Energy Recovery Evaluation of Thermochemical Conversion Technologies for Non-Recyclable Plastic Waste

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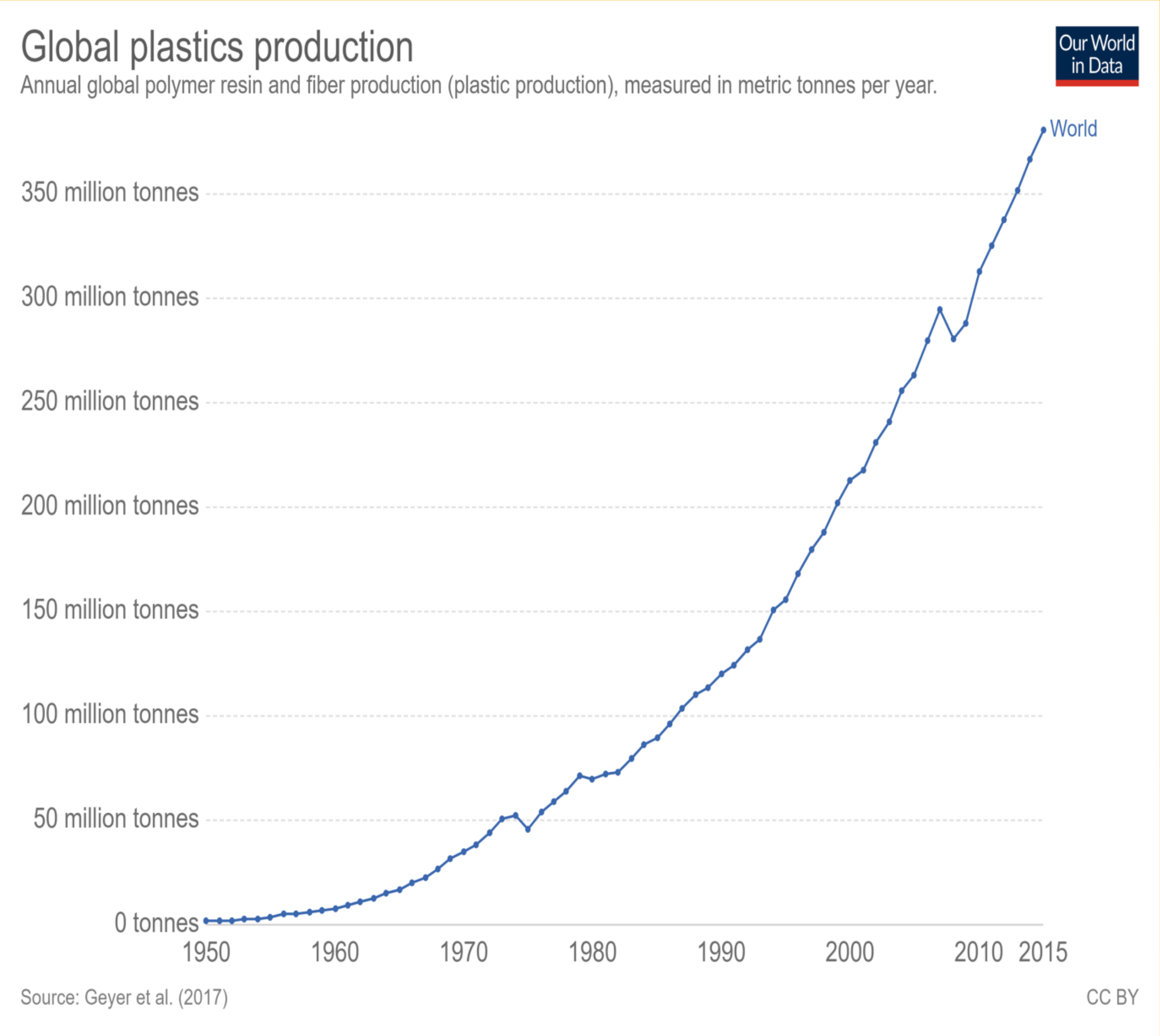

Annual global production of plastics has increased more than 200-fold since 1950.

