Workshop: Lifecycle of Plastics

Recycling methods for secondary plastics

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09/09/2020, Network-Wide Training Event 1

C-PlaNeT
CIRCULAR PLASTICS NETWORK FOR TRAINING

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Introduction

Key data of the plastics industry – EU28

Over 1.5 million people

The plastic industry gives direct employment to more than 1.5 million people in Europe

Close to 60,000 companies

An industry in which close to 60,000 companies operate, most of them SME's

More than 350 billion euros

The European plastic industry had a turnover of 355 billion euros in 2017

17 billion euros

The European plastic industry had a trade balance of more than 17 billion euros in 2017*

* Data including only plastics raw materials producers and plastics converters

https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

Key data of the plastics industry – EU28

More than 30 billion euros

The European plastic industry contributed to 32.5 billion euros to public finances and welfare in 2017

x2.4 in GDP and almost x3 in jobs

The European plastic industry has a multiplier effect of 2.4 in GDP and almost 3 in jobs*

* The European House Ambrosetti study, data for Italy, 2013

7^{th} in Europe

The European plastic industry ranks 7^{th} in Europe in industrial value added contribution. At the same level as the pharmaceutical industry* and very close to the chemical industry

* Measured by gross value added at factor prices, 2013

Over 8.4 million tonnes

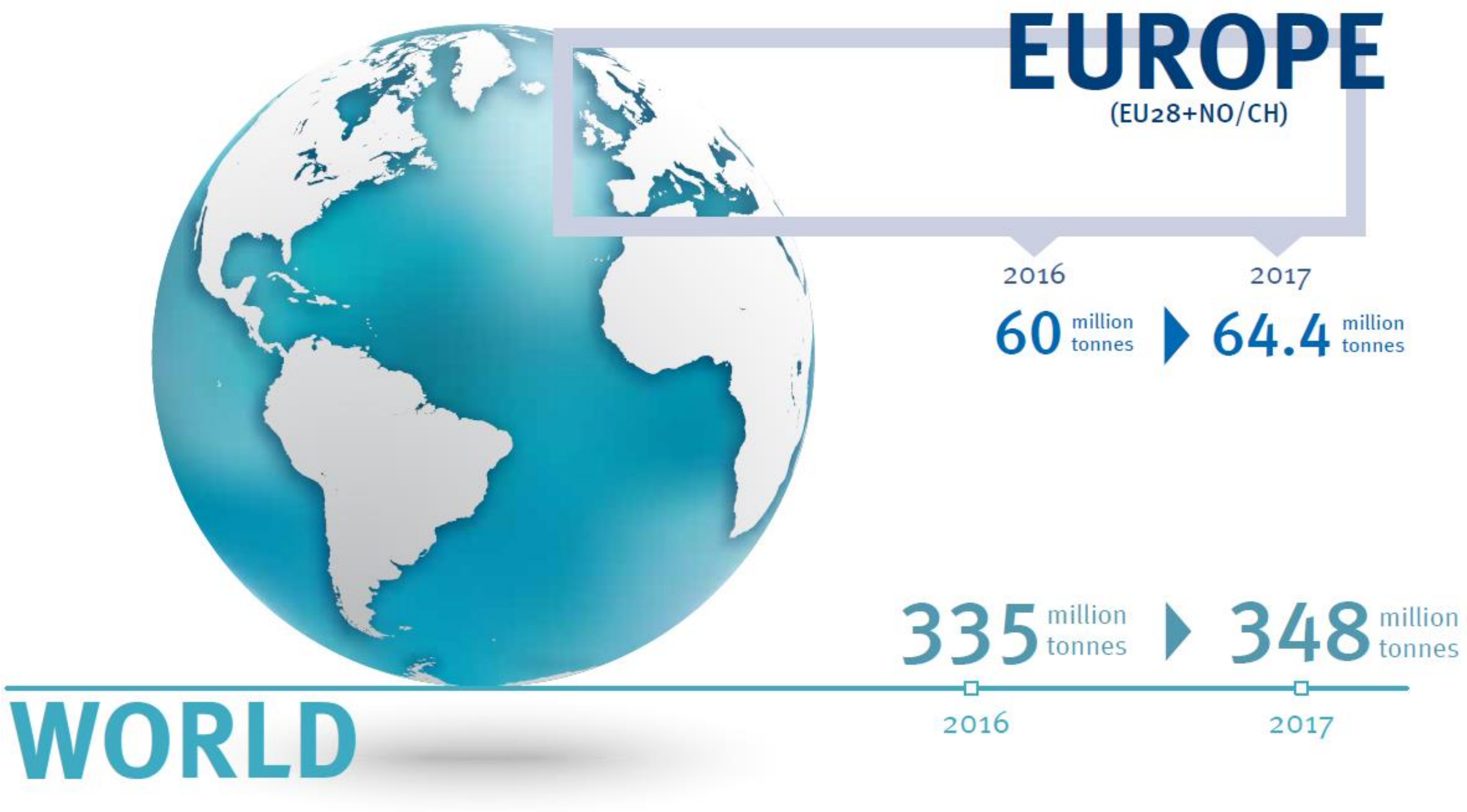
In 2016, over 8.4 million tonnes of plastic waste were collected in order to be recycled inside and outside the EU

https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

Plastics production – world

The world plastic* production almost reached 350 million tonnes in 2017.

Source: PlasticsEurope Market Research Group (PEMRG) / Conversio Market & Strategy GmbH



Includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibers.
Not included PET-, PA- and polyacryl-fibers.

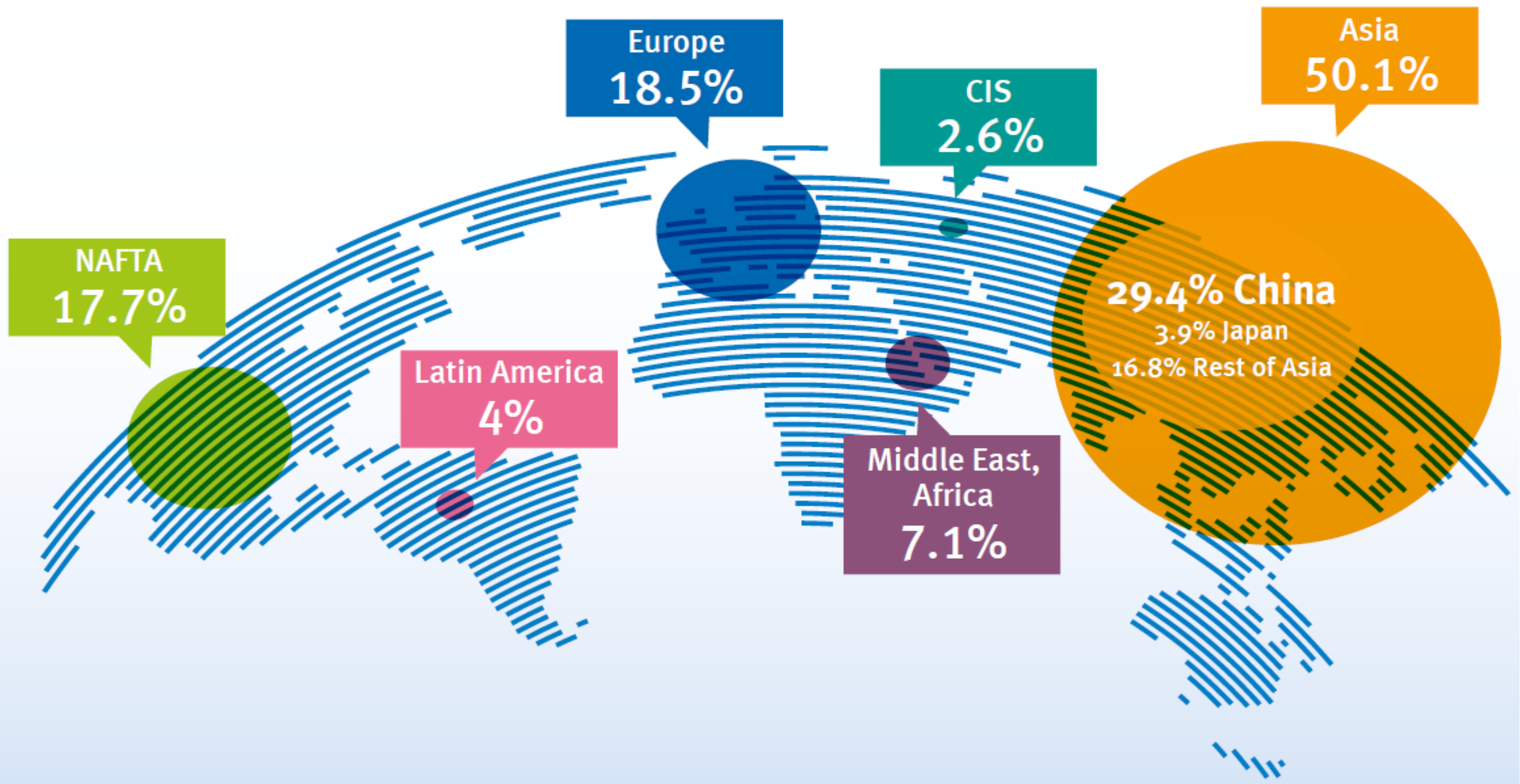
https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

Where is the production?

China is the largest producer of plastics, followed by Europe and NAFTA.

World plastics* production: 348 million tonnes.

Source: PlasticsEurope Market Research Group (PEMRG) / Conversio Market & Strategy GmbH



*Includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibers. Not included PET-, PA- and polyacryl-fibers.

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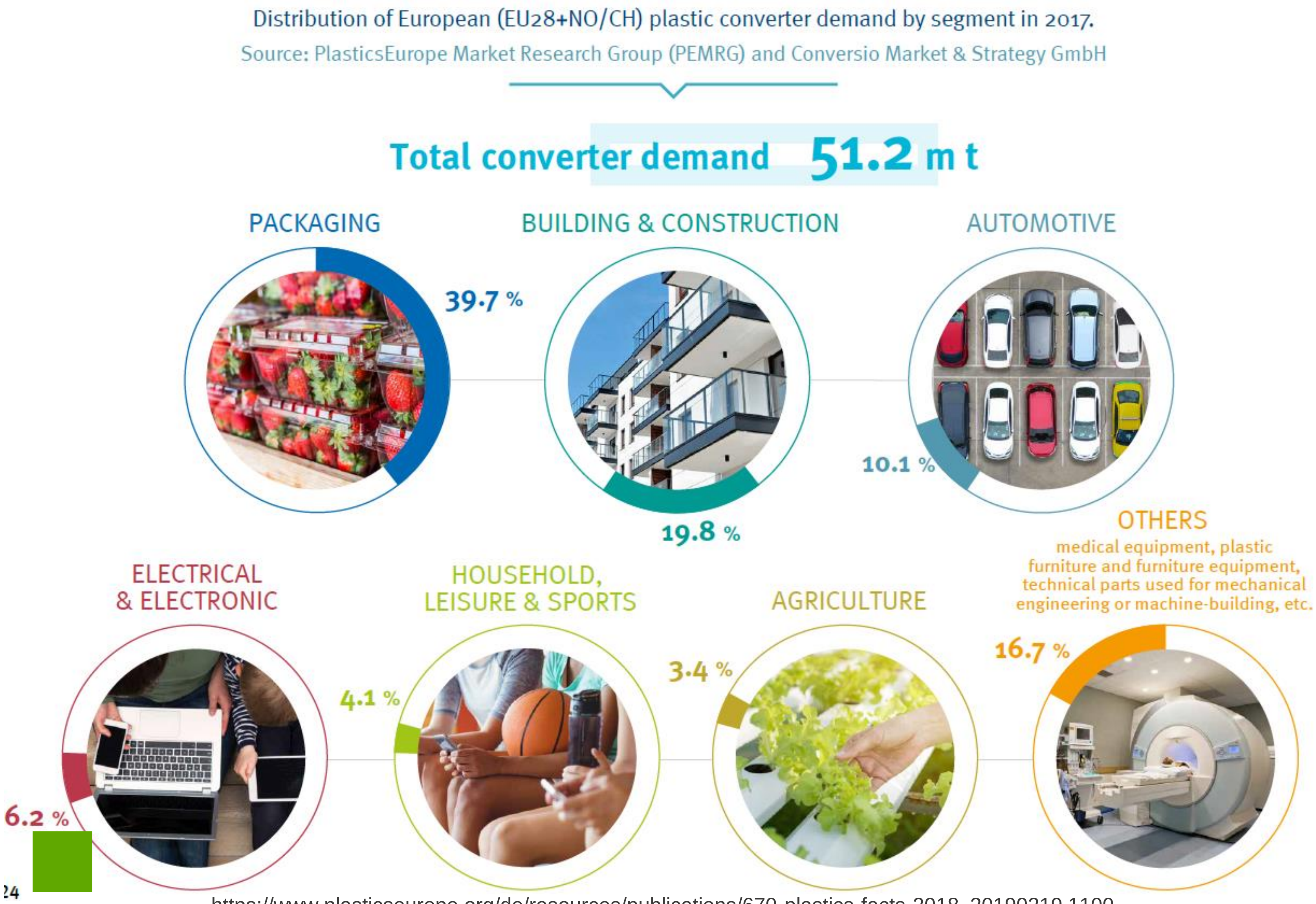
Where do we use plastic?



