Chemical Recycling and Mass Balance

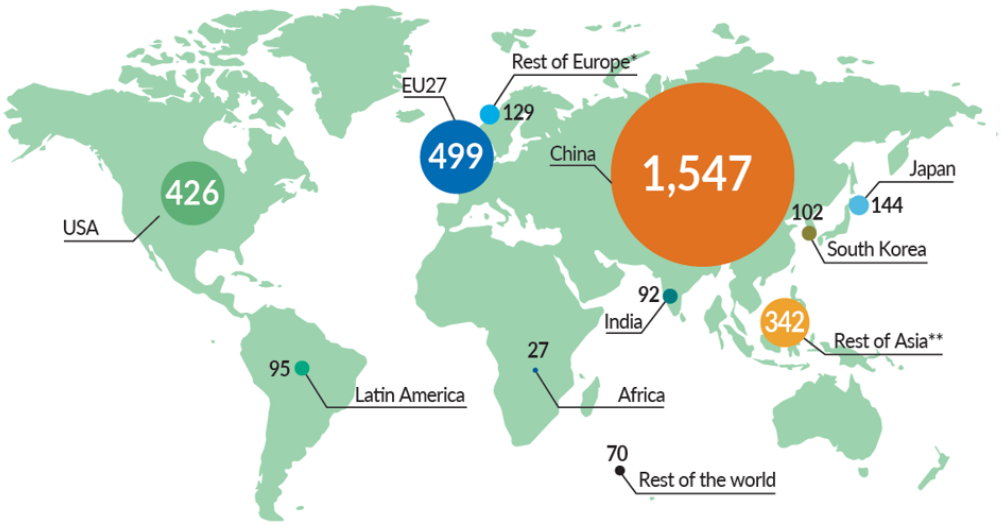
Annick Meerschman - Cefic
13th July 2023

Cefic is the voice of the chemical industry in Europe

- Based in Brussels since 1972, Cefic has grown to become one of the **largest trade organisations** in Europe and in the world
- Representing large, medium and small chemical companies in Europe – **1.1 million jobs & 15%** of world chemicals production
- One of the **most active networks** of the business community: companies + industry (sector) associations + national federations
- We **interact every day** on behalf of our members with international and EU institutions, non-governmental organisations, the international media and other stakeholders

Europe is the second largest chemicals producer in the world

World chemical sales (2020, €3,471 billion)



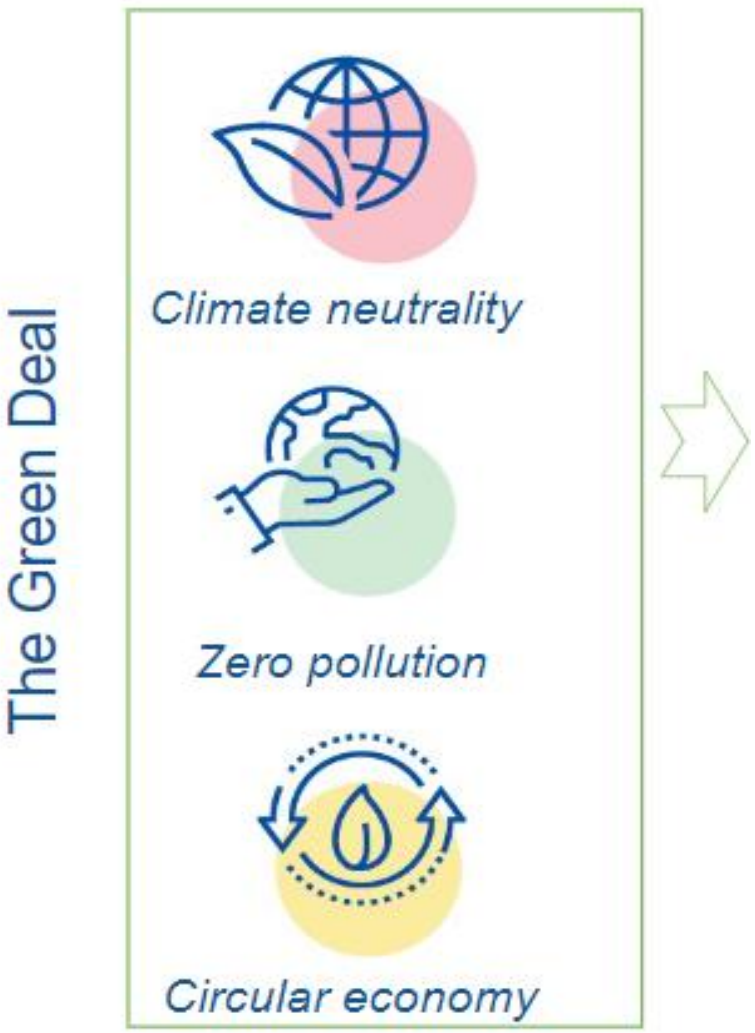
Source: Cefic; *2022 Facts & Figures*

Why this discussion on chemical recycling:

- While 53.9 million tonnes of plastic is produced yearly in Europe, approximately 84% does not currently find its way back into new products (1) .
- **Chemical recycling** has a role to play in the transition towards a circular economy, achieving the net-zero climate objective, and reducing strategic dependencies, complementing mechanical recycling.
- The industry is committed to boosting the circular economy by delivering recycled content
- Cefic is asking for a mass balance chain of custody, with a fuel-use exempt model to account for the contribution of chemical recycling
- **Single-Use Plastics Directive (SUPD) implementing act** will lay down the calculation rules for recycled content, and will potentially set an important precedent
- **We ask for your support in the context of the SUPD implementing act**

(1) Plastics Europe. The Circular Economy for Plastics – a European overview, 2022 edition. Available online; extrapolated from 2019 available figures, geographical scope: EU+3 (Norway, Switzerland, United Kingdom)

Steering towards the ambitions of the Green Deal:
Chemical Recycling: a perfect match in the mix



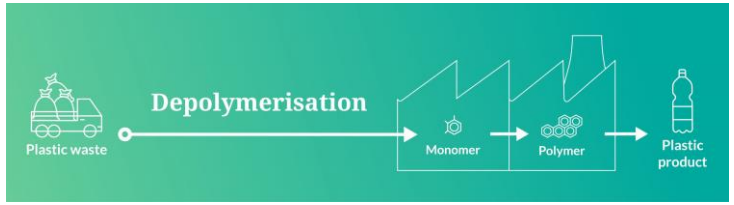
Circular Economy Action Plan: Council Conclusions – December 2020

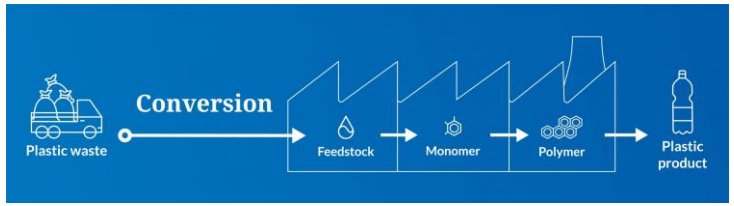
The **European ambition** to transition from a linear towards a **sustainable circular economy** calls for an **array of complementary recycling options and business models.**

The industry is committed to boosting the circular economy by delivering recycled content which is urgently needed to **strengthen the EU's strategic autonomy in raw materials** and meet climate targets.