In 2015 the world produced more than 380 million tonnes of plastic.

For context, this is roughly equivalent to the mass of two-thirds of the world population.

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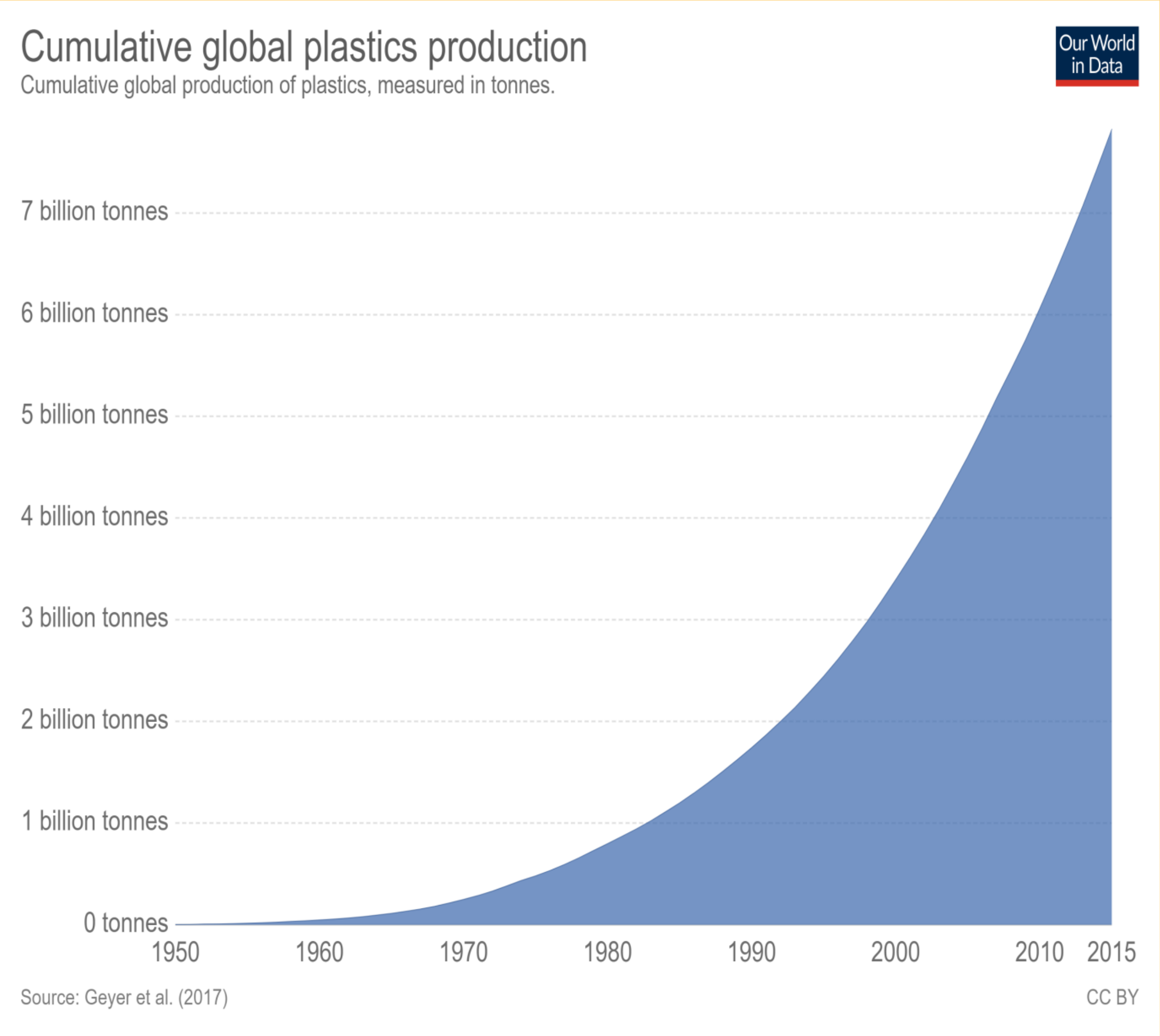

By 2015 **cumulative plastic production** was more than 7.8 billion tonnes.