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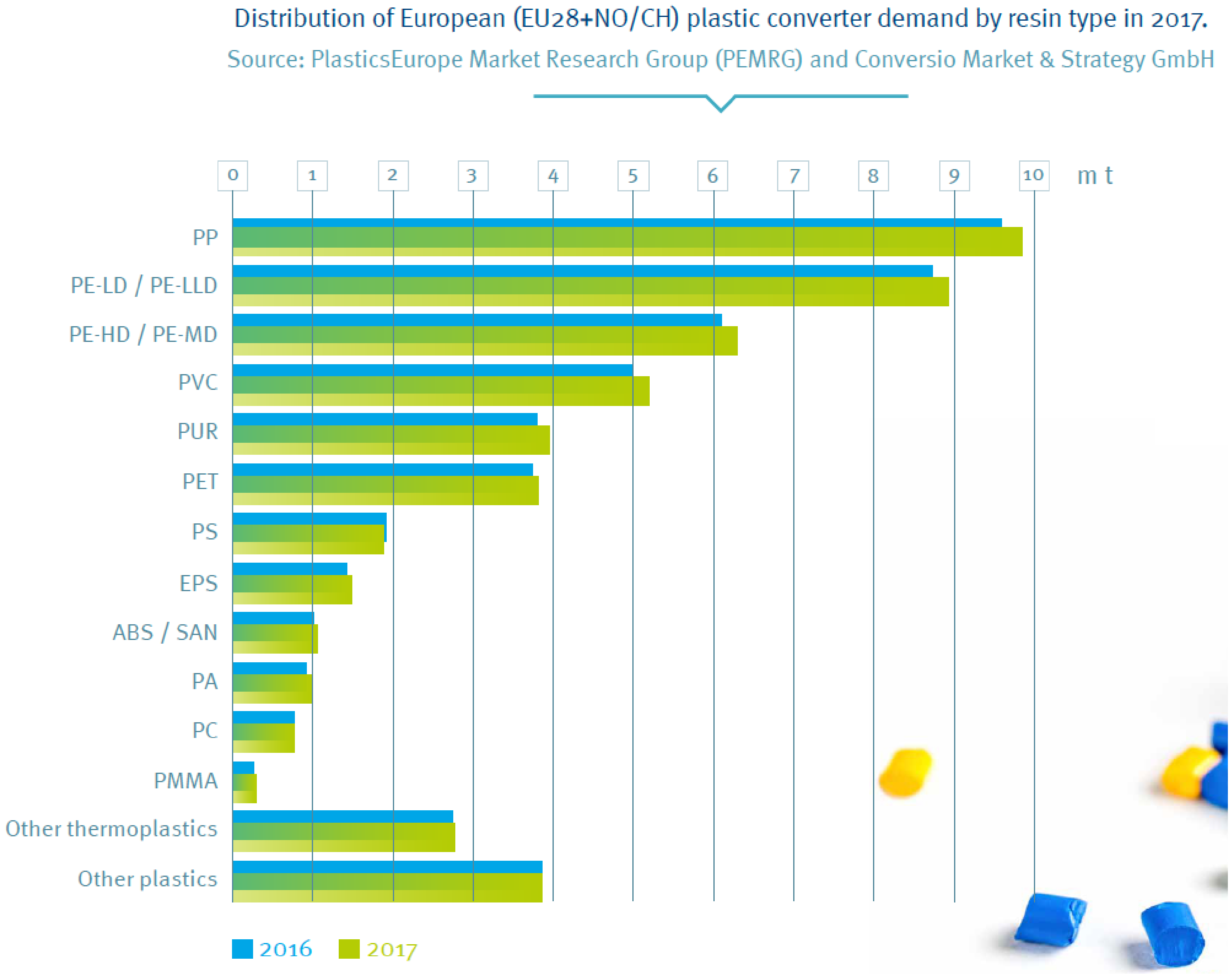
Which plastic?



https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

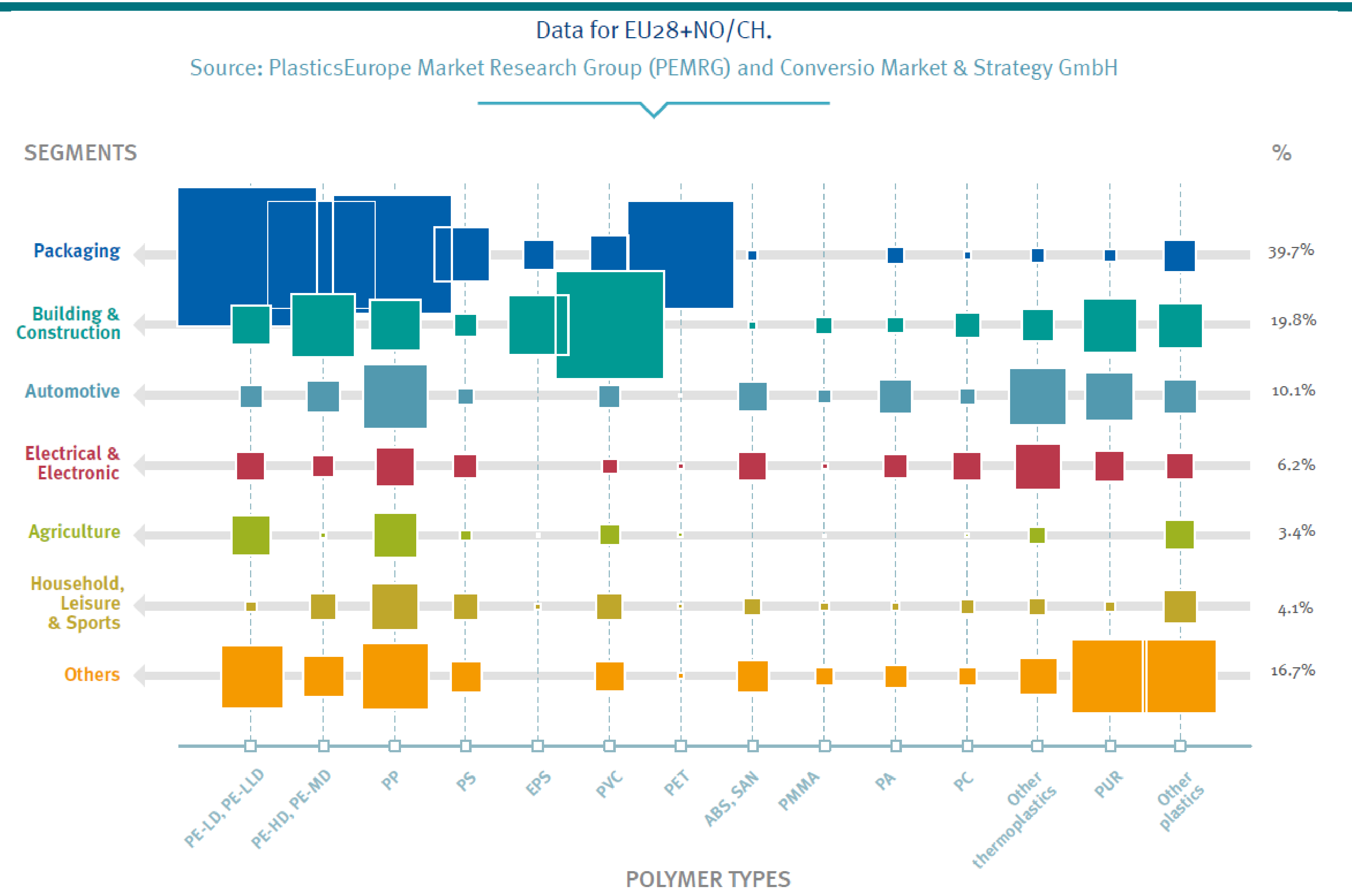
Standard plastics

Data for EU28+NO/CH.

Source: PlasticsEurope Market Research Group (PEMRG) and Conversio Market & Strategy GmbH

https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

Segments and plastic types 2017



https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

What do we do with the waste?

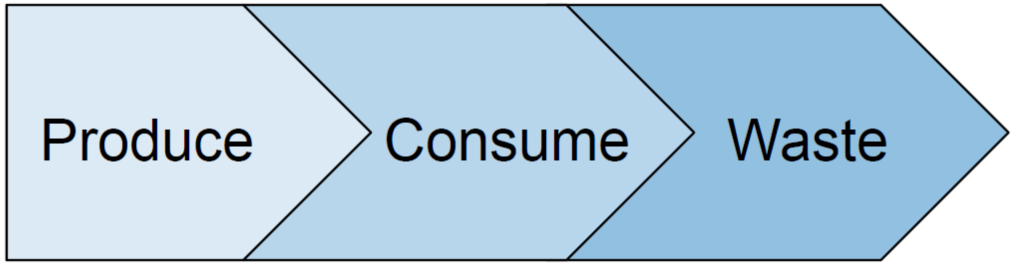
From life to waste

https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

Linear economy

PLASTICS VS. PAPER IN HISTORICAL PERSPECTIVE

- **1980 :**
  - Both 100% linear



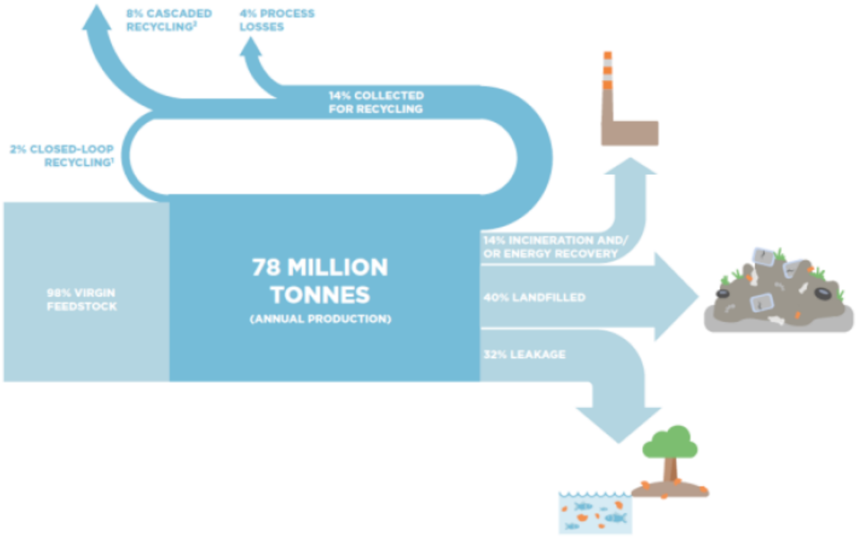
  - Plastics : inherent circularity promise ! *(« thermoplastic»)*
  - Paper : very bad image :
    - single use – littering – destroying nature – reducing oxygen in atmosphere…

Herman Van-roost, CIRCULAR PLASTICS : A NEW ROLE FOR VIRGIN POLYMER PRODUCERS, Circular Economy Stakeholders Conference Plastics Strategy Session, Brussels, March 9th 2017

