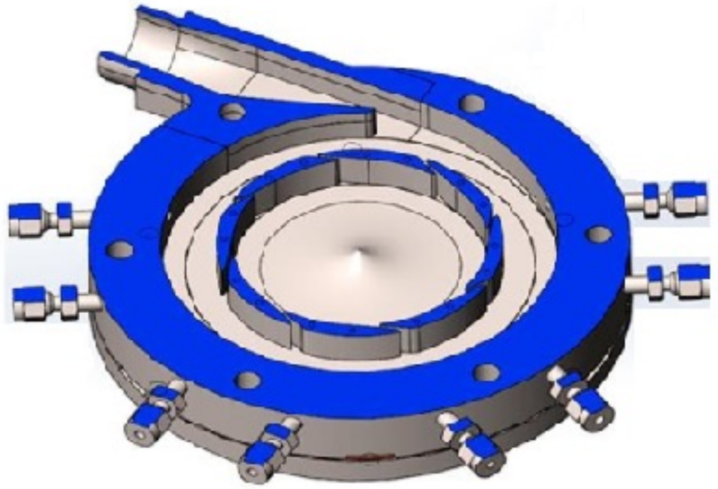
Waste plastic

Dissolution

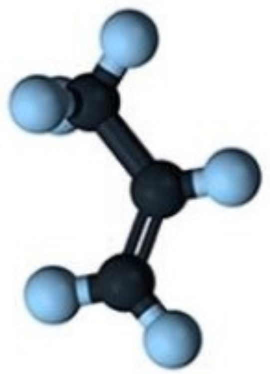
Liquid MPO

Filtration

Gas-solid catalytic reactor



P+E



+ Reduced heating duty
+ Highest E+P recovery rate
+ Uses FCC catalyst

- Novel reactor design
- Catalyst lifespan unknown
- Risk of catalyst poisoning

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Case 2. Steam cracking of pyrolysis oil

Waste plastic

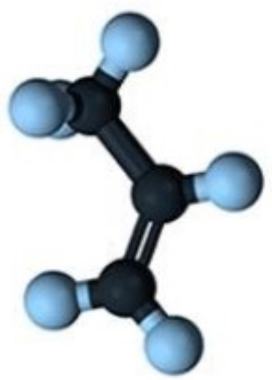
Pyrolysis

Pyrolysis oil

Upgrading

Steam cracker

P+E



+ Existing infrastructure
+ Mature technology
+ Allows for blending with fossil feed

- Requires oil decontamination
- Sensitive to waste sorting/cleaning
- Operational risks for SC operators

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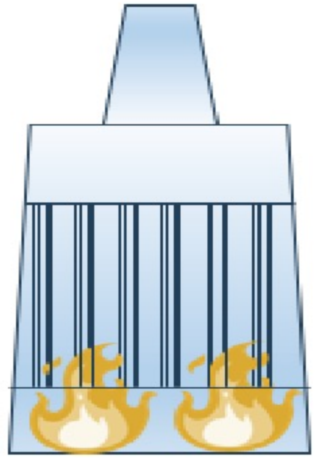
Case 3. Plastic waste gasification

Waste plastic

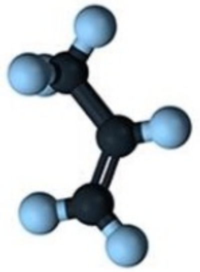
Gasifier



Methanol synthesis

Methanol to olefin plant

P+E



+ Less sensitive to feedstock quality
+ Low operational risks

- Low P+E recovery
- Highest CO2 emissions
- Complicated process