This is equivalent to more than one tonne of plastic for every person alive today.

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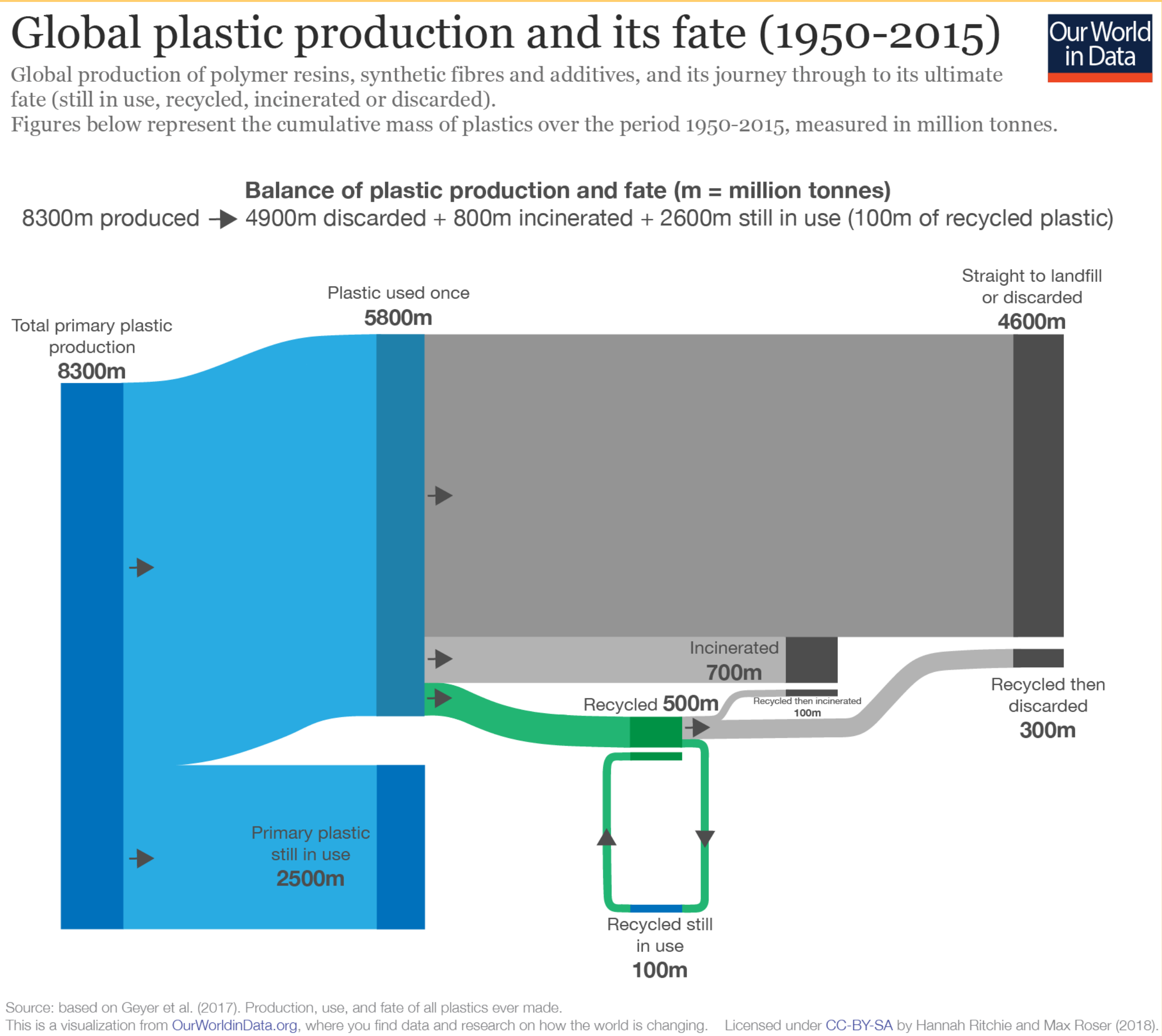