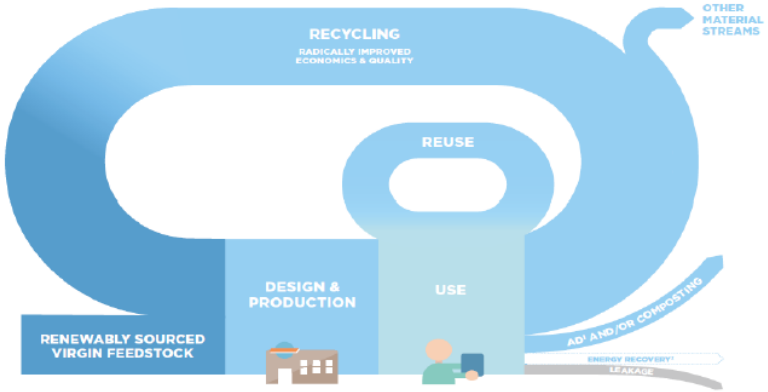
Circular economy

2017 :

- Plastics : ~9% circular
  - Growth by linear expansion
  - Bad image (packaging) : single use – littering – destroying nature – CO_2 in atmosphere…

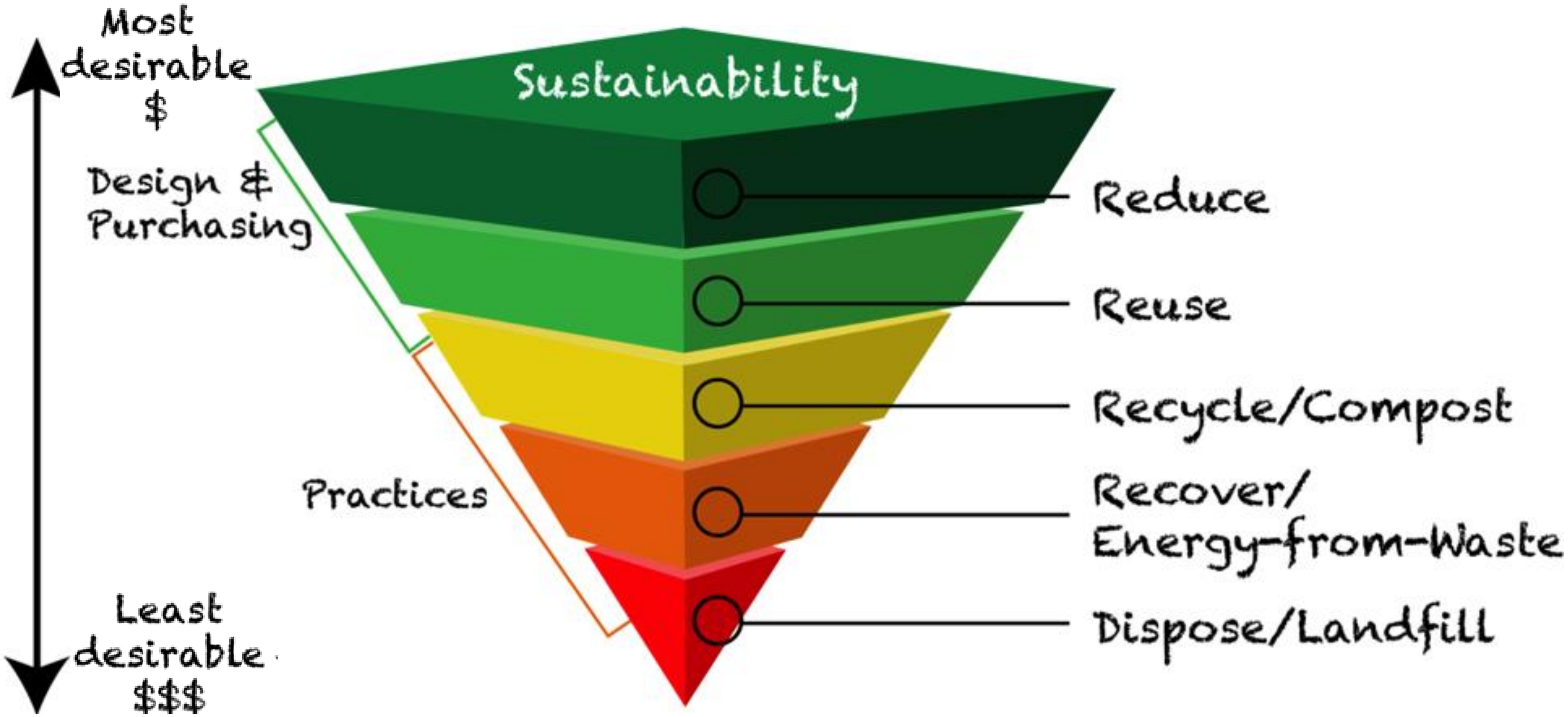


- Paper : ~70% circular
  - Growth by increased circularity
  - Not without issues, but certainly one of the best accepted materials



Herman Van-roost, CIRCULAR PLASTICS : A NEW ROLE FOR VIRGIN POLYMER PRODUCERS, Circular Economy Stakeholders Conference Plastics Strategy Session, Brussels, March 9th 2017

Basic options for waste

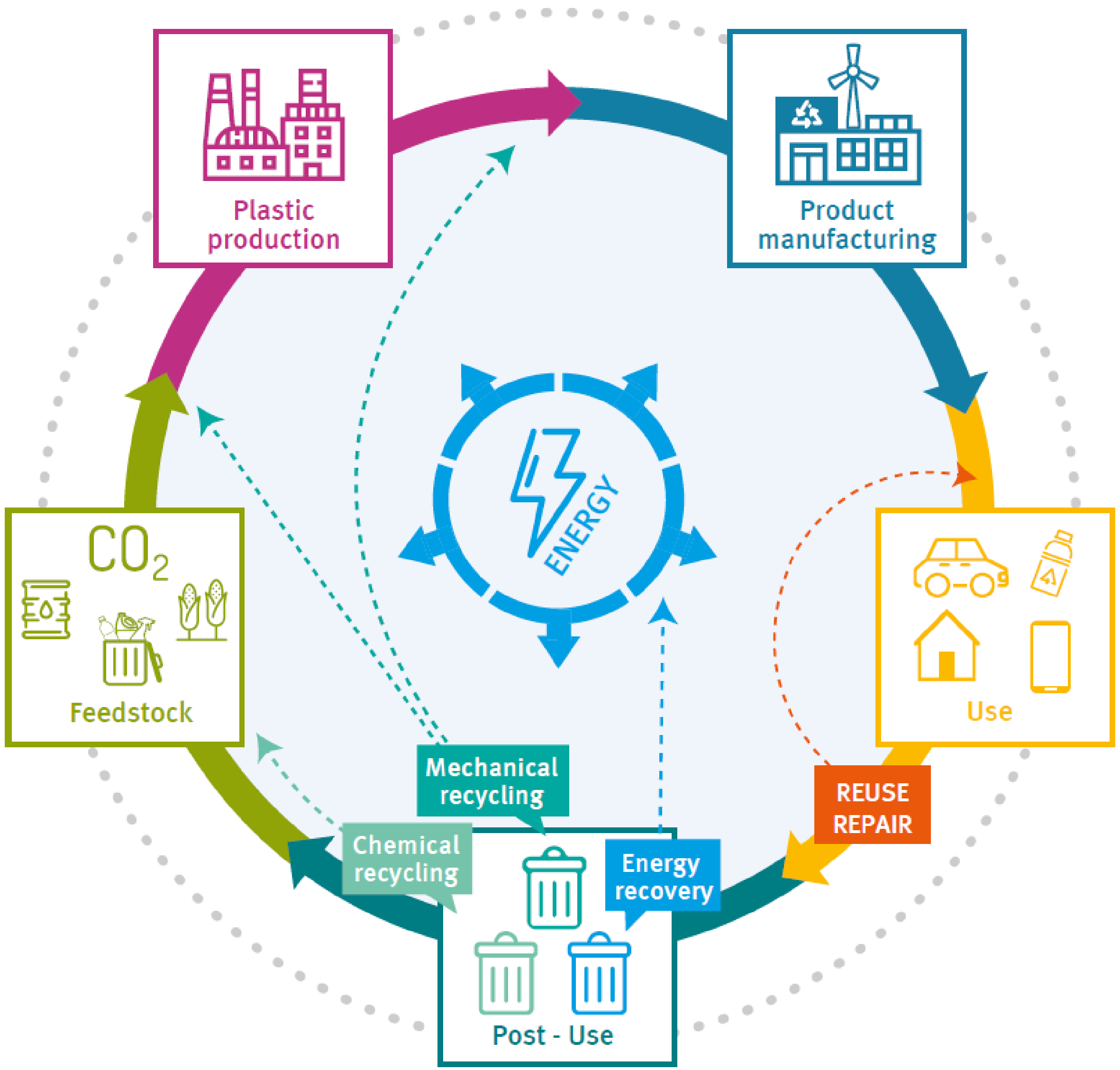


Once it goes to waste, the options are (in order of preference):