Different technologies needed to move to a circular economy:
Chemical – Dissolution – Mechanical Recycling of Plastic Waste

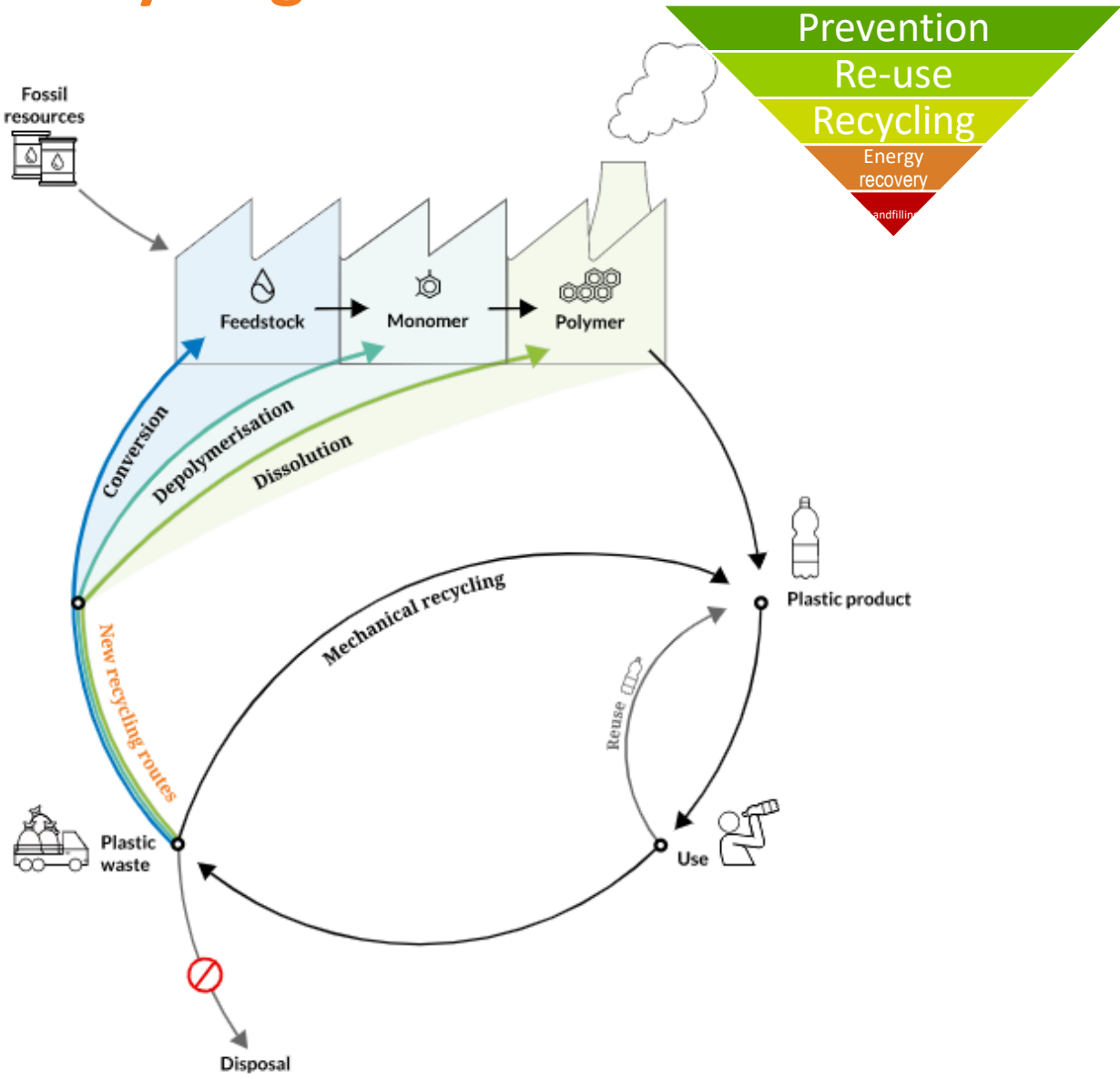
Chemical





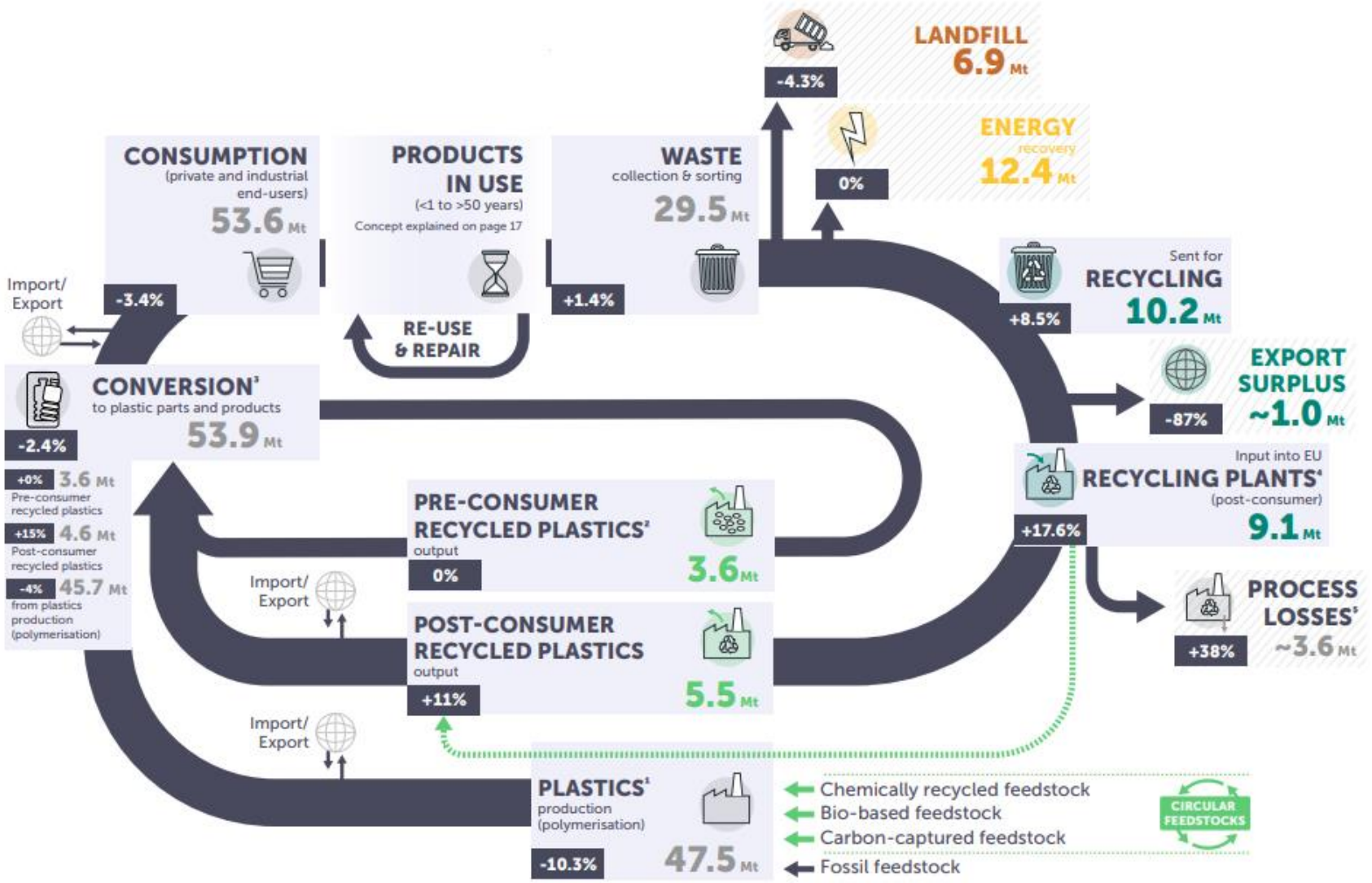
Dissolution

Mechanical



2020 Plastics Circularity

The Circular Economy for Plastics – A European Overview – Plastics Europe



Plastics Europe. The Circular Economy for Plastics – a European overview, 2022 edition. Available online; extrapolated from 2019 available figures, geographical scope: EU+3 (Norway, Switzerland, United Kingdom)

Major investments of commercial scale have already been announced, covering different chemical recycling technologies.