Of the **global plastic produced** over the period from 1950 to 2015:

- 55% straight to **landfill**,
- 30% was still in **use**,
- 8% was **incinerated**,
- 6-7% was **recycled**.

Of 5.8 billion tonnes of plastic no longer in use, 9% was recycled.

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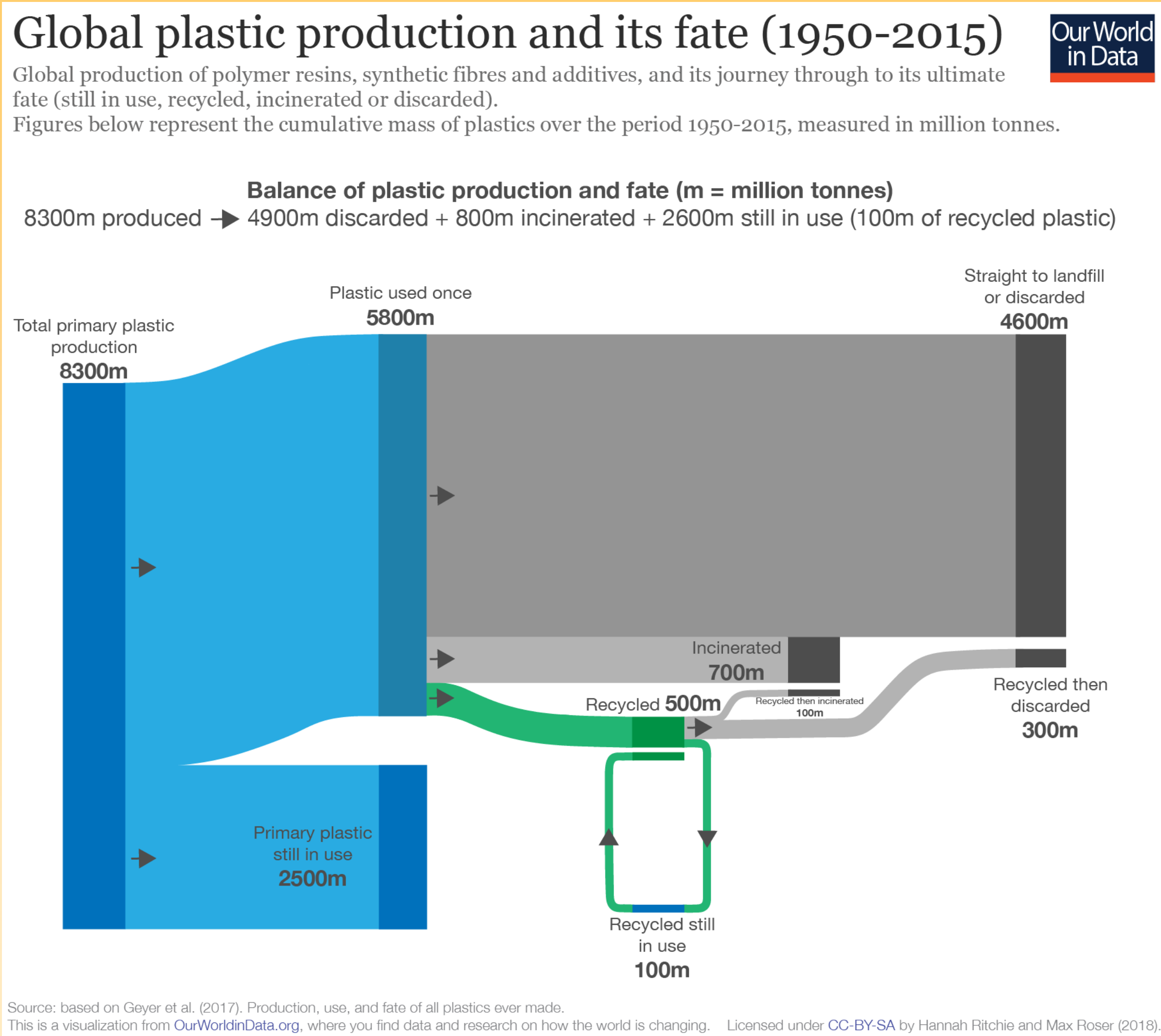