1. Recycle
2. Energy recovery
3. Landfill

K. Ragaert, et al., Lecture, UGent, 2018

Circular economy

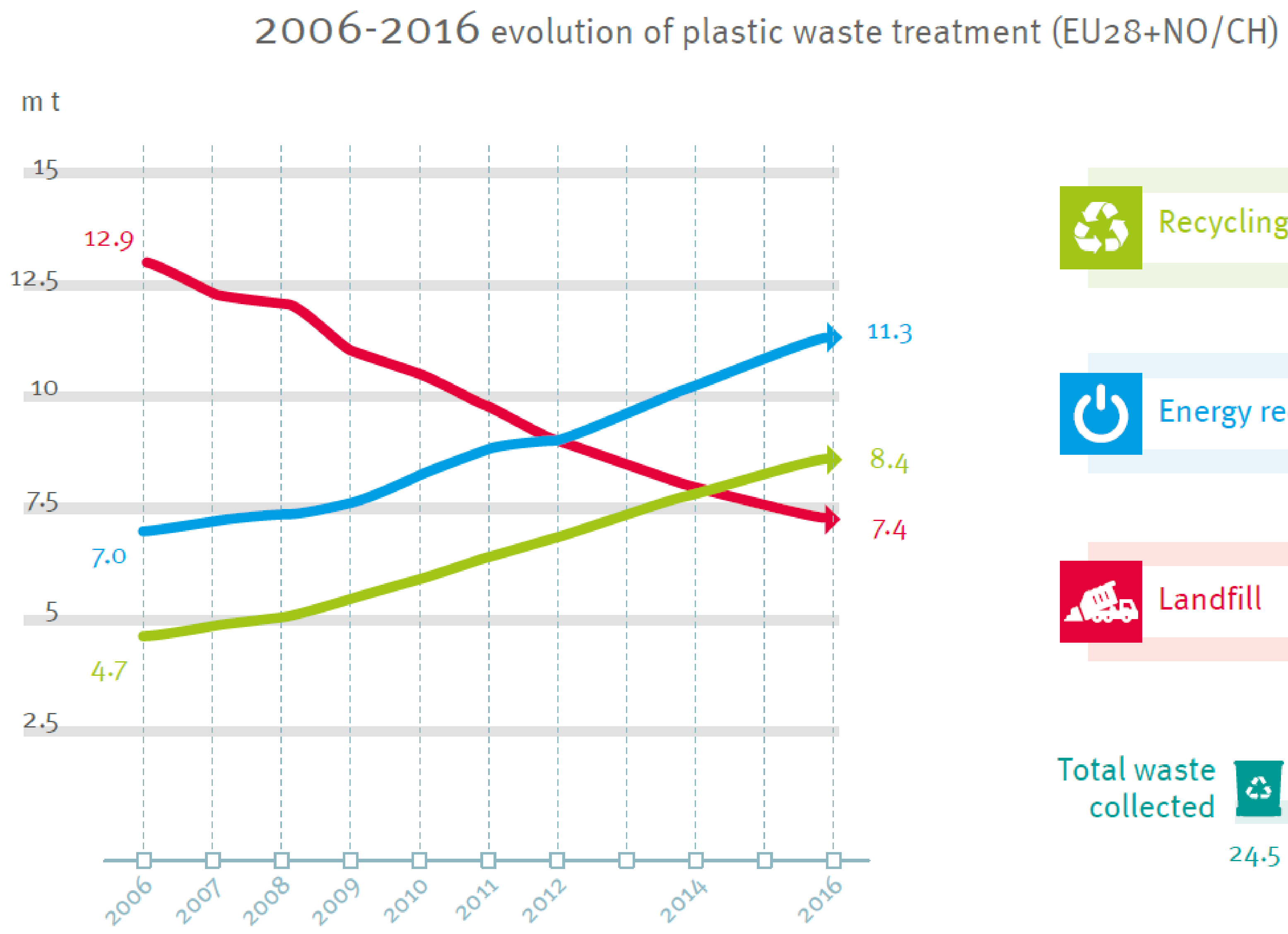


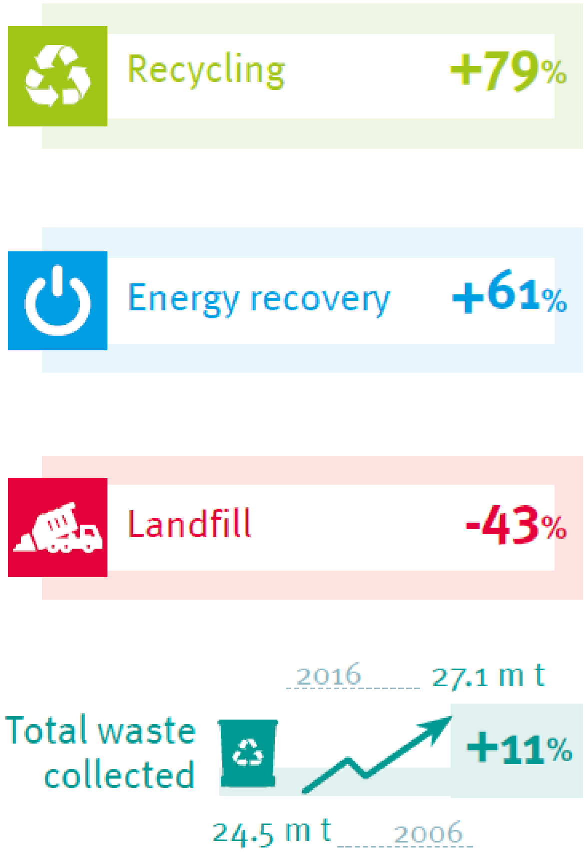
Plastics make a very **efficient use of resources,** especially during **the use phase**

At the end of their life, PLASTICS are still very **valuable resources** that can be transformed into **new feedstock** or into energy

https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

Impressive development





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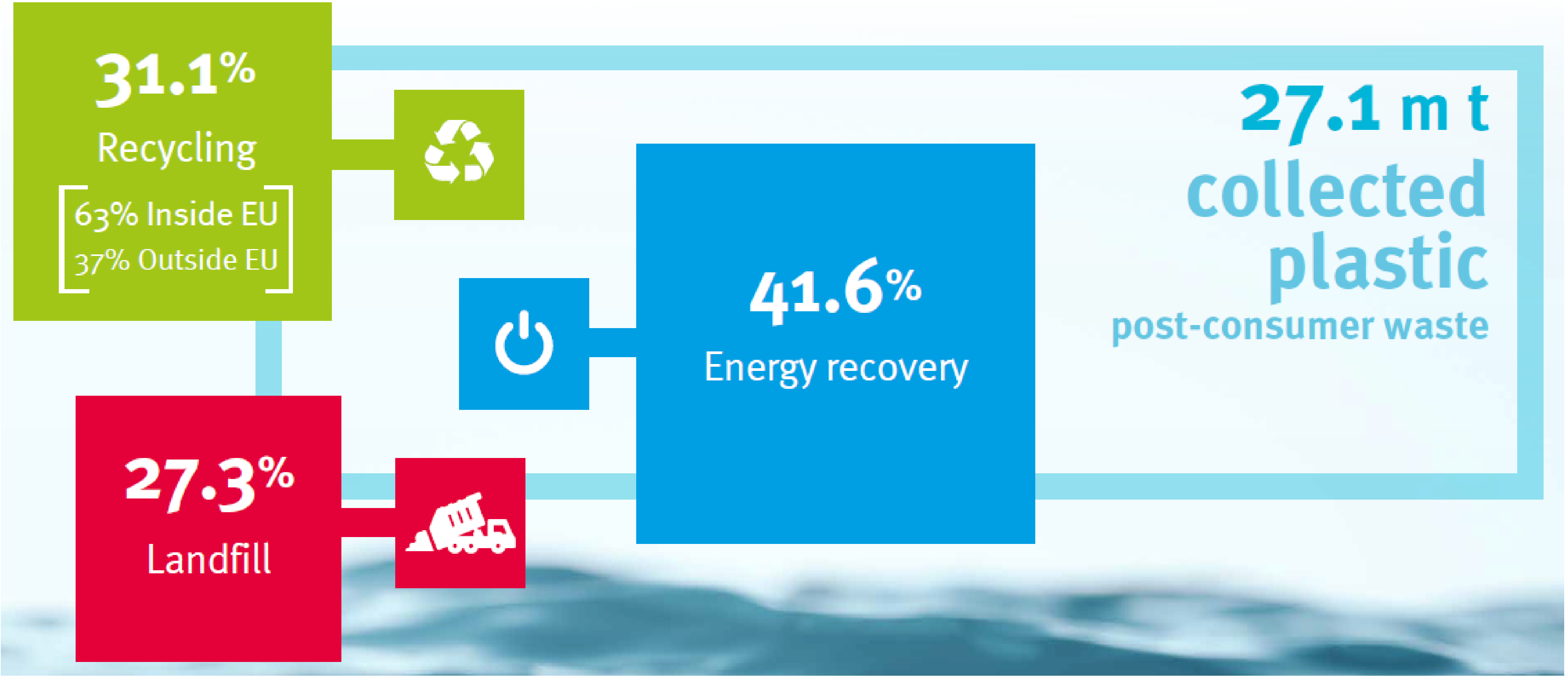
Post consumer

Plastic post-consumer waste treatment in 2016 (EU28+NO/CH)



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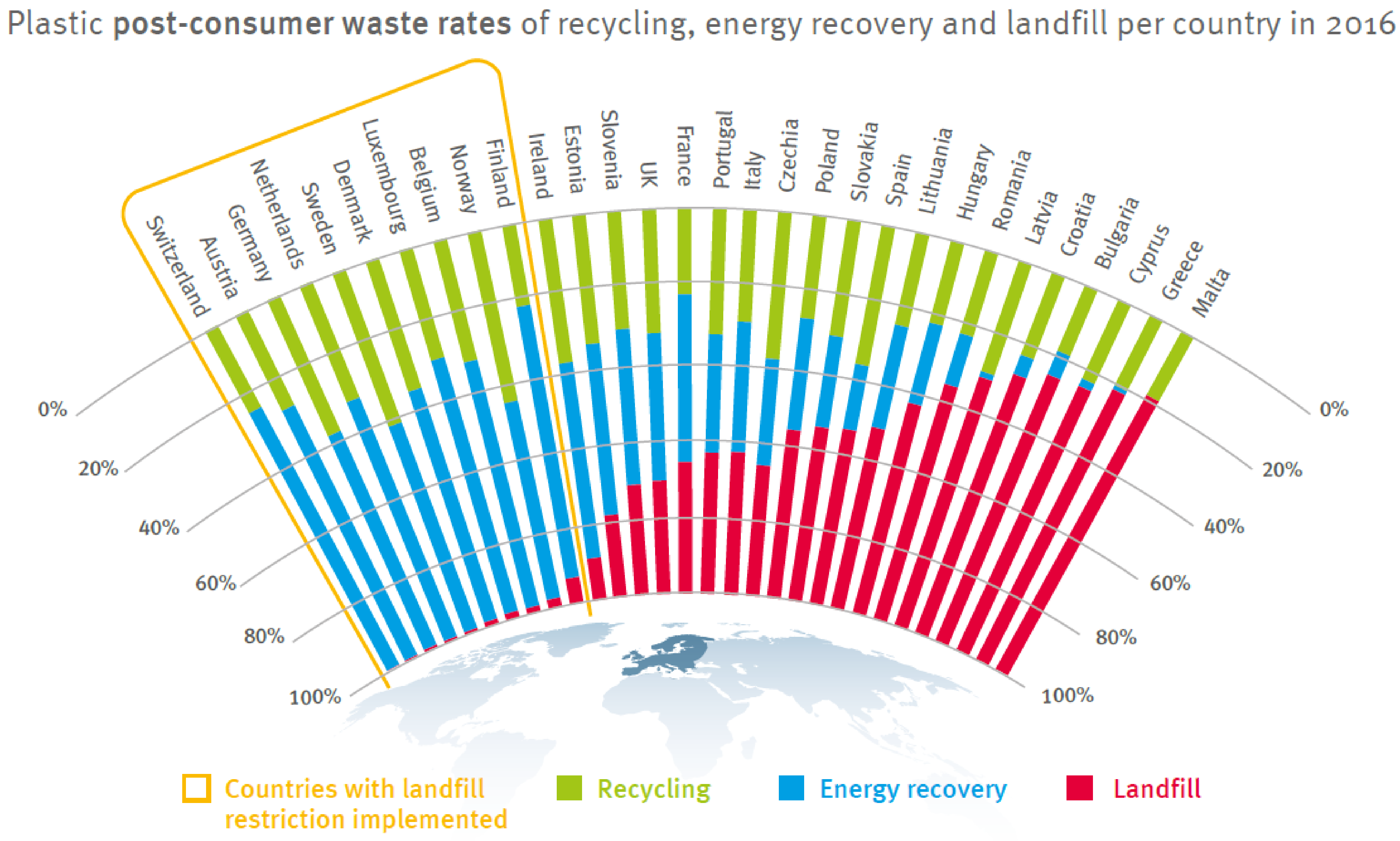
Landfill ban



https://www.plasticseurope.org/de/resources/publications/670-plastics-facts-2018, 20190219 1100