Partnerships are key

Eastman to invest up to $1 billion to accelerate circular economy through building world's largest molecular plastics recycling facility in France

January 16, 2022 · 6 min read

TotalEnergies and Indaver sign an offtake agreement for petrochemical feedstock from advanced recycling

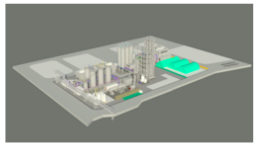
Press release, Paris - TotalEnergies, a global multi-energy company and Indaver, a leader in sustainable waste management and advanced recycling in Europe, announced a commercial agreement for the supply of petrochemical feedstock generated from recycling of mixed polyolefins waste.

Under this agreement, TotalEnergies will purchase the petrochemical feedstock produced at Indaver's first Plastics2Chemicals plant (P2C). Indaver will supply and transform post-consumer mixed plastic waste into a petrochemical feedstock at its plant in Antwerp using its proprietary depolymerization technology. Currently under construction, the plant is expected to become operational by 2024.

TotalEnergies will process this petrochemical feedstock into high-quality circular polymers at its plants in Antwerp. With properties and quality identical to virgin polymers, the recycled polymers will be suitable for a wide range of high demanding applications including food-grade packaging.

""We are delighted to support the development of advanced plastic recycling through this new offtake agreement. A collaboration throughout the value chain is critical to develop a more circular and sustainable economy. This partnership contributes to our ambition of producing 30% circular polymers by 2030.", said **Valérie Goff, Senior Vice President Renewable Fuels & Chemicals**.

"We are very pleased with this agreement. Our companies share the same vision of a true circular economy for recycled end-of-life plastics" declared ***Paul De Bruycker, CEO of the Indaver Group****. "Indaver's Plastics-to-Chemicals (P2C) depolymerisation technology allows to recycle end-of-life plastics such as polyolefins and polystyrene by converting them into a petrochemical feedstock that can be used for the production of high-demand packaging materials. With P2C, we significantly expand the possibilities for recycling of end-of-life plastics waste that could previously not be recycled or only be used for conversion into low-value applications"* Mr De Bruycker added.



LyondellBasell Makes Decision to Progress Advanced Recycling Plant in Wesseling, Germany

lyondellbasell
Advancing Possible

USA - English

NEWS PROVIDED BY
LyondellBasell
Nov 18, 2022, 07:50 ET

SHARE THIS ARTICLE

ROTTERDAM, Netherlands, Nov. 18, 2022 /PRNewswire/ -- LyondellBasell today announces it has made a decision to move forward with engineering to build an advanced recycling plant at its Wesseling, Germany, site. Using LyondellBasell's proprietary *MoReTec* technology, this commercial scale advanced recycling plant would convert pre-treated plastic waste into feedstock for new plastic production. The final investment decision is targeted for the end of 2023.

Sabic confirms it will produce circular polymers in Europe by the end of 2022

Françoise Albasini (Photo : Courtesy of Sabic)

30 April 2022

SHARE:

Located on the huge chemical platform of Brightlands Chemelot in the Netherlands, Sabic will start producing polymers from its chemical recycling process by the end of 2022. Leading cosmetics brands are already trusting the company.

More investments are taking place…

Often in collaboration with technology providers

Joint News Release

BASF and ARCUS sign agreement on the production and procurement of pyrolysis oil from mixed plastic waste

- **ARCUS plans to start up first commercial pyrolysis plant for mixed plastic waste in Germany**
- **Supply of pyrolysis oil from mixed plastic waste enables further expansion of BASF's ChemCycling™ business**
- **Agreement foresees take-up of up to 100,000 tons of pyrolysis oil per year**

Evonik partners with The Vita Group for pioneering efficient polyurethane mattress recycling process

- **The process helps the flexible polyurethane foam industry to increase circularity**
- **Hydrolysis technology enables used flexible polyurethane foams and mattress materials to be recycled**
- **Innovation will significantly reduce the number of mattresses incinerated or going into landfill each year**

INEOS and Petroineos at Grangemouth partner with Plastic Energy in an important breakthrough in the recycling of plastic.

Friday, December 17, 2021 INEOS Group

- **The process will use existing refinery operations replacing oil with TACOIL made from waste flexible food packaging to remake virgin plastic for reuse in food and hygiene applications.**
- **This trial and the evolution of the policy environment in the UK will inform the development of a large-scale advanced recycling plant, which aims to be the first of its kind in the UK.**

Dow and Mura Technology announce largest commitment of its kind to scale advanced recycling of plastics

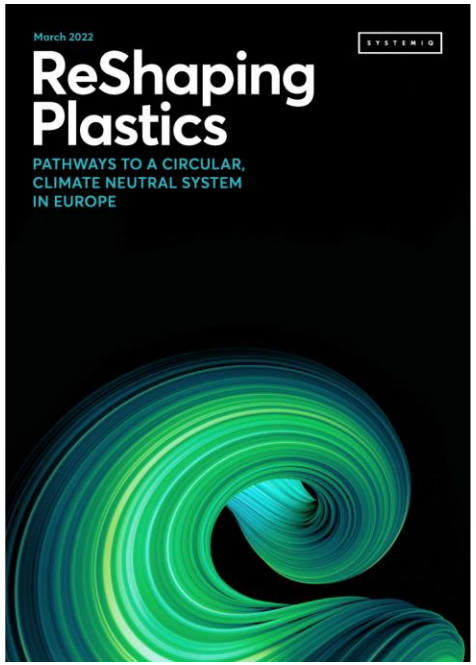
07/21/2022

- Dow and Mura Technology to build multiple facilities in the U.S. and Europe, adding as much as 600 kilotons of aggregate advanced recycling capacity by 2030.
- Expansion of Mura's pipeline builds on its first plant in Teesside, U.K., which is on track to be fully operational in 2023.
- By using advanced recycling as a complementary technology to mechanical recycling, Dow is making significant progress towards its sustainability, climate and plastic waste reduction targets.
- Dow to become a key off-taker of circular feed from Mura, supplying major brands across the globe with sustainable products and helping to scale the elimination of plastic waste.
- Dow's support of Mura Technology provides critical resources for Mura to finance and deliver on its multi-year pipeline of advanced plastic recycling projects.