Longer-term **innovations** should aim to shift away from a linear make-use-dispose model.

To be effective, innovation needs to take account of:

- How essential plastic is in many aspects.
- Plastic alternatives often have other environmental impacts. There are usually trade-offs.
- To be globally effective, must be

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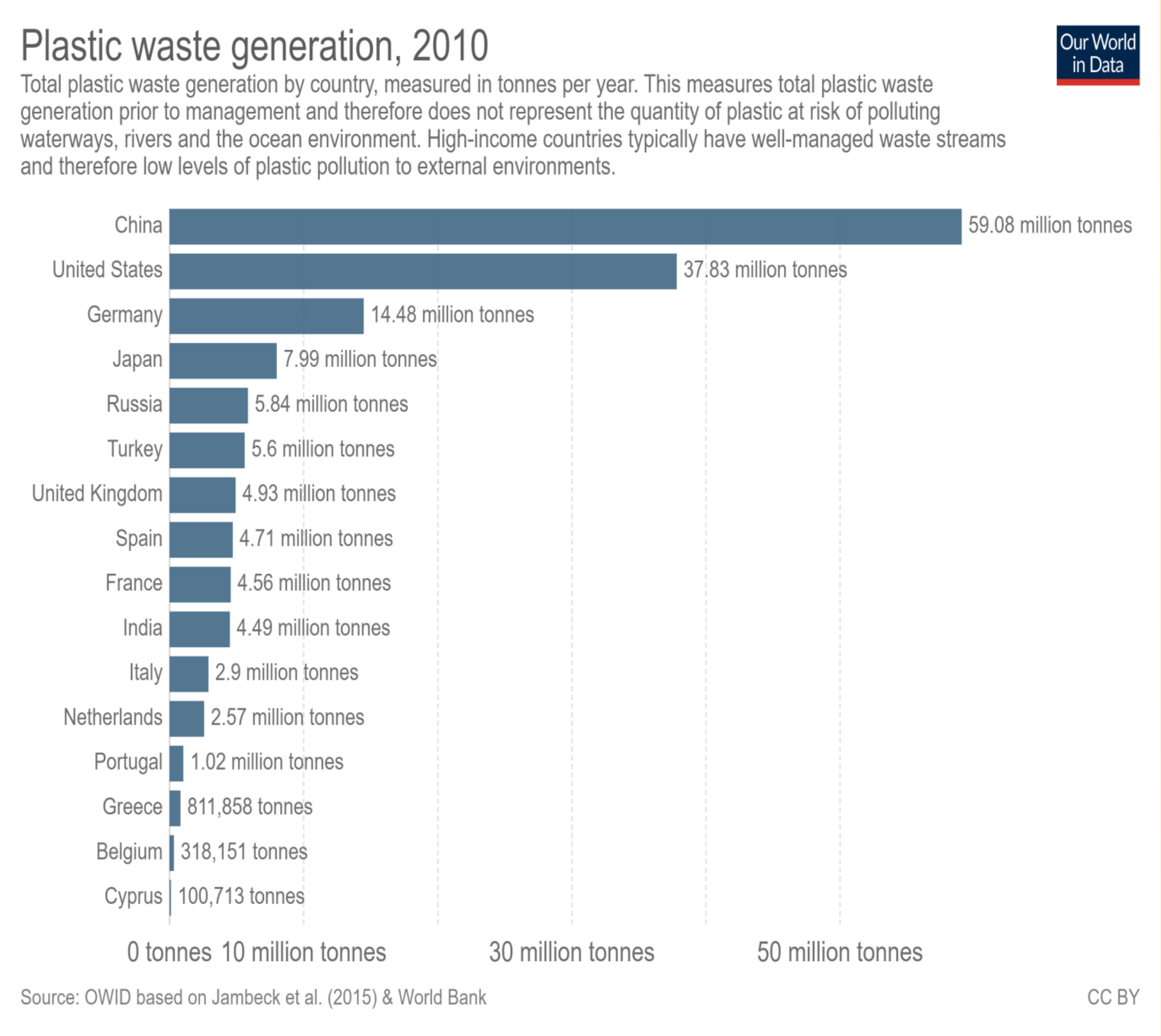