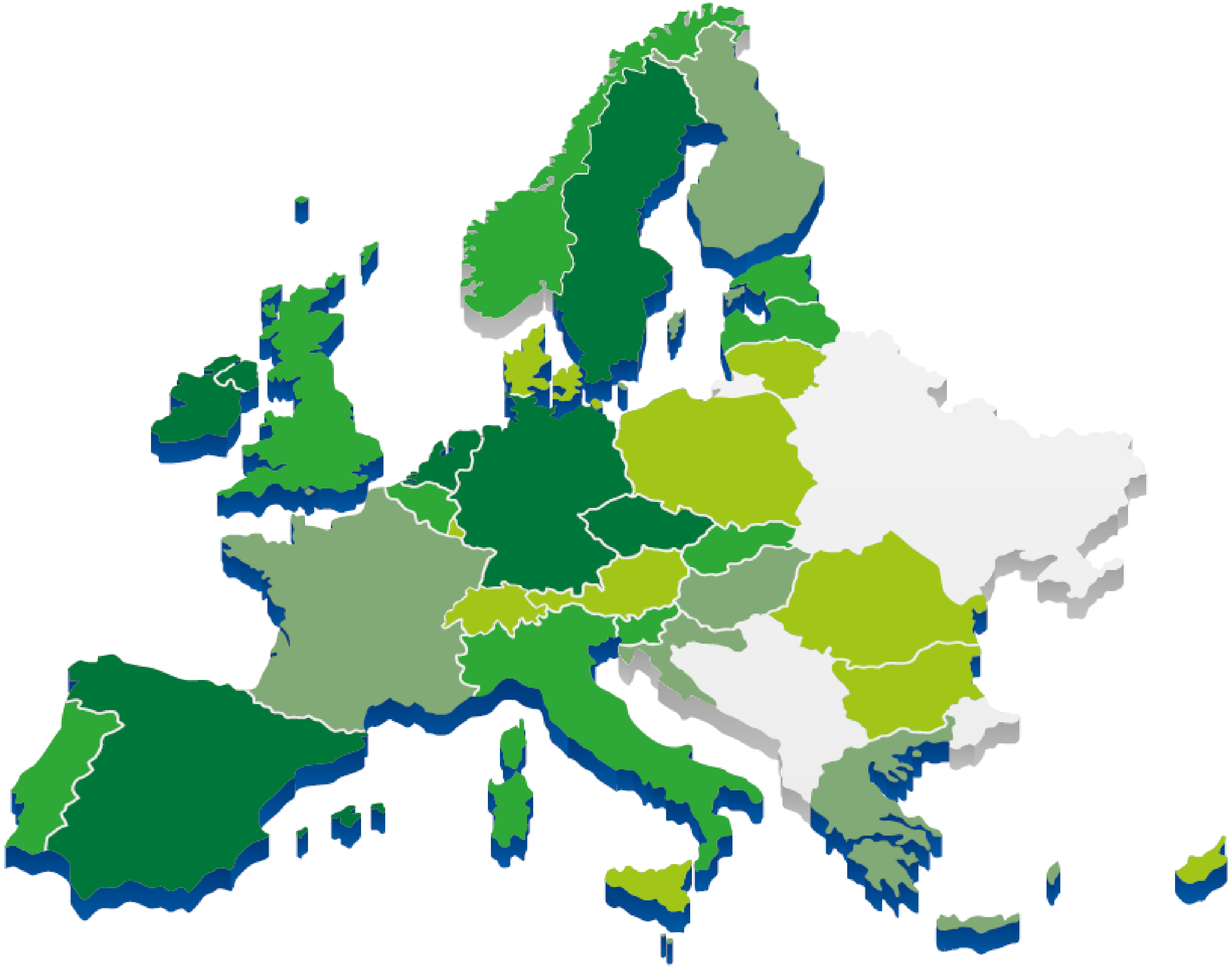
Packaging recycling rates in Europe

More than 45%

From 40 to 45%

From 30 to 40%

Less than 30%



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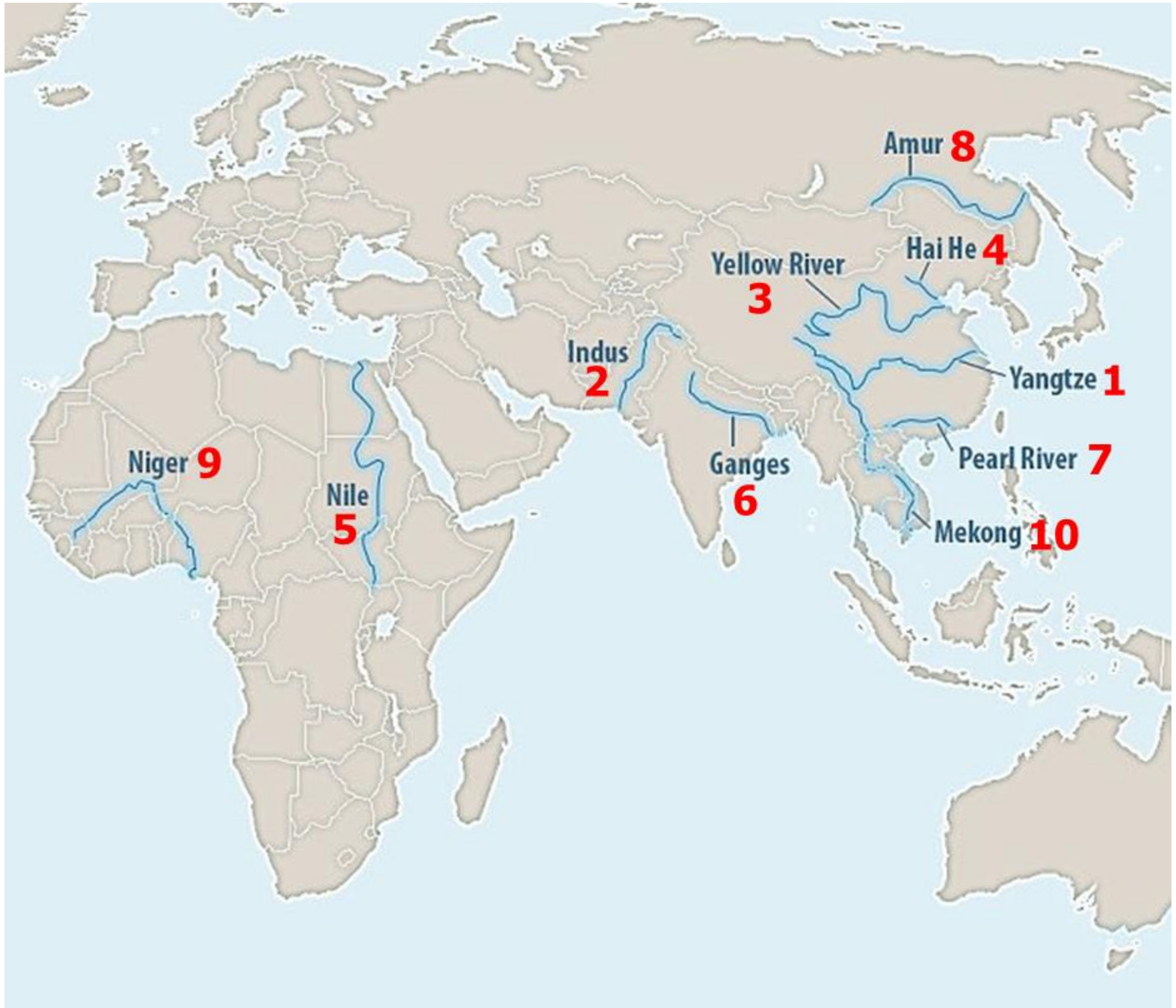
Mismanagement of waste

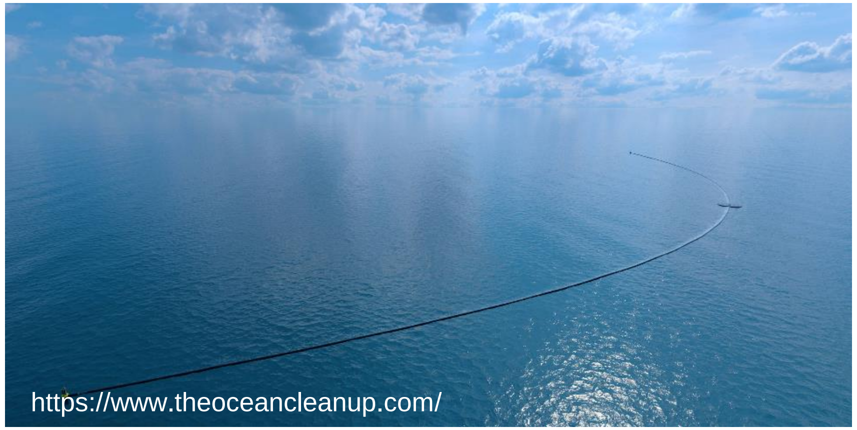


- 95% of plastic polluting the world‘s oceans pours in from just ten rivers
- 8 million tonnes of plastic per year found in the ocean = 1 truckload per minute
- More plastic than fish estimated for the year 2050

http://www.dailymail.co.uk/sciencetech/article-4970214/95-plastic-oceans-comes-just-TEN-rivers.html?ito=facebook_share_article-factbox#mol-106768a0-a208-11e7-8b31-ebd62c4a1e29

Plastics in the oceans

- Ten rivers carry by far the most plastic waste into the sea.
  (Helmholtz Centre for Environmental Research in Leipzig and the Weihenstephan-Triesdorf University of Applied Sciences)
- The scientists evaluated data on the pollution of 1350 rivers worldwide.
- 8 Asian rivers, in 1st place Yangtze, 2nd Indus, 3rd Yellow River (Huang He).
  Non-Asian: Nile and Niger.
- Absurd: Ocean cleanup!



https://www.theoceancleanup.com/

Süddeutsche Zeitung, 13.10.2017

Motivation for recycling

IKEA

- From the plastic bottle to the kitchen front – promotion to be sustainable

DM

- Children´s laughter with empty plastic bottles

Helfen Sie mit, Rutschen für das SOS-Kinderdorf zu bauen: Mit Ihren aufgebrauchten Fa Produkten.

Beiträge Produkte Kommentare

Gefällt mir 44 Twittern G+ Teilen 0

Wer denkt, dass leere Plastikflaschen in den Müll gehören, irrt. Denn dm verarbeitet aufgebrauchte Plastikprodukte weiter: Zu Rutschen für das SOS-Kinderdorf.

https://www.meindm.at/baby-eltern/beitrag/Plastikflaschen-spenden-und-Kindern-Freude-bereiten-dm-Online-Shop/

Stabilo

- Screw caps to highlighters

Gemeinsames Recycling-Projekt von STABILO, Coca-Cola und Interseroh

https://www.recyclingnews.info/recycling/schraubverschluesse-zu-textmarkern/

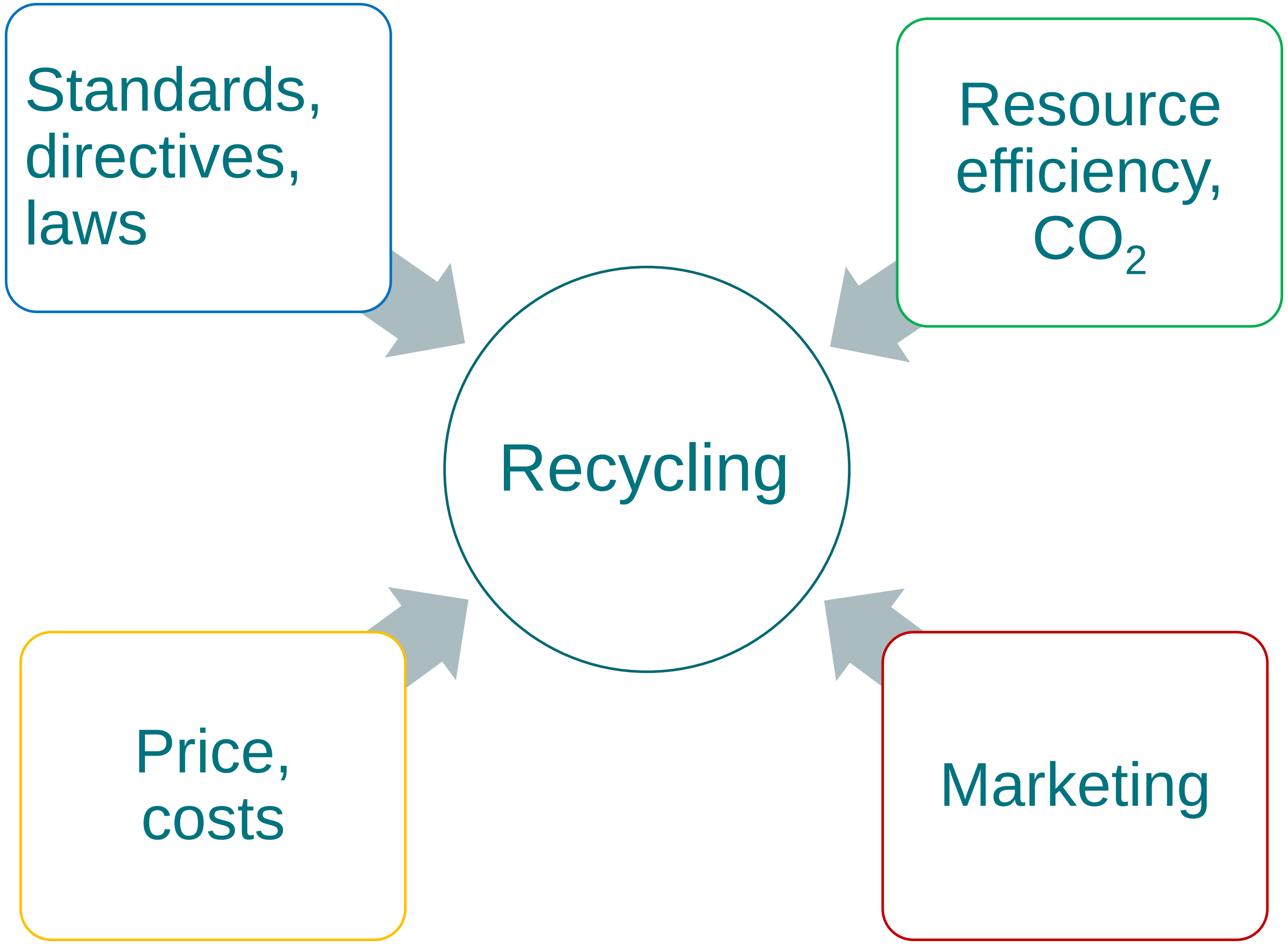
Successful examples as Stimuli!