Chemical Recycling: Making Plastics Circular

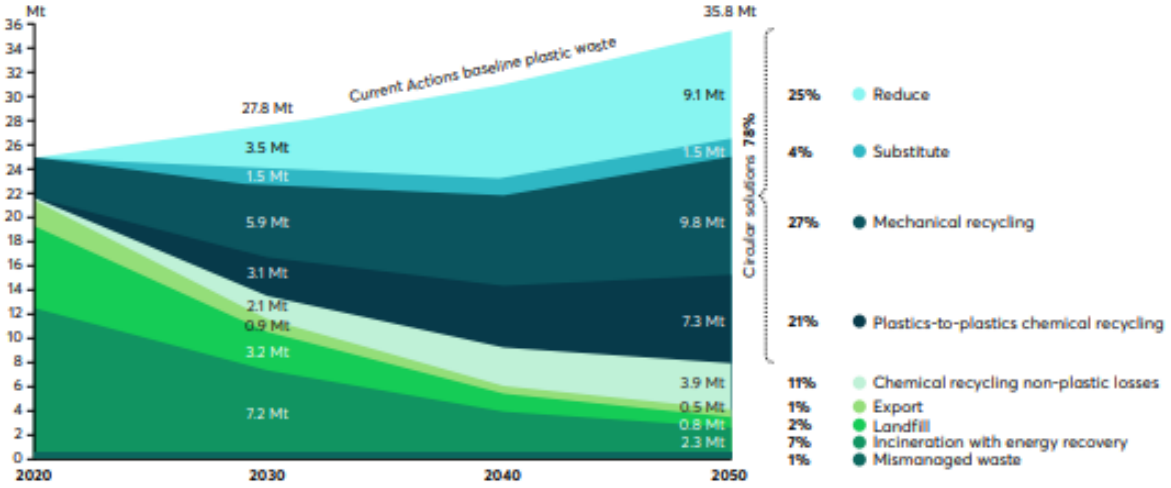
Welcome to the European Chemical Industry 'Virtual Exhibition on Chemical Recycling'

Chemical recycling is a key element in the transition towards net-zero



By 2050, the Plastics system could achieve 78% circularity with 30% of waste avoided through reduction and substitution and 48% being recycled, leaving 9% in landfills and incinerators

Physical fate of plastic waste from packaging, household goods, automotive and construction 2020-2050 (Mt)



Source: "ReShaping Plastics" model

xlii Defined as the share of plastic utility that is treated in any way other than landfill, incineration with energy recovery, exported, or mismanaged.

Chemical recycling can strongly contribute to circularity as a complementary technology

Resources, Conservation & Recycling 192 (2023) 106916

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

How much can chemical recycling contribute to plastic waste recycling in Europe? An assessment using material flow analysis modeling

Irdanto Saputra Lase [a,b,*], Davide Tonini [b], Dario Caro [b], Paola F. Albizzati [c], Jorge Cristóbal [c], Martijn Roosen [a], Marvin Kusenberg [a], Kim Ragaert [a], Kevin M. Van Geem [d], Jo Dewulf [e], Steven De Meester [a,*]

ARTICLE INFO

Keywords:
Material flow analysis
Chemical recycling
Plastic waste
Circularity indicator
Recycled content

ABSTRACT

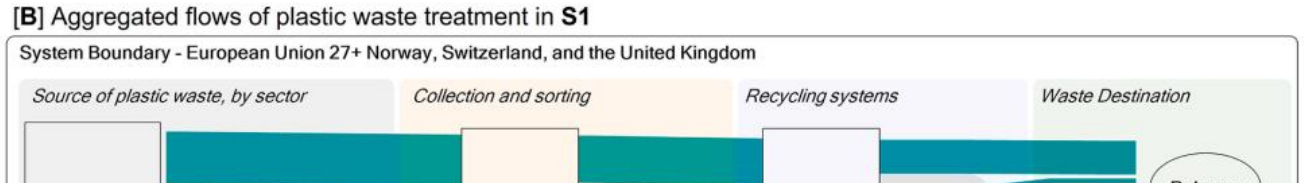
Plastic recycling rate in Europe is low, urging developments in recycling technology and strategies to increase circularity. Mechanical recycling (MR) has been the reference recycling technology for years, but in the near future chemical recycling (CR) options are expected to contribute to improve plastic circularity. This study uses a material flow analysis (MFA) at European level to provide quantitative estimates of the contribution of CR technologies to plastic recycling. Ten most used polymer types from five sectors are selected. A status quo 2018 scenario is modelled and compared to five potential future scenarios (in 2030) of plastic waste treatment, including one that only looks at improved waste collection, sorting, and MR technologies and four exploring developments of CR options. The so-called 'missing plastics', i.e., plastic waste generated but currently not accounted for in statistics, is considered in one of the future scenarios. The MFA results are compared by calculating four circularity indicators namely end-of-life recycling rate (EoL-RR), plastic-to-plastic rate, plastic-to-chemicals rate, and plastic-to-fuels rate. The results indicate that in the most optimistic scenario the EoL-RR in 2030 is 72–80% (sum of plastic-to-plastic and plastic-to-chemical rates, excluding plastic-to-fuel rate), in which 41–46% is plastic-to-plastic from MR, 13–38% is plastic-to-plastic from CR and 19–38% is plastic-to-chemicals. The highest achievable plastic-to-plastic rate is estimated to be 61% (46% from MR and 15% from CR). In all future scenarios, the plastic-to-fuel rate is estimated to be 3–6%. The MFA results are also used to estimate potential recycled content availability in 2030, which suggest that closed-loop recycling and processing the 'missing plastics' will be necessary to achieve the targets.