This chart presents the **total plastic waste generation by country**, measured in tonnes per year.

With the largest population, China produced the largest quantity of plastic, at nearly 60 million tonnes.

This was followed by the United States at 38 million, Germany at 14.5 million, and Brazil at 12 million tonnes.

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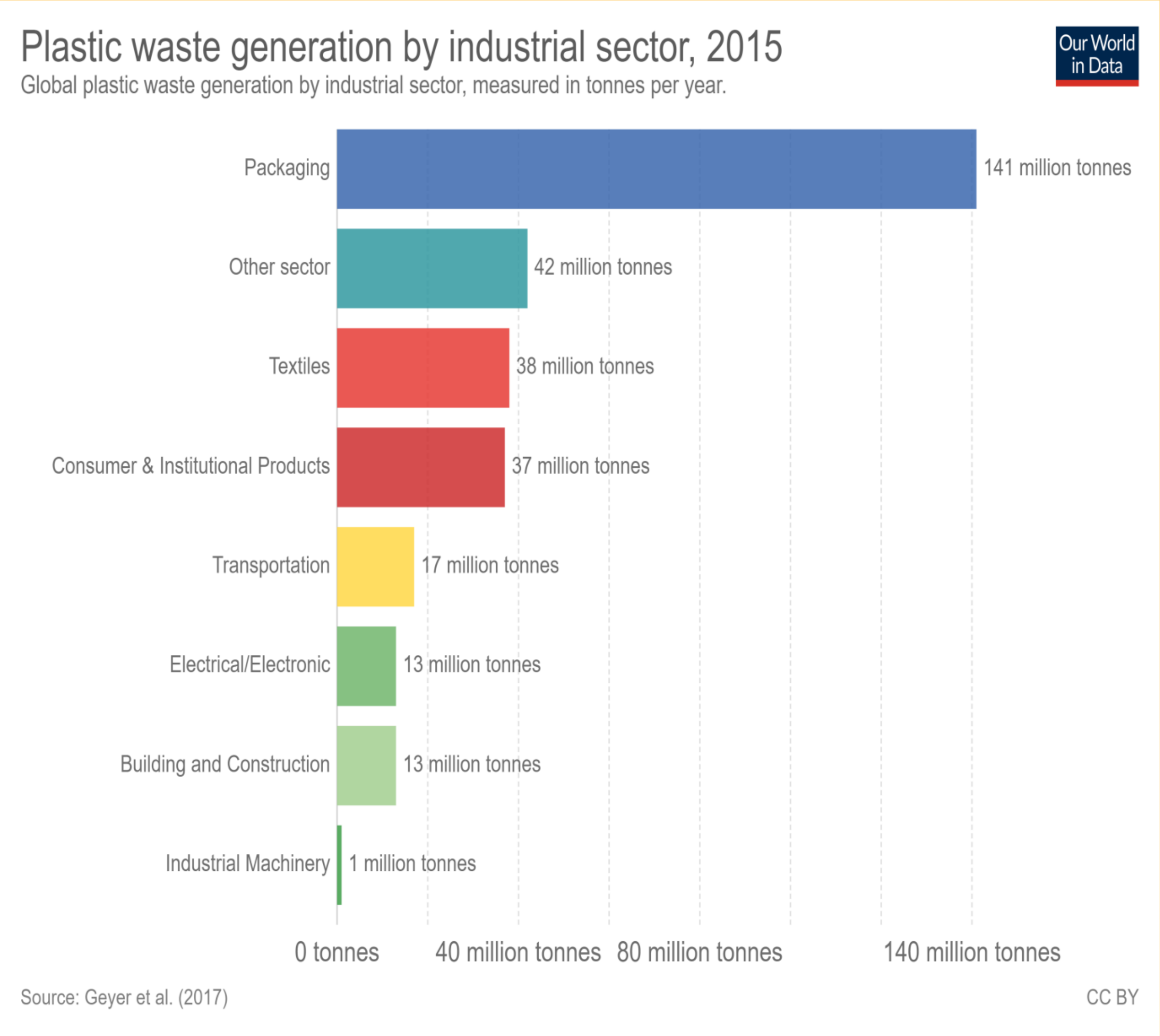