TRODAT PRINTY 4912
Source: http://www.trodat.net

- Project Rec2TecPart
- Recycling of technical polymers (POM)

- Example of office printer:
  - Upcycling of PCR plastic
  - Up to 65% recycling material
  - Change of approach:
    - **Recycled material does not need to be equal to original material, but has to fulfill product requirements!**

Motivation for recycling



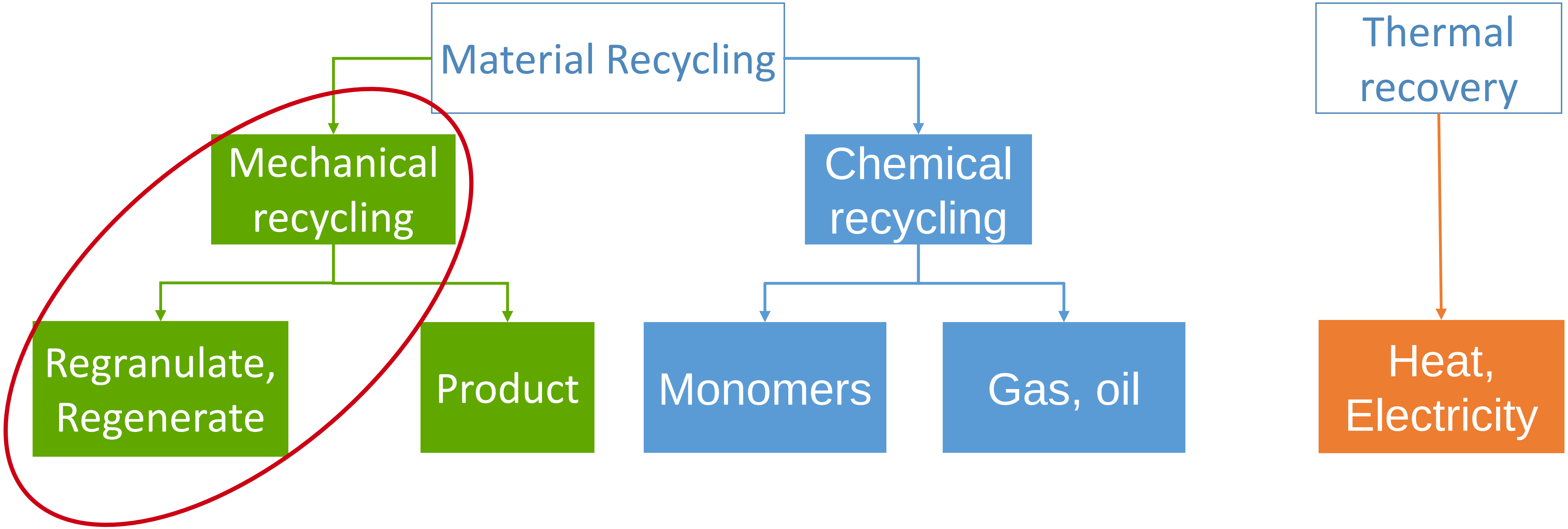
Why recycling?

- Reduction of petroleum consumption and CO_2 generation
- Stop landfilling
- Stop polluting human resources
- Proportion of plastics in the waste is only 15 w.-%, but more than 50 vol.-%
- 40% of all plastics products have a lifetime < 1 year
- More than 1 million plastic bottles are sold every minute, but fewer than half of them are recycled
- …

http://www.dailymail.co.uk/sciencetech/article-4970214/95-plastic-oceans-comes-just-TEN-rivers.html?ito=facebook_share_article-factbox#mol-106768a0-a208-11e7-8b31-ebd62c4a1e29, 10.6.2018

Recycling technologies

Ways to recycle



Mechanical recycling

Regeneration of recyclates

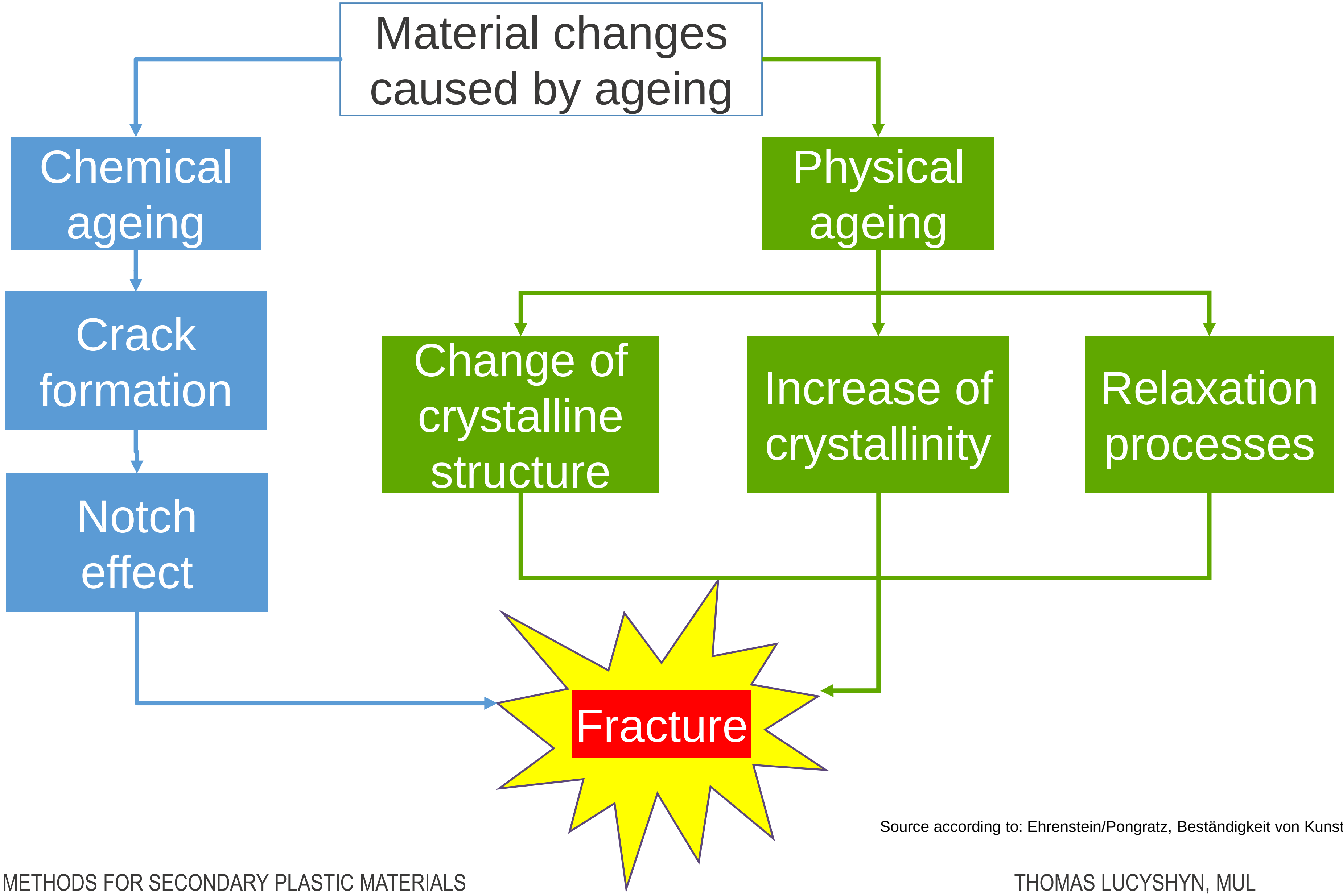
- Why regeneration? Where is the problem?
  - Polymers coming from waste have a „history“

- What are the reasons?
  - Properties of polymers are taylor-made and optimized to a high degree
  - Desired properties achieved by adding various additives and stabilzer systems → those are „consumed“ when processed multiple times
    → material properties are changing
  - Ageing
    - The total of chemical and physical changes resulting in changed mechanical properties → reduction of applicability
    - Internal and external ageing effects

Internal and external ageing

- Internal ageing:
  - Thermodynamic instabilities within the material, which are affected by heat
  - Examples:
    - Incomplete polycondensation
    - Instable crystallization states
    - Immiscibility of polymers and plasticizers
    - Internal stresses (due to inhomogenous densities, molecular orientations)
- External ageing:
  - Chemical and physical influences from environment
  - Material surface often in contact with oxygen and moisture → reactions with oxygen are often dominant processes
  - Examples:
    - Weather, ionising radiation, heat, chemicals, biological media

Chemical and physical ageing



Source according to: Ehrenstein/Pongratz, Beständigkeit von Kunststoffen, Band 1, Hanser 2007

Chemical ageing

- All processes causing a change in the following material properties:
  - chemical composition
  - molecular structure
  - molecular weight

- **All of these processes are irreversibel!**

- Examples:
  - Oxidation, degradation, hydrolysis, post condensation, post polymerization

Chemical ageing

- Weak points of polymers are their macromolecular architecture and weak bonding forces

- Changes can be classified into 3 groups:
  - Changes of molecular architecture (reduction of molecular weight and change of molecular weight distribution, cross-linking and branching)
  - Forming of functional (chemically active) groups
  - Splitting off low molecular weight components (depolymerization, splitting off of side groups)

Chemical ageing

- Changes can have dramatic effects on mechanical properties
- Furthermore, color changes and nasty odors can result
- Changes of optical appearance
- Example:
  - Reduction of molecular weight affects mechanical and rheological properties

$$\eta_0 = K \cdot M_w^{3.4}$$

Physical ageing

- All processes changing the morphology, molecular orientation, component concentration, external shape or surface appearance or measurable physical properties

- **All of these processes are reversibel!**

- Examples:
  - Relaxation, post crystallization, phase separation, migration of plasticizers, agglomerations (e.g. blooming of additives on surface)

Physical ageing

- Often combined with changes of physical structure and dimensions
- Creation of stresses inside the material → cracks and fractures
- Changes of water and oxygen diffusion due to changes in crystallinity and orientations → acceleration of chemical ageing

Influence of temperature on ageing of polymers

- Temperature has an accelerating effect on chemical and physical reactions (exponential effect according to Arrhenius)
- Three cases:
- Thermal degradation
  - Chain scission (reduction of molecular weight)
  - Depolymerization (creation of monomers)
  - Separation of side groups (for weak bondings)
  - Cross-linking (at rather low temperatures)
- Thermo-oxidative degradation
- Thermo-mechanical degradation

What is happening during (re-)processing?