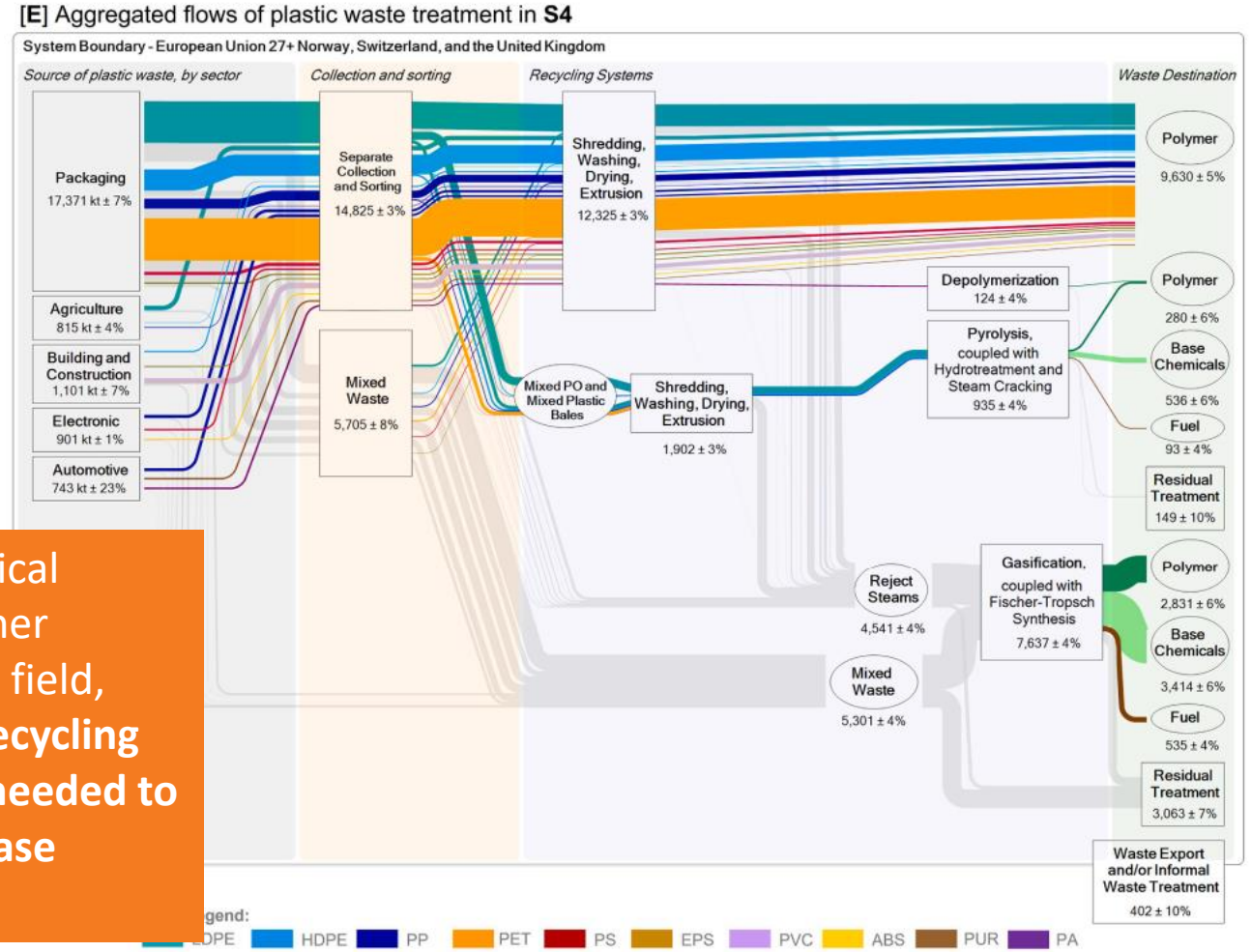
1. Introduction

Plastic is a bulk term for a wide range of polymers that is widely used in various applications due to their light weight, durability, affordability and broad application range (Lebreton and Andrady, 2019; Hou et al., 2021). In 2019, global plastic use amounted to 460 million tonnes (Mt), of which more than 60% was used in the packaging, construction, and automotive sectors. In the same year, 353 Mt of plastic waste were generated, of which only 6% was effectively recycled globally while the remaining mass was mostly incinerated or landfilled (OECD, 2022). Some studies also emphasize the leakage of macro- and micro-plastics into the environment (Ryberg et al., 2019; Paahs et al., 2020; Boucher et al., 2020). Moreover, the demand for plastic, and the subsequent plastic waste generation, is expected to increase considerably in

* Corresponding authors.
E-mail addresses: irdantosaputra.lase@ugent.be (I.S. Lase), steven.demeester@ugent.be (S. De Meester).

https://doi.org/10.1016/j.resconrec.2023.106916
Received 21 November 2022; Received in revised form 26 January 2023; Accepted 6 February 2023
Available online 26 February 2023





On top of mechanical recycling and further innovations in this field, **complementary recycling technologies are needed to significantly increase circularity**

By 2030

S1: Mechanical recycling optimized with best practices and technological advances

- EoL RR 49%
- P2P 49%

S4: Chemical recycling as complementary to mechanical recycling

- EoL RR 80%
- P2P 61%
- P2C 19%

New European Commission Study Confirms Chemical Recycling Is Better Than Incineration Of Plastic Waste

A new report published by the European Commission's Joint Research Centre "Environmental and economic assessment of plastic waste – A comparison of mechanical, physical, chemical recycling and energy recovery of plastic waste" did a comparative environmental and economic assessment of plastic waste recycling and energy recovery technologies.

STOP LINEAR - GO CIRCULAR:

- From a climate change perspective and based on Life Cycle Assessments (LCA), the preferred management option for plastic waste is recycling (mechanical, physical or chemical).
- Recycling (mechanical, physical or chemical) is preferable to energy recovery (incineration) in all analysed pathways. As the European energy mix will get cleaner, the gap between recycling and energy recovery will further increase in favour of recycling, the study concludes.
- **Clarifying the use of a mass balance chain of custody method to calculate the recycled content of plastics in products is one the most important drivers of investments into chemical recycling in the EU.**

Mass balance
Fuel-use exempt

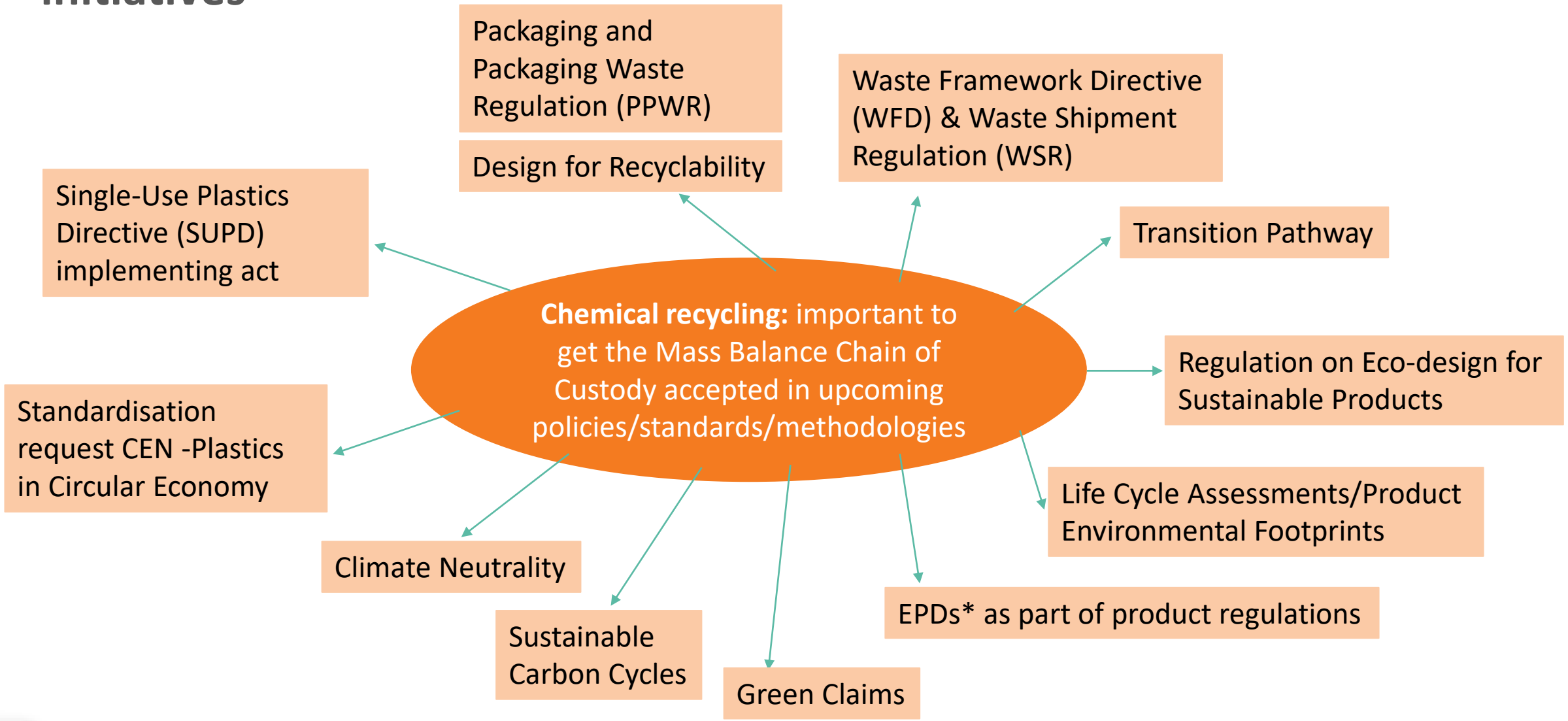
Legislative agenda

- Single-Use Plastics Directive (SUPD)
- Packaging and Packaging Waste Regulation (PPWR)