Packaging is the largest contributor to plastic waste; accounting for around 42% of the total.

Packaging is the dominant form of waste because it:

- is the sector which uses the most plastic,
- has a very low product lifetime, so typically becomes waste within 6 months.

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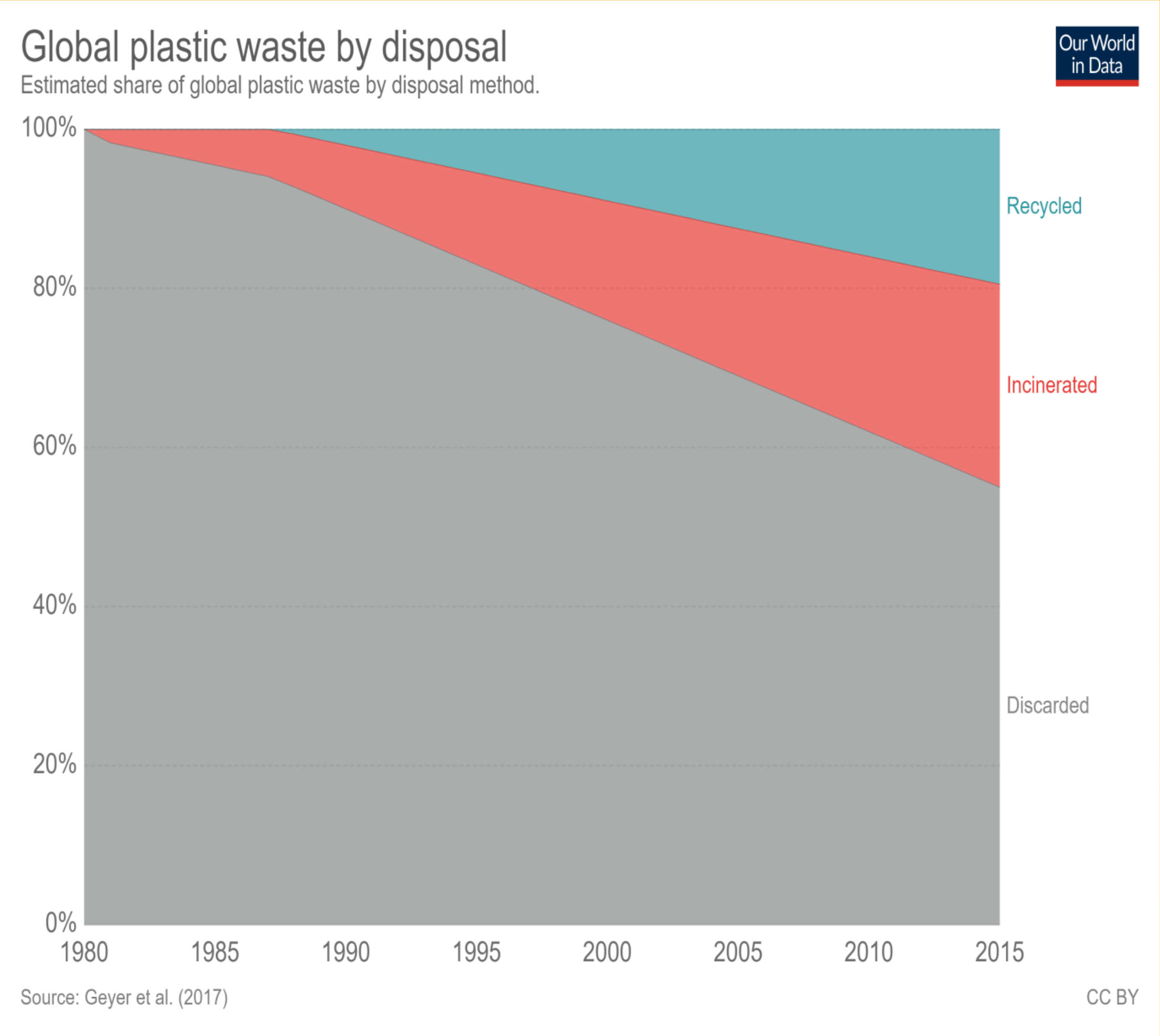