- Ageing is strongly connected to processing, as chemical and physical structure is influenced by processing conditions

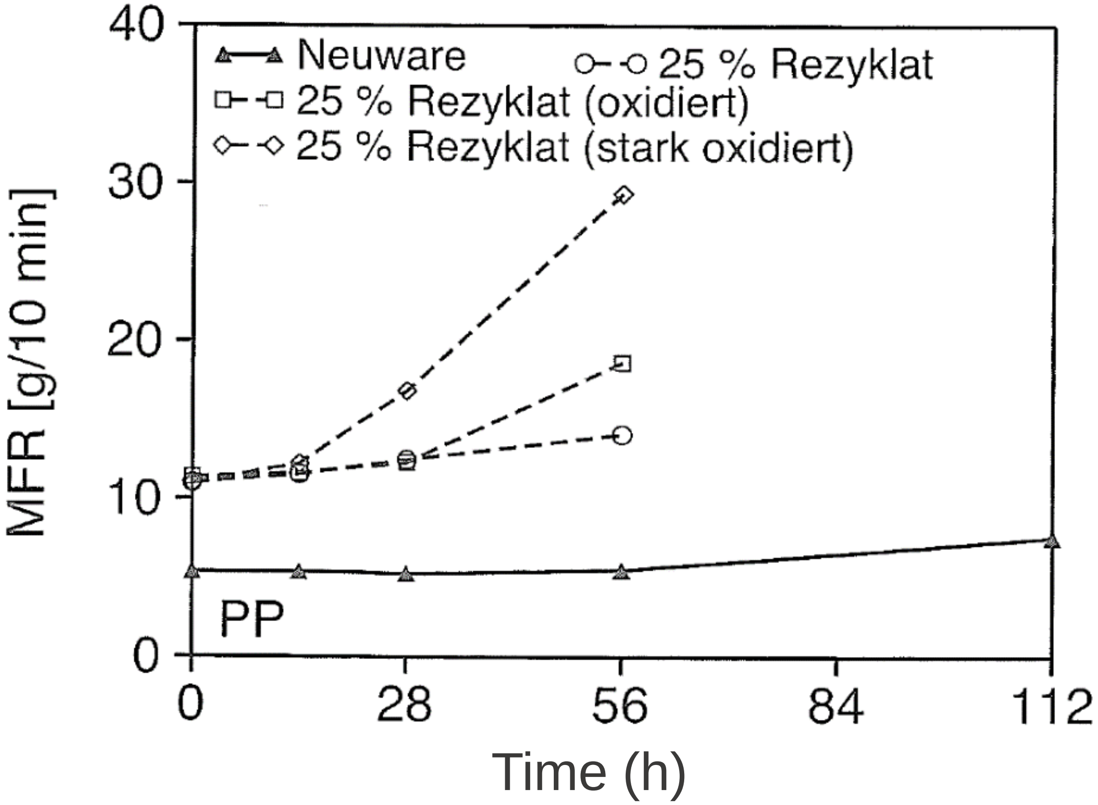
- Mainly chemical ageing: elevated temperatures + oxygen are the fiercest enemies of polymers

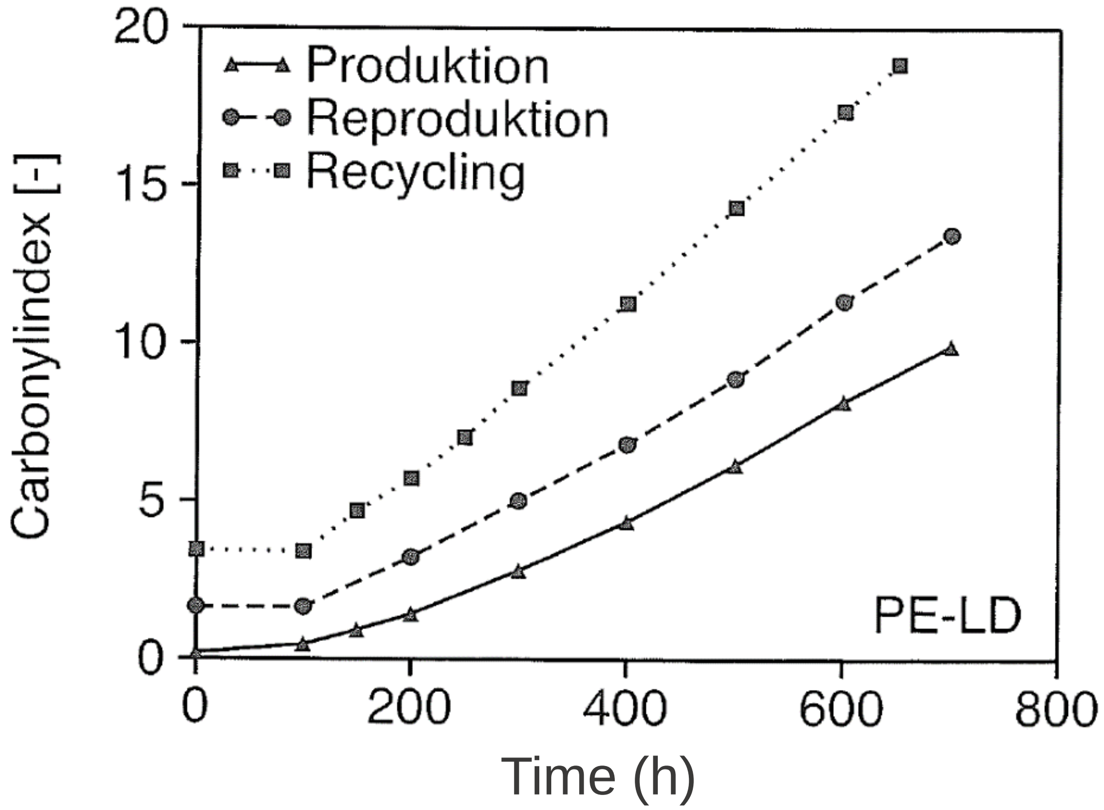
- Physical ageing is not happening during processing, …

- … but physical structure is influenced and thus subsequent physical ageing processes

What can we do about ageing??

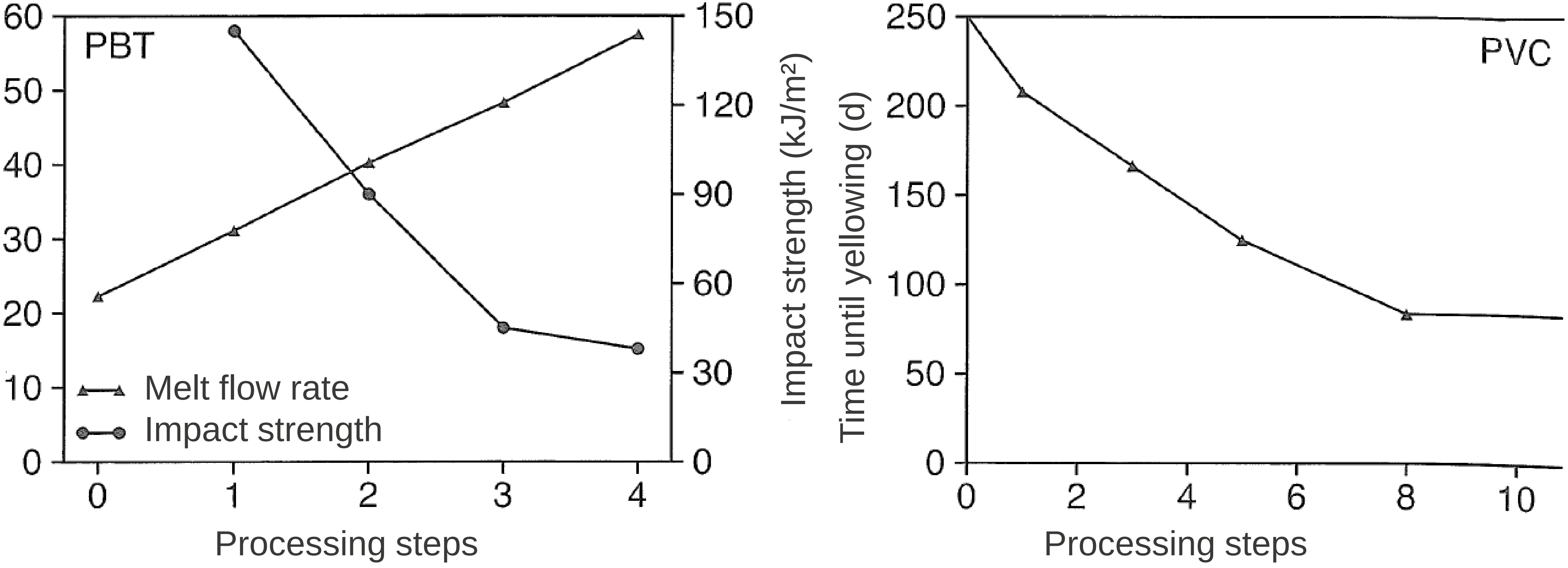
- Stabilization/additivation is the key!
- Why? – loss of properties due to processing and ageing





Source: Ehrenstein/Pongratz, Beständigkeit von Kunststoffen, Band 1, Hanser 2007

Reduction of properties during (re-)processing



Source: Ehrenstein/Pongratz, Beständigkeit von Kunststoffen, Band 1, Hanser 2007

Stabilizing of recycleate

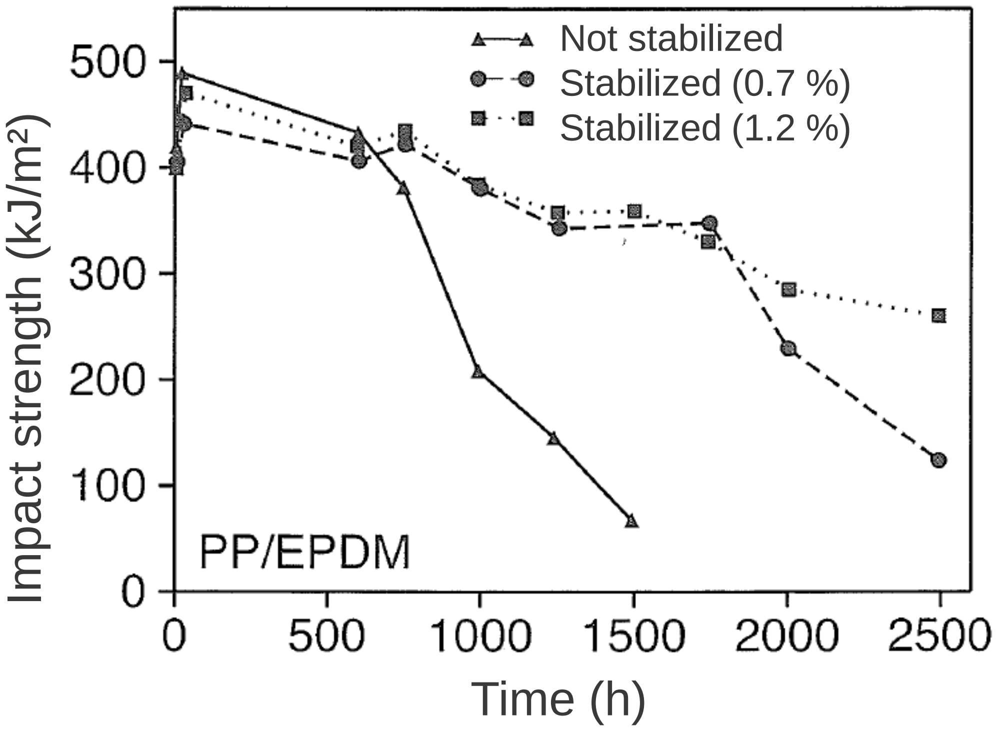
- Suitable additives are necessary:

Polymeric additives	**Virgin material** **Modifiers (impact)** **Compatibilizers**
Reinforcements	**Fibers (glass, cellulose)** **Fillers (talcum, wollastonite, calcium carbonate, wood flour)**
Functional additives	**Pigments** **Processing aids (lubrication)** **Rheology modifiers** **Stabilizers (processing, heat, light)** **Reactive molecules (increase of molecular weight)**

Quelle: Ehrenstein/Pongratz, Beständigkeit von Kunststoffen, Band 1, Hanser 2007

Stabilization of recyclates

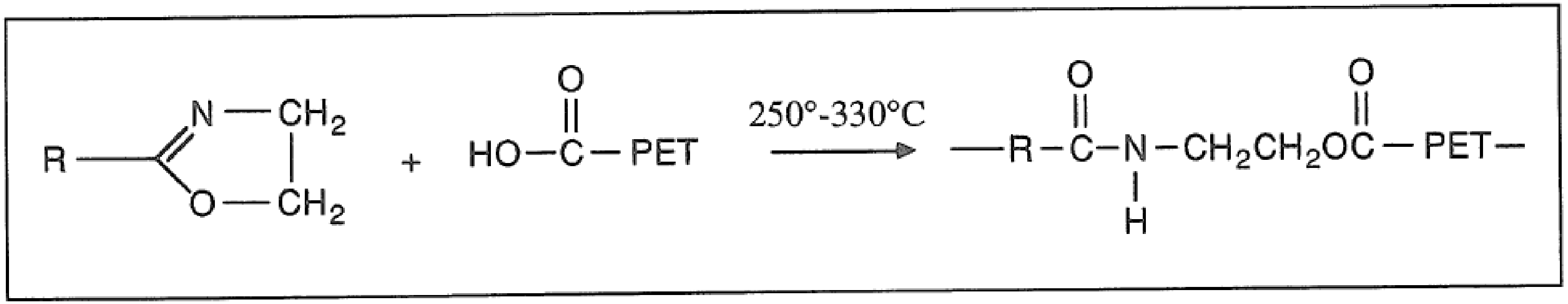
- Stabilizers and additives have to be replaced at least in the quantity as in the original material – but mostly even more
- Example: Use of stabilizers for a recyclate for car bumpers