- Directive on end-of-life vehicles (ELVs)
- Construction Products Regulation
- Ecodesign for Sustainable Products Regulation

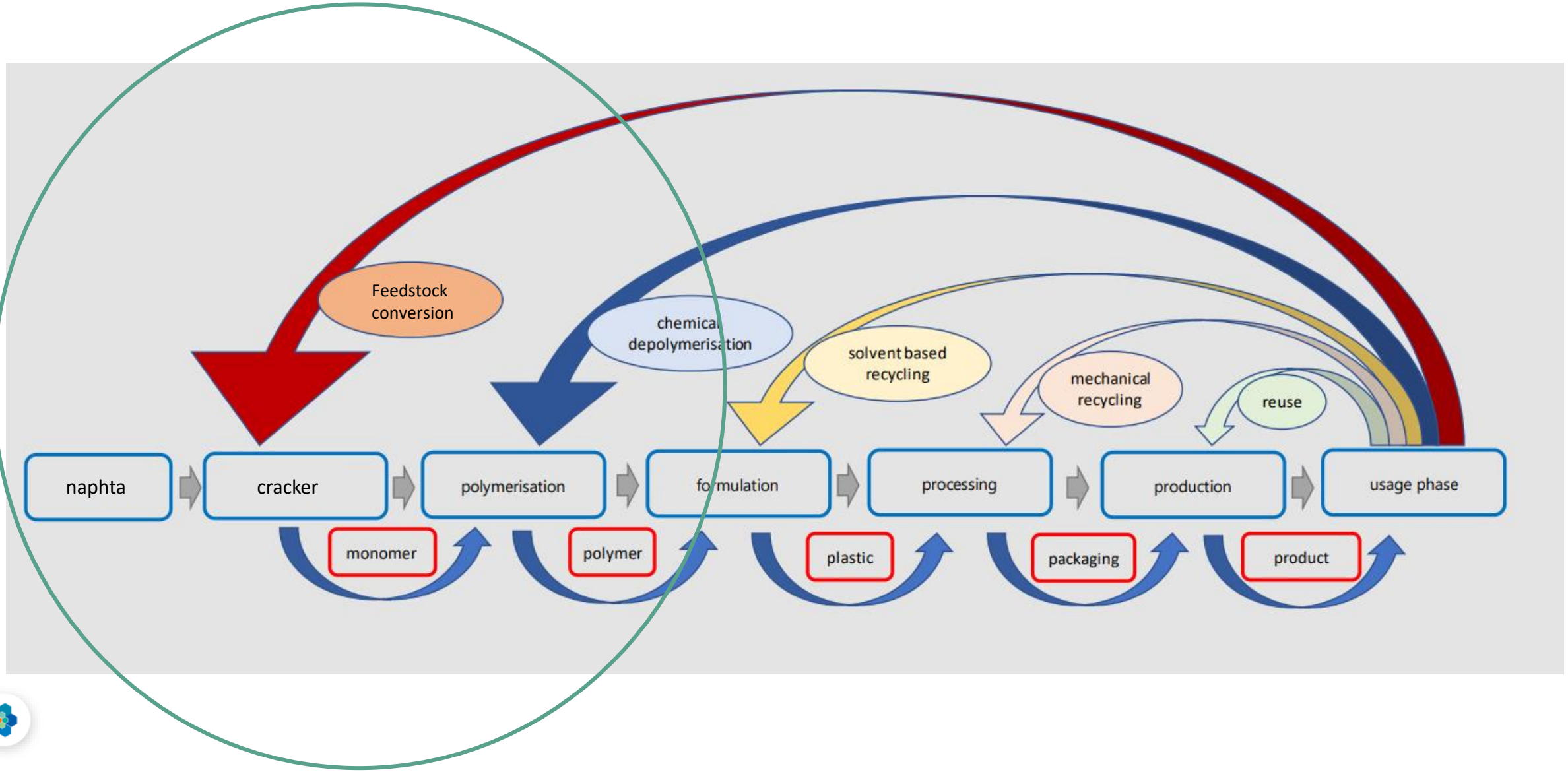
Current voluntary certification exists, but is not counted towards targets

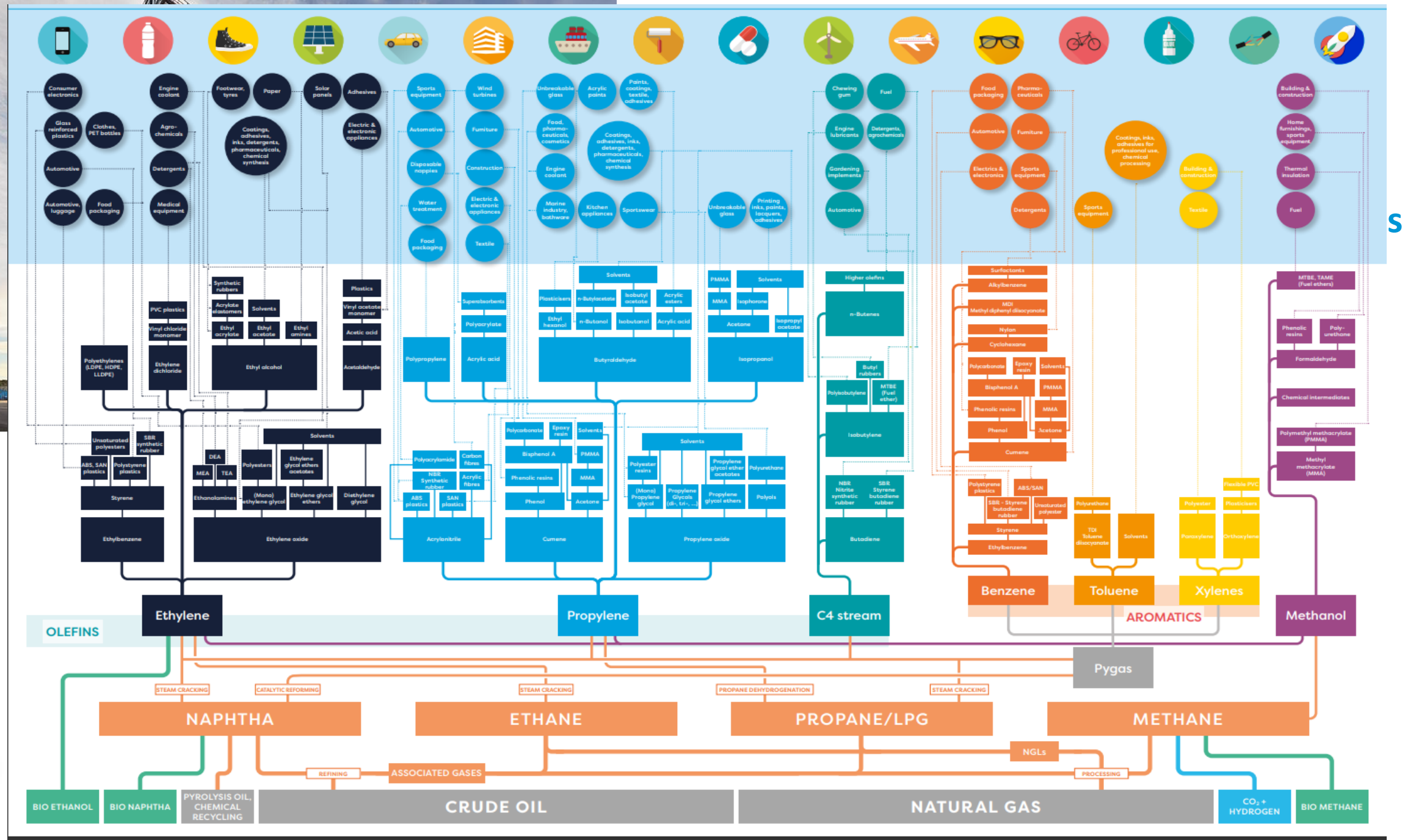
Chemical recycling potential needs to be recognized in a range of initiatives



* EPDs: An Environmental Product Declaration (EPD) is defined by International Organization for Standardization (ISO) 14025 as a Type III declaration that "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function."[1] The EPD methodology is based on the Life Cycle Assessment (LCA)[2] tool that follows ISO series 14040.[3][4][5] – a verified EPD can earn your products credits for LEED v4 and other green building rating systems.

Chemical recycling reintroduces secondary raw material upstream in the value chain




Consumer electronics
Glass reinforced plastics
Clothes, PET bottles
Automotive
Automotive, luggage
Food packaging
Engine coolant
Agro-chemicals
Detergents
Medical equipment
Footwear, tyres
Paper
Coatings, adhesives, inks, detergents, pharmaceuticals, chemical synthesis
Solar panels
Adhesives
Electric & electronic appliances
Sports equipment
Automotive
Disposable nappies
Water treatment
Food packaging
Wind turbines
Furniture
Construction
Electric & electronic appliances
Textile
Unbreakable glass
Acrylic paints
Paints, coatings, textile, adhesives
Food, pharmaceuticals, cosmetics
Engine coolant
Coatings, adhesives, inks, detergents, pharmaceuticals, chemical synthesis
Marine industry, bathware
Kitchen appliances
Sportswear
Unbreakable glass
Printing inks, paints, lacquers, adhesives
Chewing gum
Fuel
Engine lubricants
Detergents, agrochemicals
Gardening implements
Automotive
Food packaging
Pharmaceuticals
Automotive
Furniture
Electrics & electronics
Sports equipment
Detergents
Coatings, inks, adhesives for professional use, chemical processing
Sports equipment
Building & construction
Textile
Building & construction
Home furnishings, sports equipment
Thermal insulation
Fuel
Polyethylenes (LDPE, HDPE, LLDPE)
PVC plastics
Vinyl chloride monomer
Ethylene dichloride
Synthetic rubbers
Acrylate elastomers
Solvents
Ethyl acrylate
Ethyl acetate
Ethyl amines
Ethyl alcohol
Plastics
Vinyl acetate monomer
Acetic acid
Acetaldehyde
Unsaturated polyesters
SBR synthetic rubber
ABS, SAN plastics
Polystyrene plastics
Styrene
Ethylbenzene
DEA
MEA
TEA
Ethanolamines
Solvents
Polyesters
Ethylene glycol ethers acetates
(Mono) ethylene glycol
Ethylene glycol ethers
Diethylene glycol
Ethylene oxide
Superabsorbents
Polyacrylate
Polypropylene
Acrylic acid
Solvents
Plasticisers
n-Butylacetate
Isobutyl acetate
Acrylic esters
Ethyl hexanol
n-Butanol
Isobutanol
Acrylic acid
Butyraldehyde
PMMA
Solvents
MMA
Isophorone
Acetone
Isopropyl acetate
Isopropanol
Polyacrylamide
Carbon fibres
NBR Synthetic rubber
Acrylic fibres
ABS plastics
SAN plastics
Acrylonitrile
Polycarbonate
Epoxy resin
Solvents
Bisphenol A
PMMA
Phenolic resins
MMA
Phenol
Acetone
Cumene
Solvents
Polyester resins
Propylene glycol ether acetates
Polyurethane
(Mono) Propylene glycol
Propylene Glycols (di-, tri-, ...)
Propylene glycol ethers
Polyols
Propylene oxide
Higher olefins
n-Butenes
Butyl rubbers
Polyisobutylene
MTBE (Fuel ether)
Isobutylene
NBR Nitrile synthetic rubber
SBR Styrene butadiene rubber
Butadiene
Surfactants
Alkylbenzene
MDI Methyl diphenyl diisocyanate
Nylon
Cyclohexane
Polycarbonate
Epoxy resin
Solvents
Bisphenol A
PMMA
Phenolic resins
MMA
Phenol
Acetone
Cumene
Polystyrene plastics
ABS/SAN
SBR - Styrene butadiene rubber
Unsaturated polyester
Styrene
Ethylbenzene
Polyurethane
TDI Toluene diisocyanate
Solvents
Polyester
Plasticisers
Paraxylene
Orthoxylene
MTBE, TAME (Fuel ethers)
Phenolic resins
Poly-urethane
Formaldehyde
Chemical intermediates
Polymethyl methacrylate (PMMA)
Methyl methacrylate (MMA)
Ethylene
Propylene
C4 stream
Benzene
Toluene
Xylenes
AROMATICS
Methanol
OLEFINS
Pygas
STEAM CRACKING
CATALYTIC REFORMING
STEAM CRACKING
PROPANE DEHYDROGENATION
STEAM CRACKING
NAPHTHA
ETHANE
PROPANE/LPG
METHANE
NGLs
REFINING
ASSOCIATED GASES
PROCESSING
BIO ETHANOL
BIO NAPHTHA
PYROLYSIS OIL, CHEMICAL RECYCLING
CRUDE OIL
NATURAL GAS
CO_2 + HYDROGEN
BIO METHANE

Need for a mass balance chain of custody to calculate chemically recycled content in plastics and chemicals

A chain of custody is the chronological documentation or paper trail that records the sequence of custody, control, transfer, analysis, and disposition of materials, including physical or electronic evidence. Different models and options exist, as per the ISO 22095 standard.

Mass balance, a widely employed **"chain of custody"** model, ensures confidence in the input and output of a process, and it has proven successful in various sectors like biofuels, cocoa, and coffee.