Source: Ehrenstein/Pongratz, Beständigkeit von Kunststoffen, Band 1, Hanser 2007

Stabilization of recyclates – chain extenders

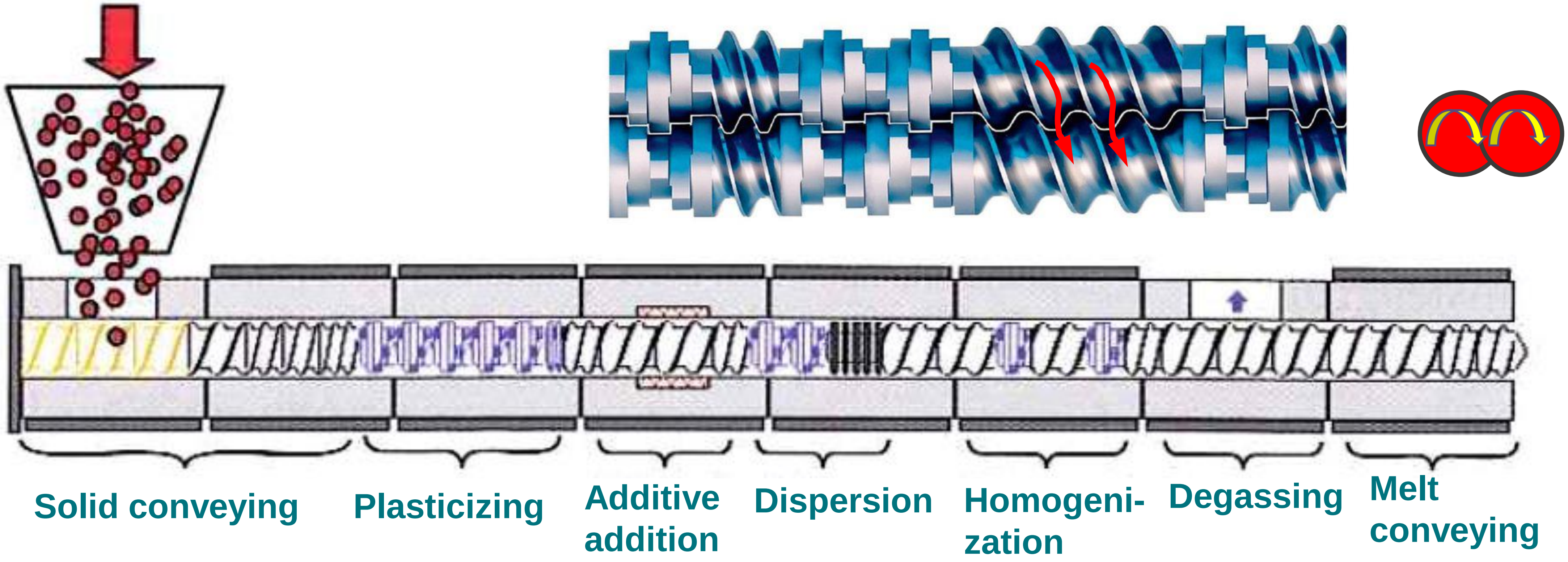
- Functional additives
- Example: chain extenders for PET
- Polyfunctional compounds which can react with the carboxylate group of PET → increase of molecular weight
- Reaction temperatures of 250 – 330°C



Source: John Scheirs, Polymer Recycling, Wiley Series 1998

How do we get all of this staff into the polymer?

- Compounding
- Compounders are co-rotating twin-screw extruders → mixers



Other recycling routes

Chemical recycling

- For heterogeneous, strongly contaminated plastics and blends
- Production of petrochemical base substances
- *Gasification*
  - Oxidation unter oxygen deficiency
  - → synthesis gas (CO, H_2)
- *Cracking*
  - Fission process
  - → Gasoline, fuel oil, liquid gas
- *Hydrogenation*
  - Reaction with H_2 („Coal liquefication“)
  - → fuels

Thermal recovery

- Substitute fuel in
  - Cement rotary kiln
    - Kilning of cement clinkers
  - Waste incinerating plant
    - Throughput reduction due to too high fuel values
    - Limitation to 5 %!

- Recovery of thermal energy
  - Electricity, heat

Energy recovery / thermal recycling

Material	Fuel value in $MJ \cdot kg^{-1}$
Crude oil	42.3
Coal	29.3
Petrol	43.5
Domestic gas	40.3
Polypropylene	44.0
Polyethylene	43.3
Polystyrene	40.0

Bianca Schmitt „Kunststoffe im produzierenden Gewerbe: Vergleichende ökologische Betrachtung verschiedener Verwertungswege im Bilanzrahmen Luxemburg, Diplomarbeit Fachhochschule Trier

Which recycling path is the right one?

Factor process orientated thinking

It is not enough to look at the recycling at the end of the lifetime of plastics, we also have to look at the beginning and the lifetime itself!

Factor waste stream

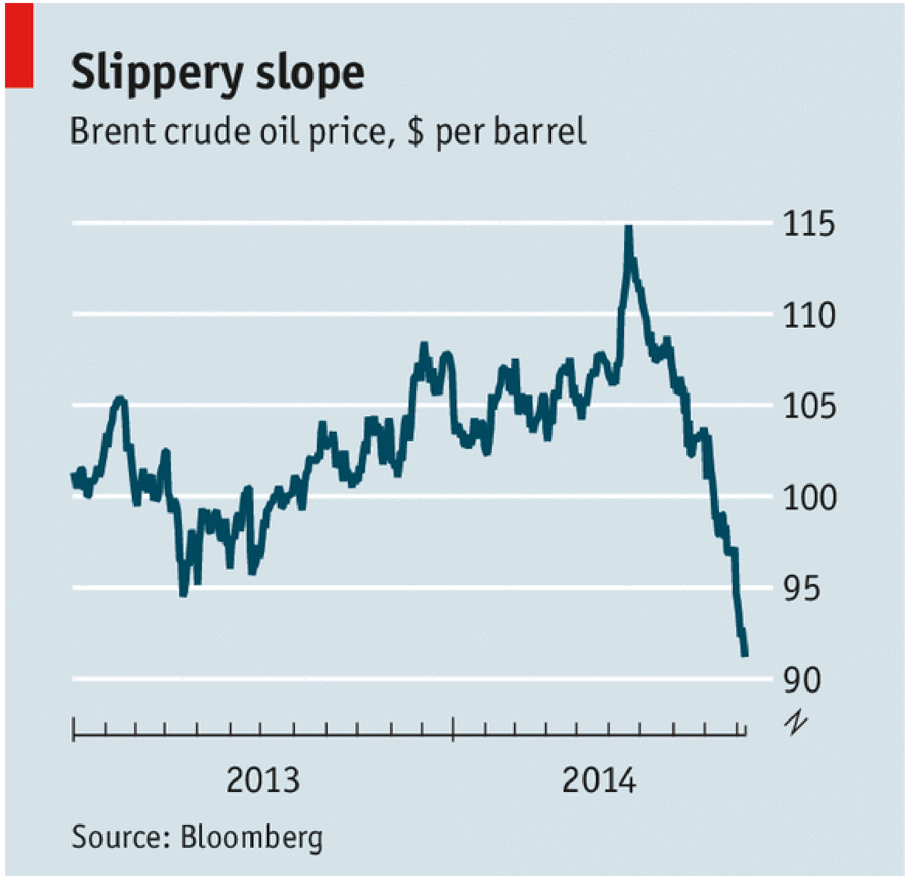
- Post consumer
- Post industrial
- Clean or contaminated (up to 10 m% contaminations!)

- Homogenous material stream
  - PET, PVC
  - Polyolefines

- Heterogeneous material stream (WEEE etc.)
  - Separable
    - Regranulate
    - Regenerate
  - Not separable
    - Chemical Recycling
    - Thermal Recycling
    - Filler

Factor economy

- Price of virgin material is decisive
- Cost structure is crucial (necessity to export)



Evaluation of the best recycling technology

- Depending on
  - Degree of contamination
  - Mono-fraction or multi-fraction
  - Sustainability

- Preferred route: mechanical recycling

- Chemical recycling not yet economical

- Thermal recycling is economical,
  but ecologically positive only in the energy category

Summary

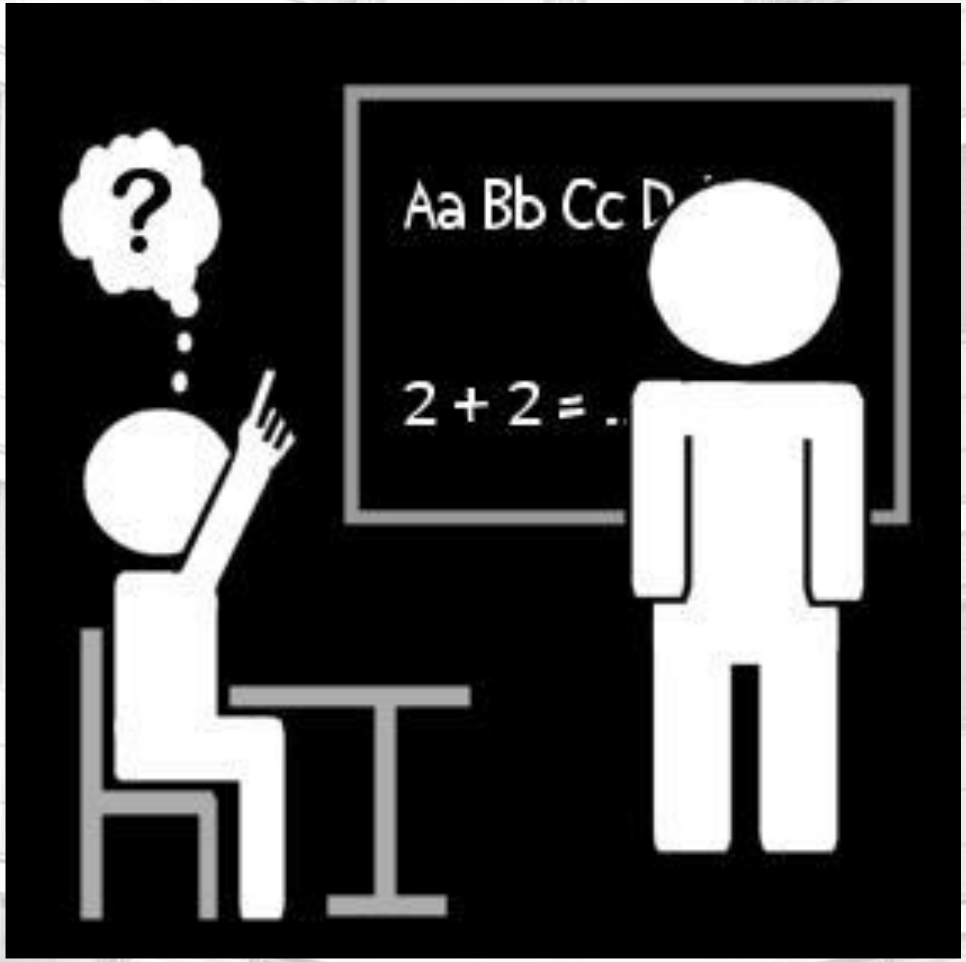
Summary

- Polymers are great materials with a high potential for circular economy
- Make waste accessible to produce raw materials by recycling
- Process thinking
- Recycling-friendly design
- Customer orientation
- Regulation by legislators (trade, export, waste)
- Preferred route: mechanical recycling

Acknowledgement

- Dr. Martin Spörk
- Dr. Matthias Katschnig

who did a great job in helping preparing these slides!



Questions?

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