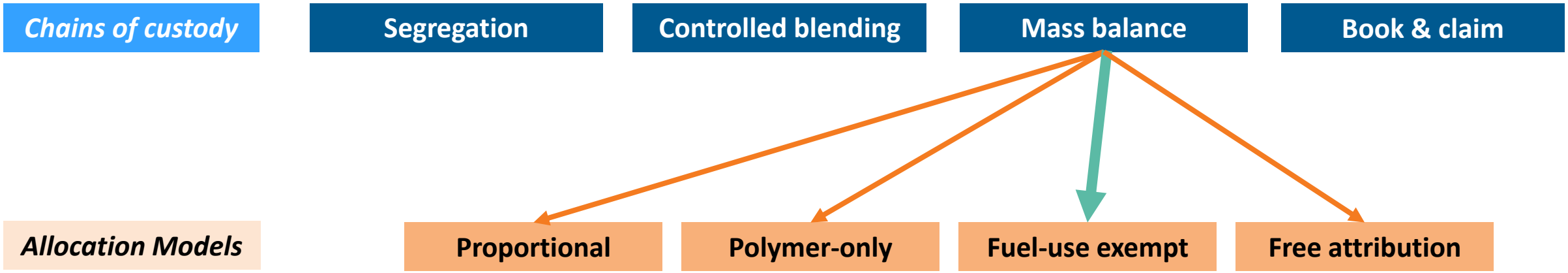
Why do we need this for chemical recycling?

- Purposing existing industrial installations for the circular economy
- These continuous, large scale production processes have multiple outputs
- Leveraging recycled feedstock together with virgin fossil feedstock in existing assets

Cefic Position paper, December 2022
5-point Action Plan on Chemical Recycling

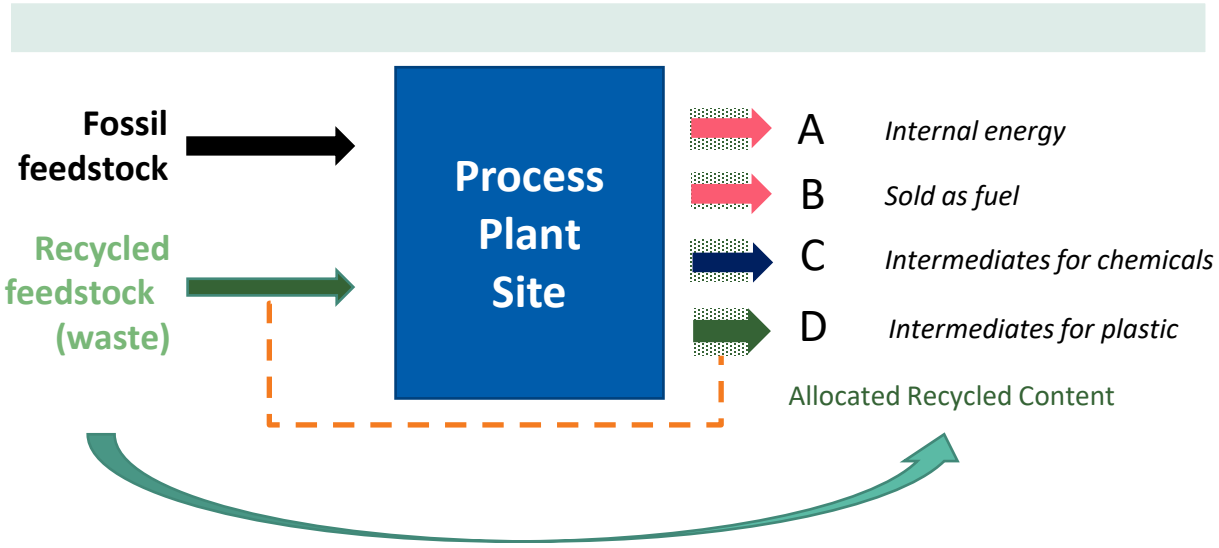
Contributions of recycling need to be accounted for with a robust chain of custody model

A **chain of custody** is the chronological documentation or paper trail that records the sequence of custody, control, transfer, analysis, and disposition of materials, including physical or electronic evidence. Different models and options exist, as per the ISO 22095 standard.



+ third-party certification: credible and transparent claims

Mass balance with a Fuel Use Exempt model



Replacing Fossil Feedstock

Chain of Custody: Mass Balance

"Fuel Use Exempt" Model

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

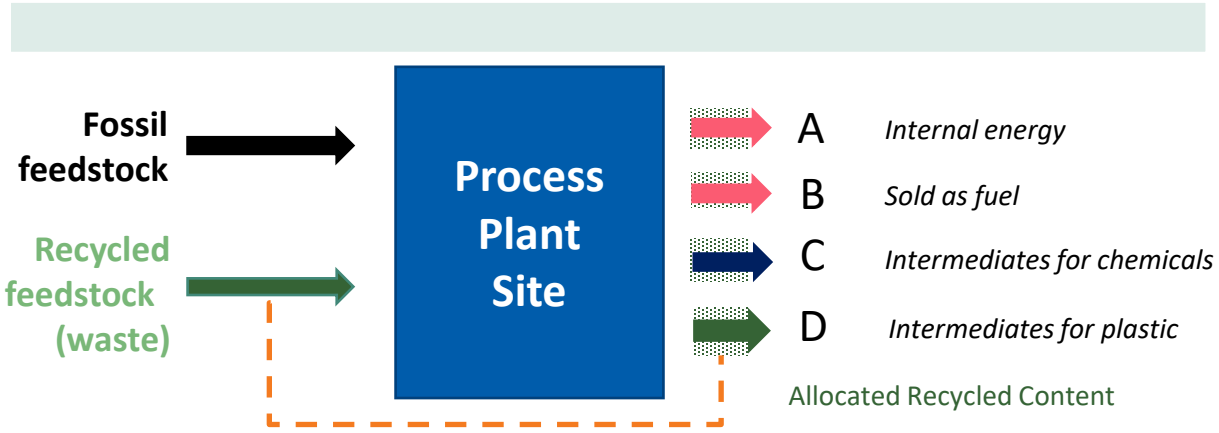
Recycling Definition

'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material **but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations**;

Reference: EU Waste Framework Directive

+ third-party certification: credible and transparent claims

Mass balance – generic example



Chain of Custody: Mass Balance

"Fuel Use Exempt" Model

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

"Polymers only" Model

Deduction of process losses, auto-consumed energy, output used as fuels, non-polymer outputs

"Proportional " Model

Deduction of process losses, auto-consumed energy, output used as fuels, proportionally split over different output materials

Why are stricter models *not appropriate*?

Attribution rule	
Polymers only	• Inefficient in transition to circular economy • Unduly restricts the quantities of recycled plastics (- 20%) and increases their costs (+20%) compared to fuel-use exempt • More fossil is replaced than accounted for
Proportional	• Reduces to the minimum level the recycled quantities that can be attributed to the specific polymers where there is a market demand for recycled content • and proportionally increases the costs

Conclusions

- **Chemical recycling** has a key role to play in the transition towards a circular economy, achieving the net-zero climate objective, and reducing strategic dependencies, complementing mechanical recycling
- Achieving the recycling targets requires taking into account the contribution of chemical recycling
- A mass balance chain of custody is essential in the calculation rules
- **Fuel-use exempt is the preferred option as the only viable allocation model**
- **We ask for your support in the context of the SUPD implementing act**

Thank you for your attention

For more information, please contact
Annick Meerschman – ame@cefic.be