It is estimated that in 2015, around:

- 55% of global plastic waste was **discarded**,
- 25% was **incinerated**,
- 20% was **recycled**.

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Which plastics are recyclable?

Our World in Data

Summary of plastic polymer groups, their common uses, properties and recyclability. Numerical coding (from 1-7) is typically provided on plastic items and gives information of their polymer grouping below. Recyclability is based on common recycling schemes but can vary between countries as well as regionally within countries; check local recycling guidelines for further clarification.

Symbol	Polymer	Common Uses	Properties	Recyclable?
1 PETE	Polyethylene terephthalate	Plastic bottles (water, soft drinks, cooking oil)	Clear, strong and lightweight	Yes; widely recycled
2 HDPE	High-density polyethylene	Milk containers, cleaning agents, shampoo bottles, bleach bottles	Stiff and hardwearing; hard to breakdown in sunlight	Yes; widely recycled
3 PVC	Polyvinyl chloride	Plastic piping, vinyl flooring, cabling insulation, roof sheeting	Can be rigid or soft via plasticizers; used in construction, healthcare, electronics	Often not recyclable due to chemical properties; check local recycling
4 LDPE	Low-density polyethylene	Plastic bags, food wrapping (e.g. bread, fruit, vegetables)	Lightweight, low-cost, versatile; fails under mechanical and thermal stress	No; failure under stress makes it hard to recycle
5 PP	Polypropylene	Bottle lids, food tubs, furniture, houseware, medical, rope, automobile parts	Tough and resistant; effective barrier against water and chemicals	Often not recyclable; available in some locations; check local recycling
6 PS	Polystyrene	Food takeway containers, plastic cutlery, egg tray	Lightweight; structurally weak; easily dispersed	No; rarely recycled but check local recycling
7 OTHER	Other plastics (e.g. acrylic, polycarbonate, polyactic fibres)	Water cooler bottles, baby cups, fiberglass	Diverse in nature with various properties	No; diversity of materials risks contamination of recycling

Source: based on general US & UK guidelines, and chemical polymer properties. Icon graphics from Noun Project.
This is a visualization from OurWorldinData.org, where find data and research on how the world is changing.

This table summarizes:

- the **key categories** of plastics,
- their **common uses**,
- **properties**, and
- whether they can be **recycled** or **not**.

Most plastic items have a marked symbol numbered from 1 to 7 on them — this provides guidance on recyclability.

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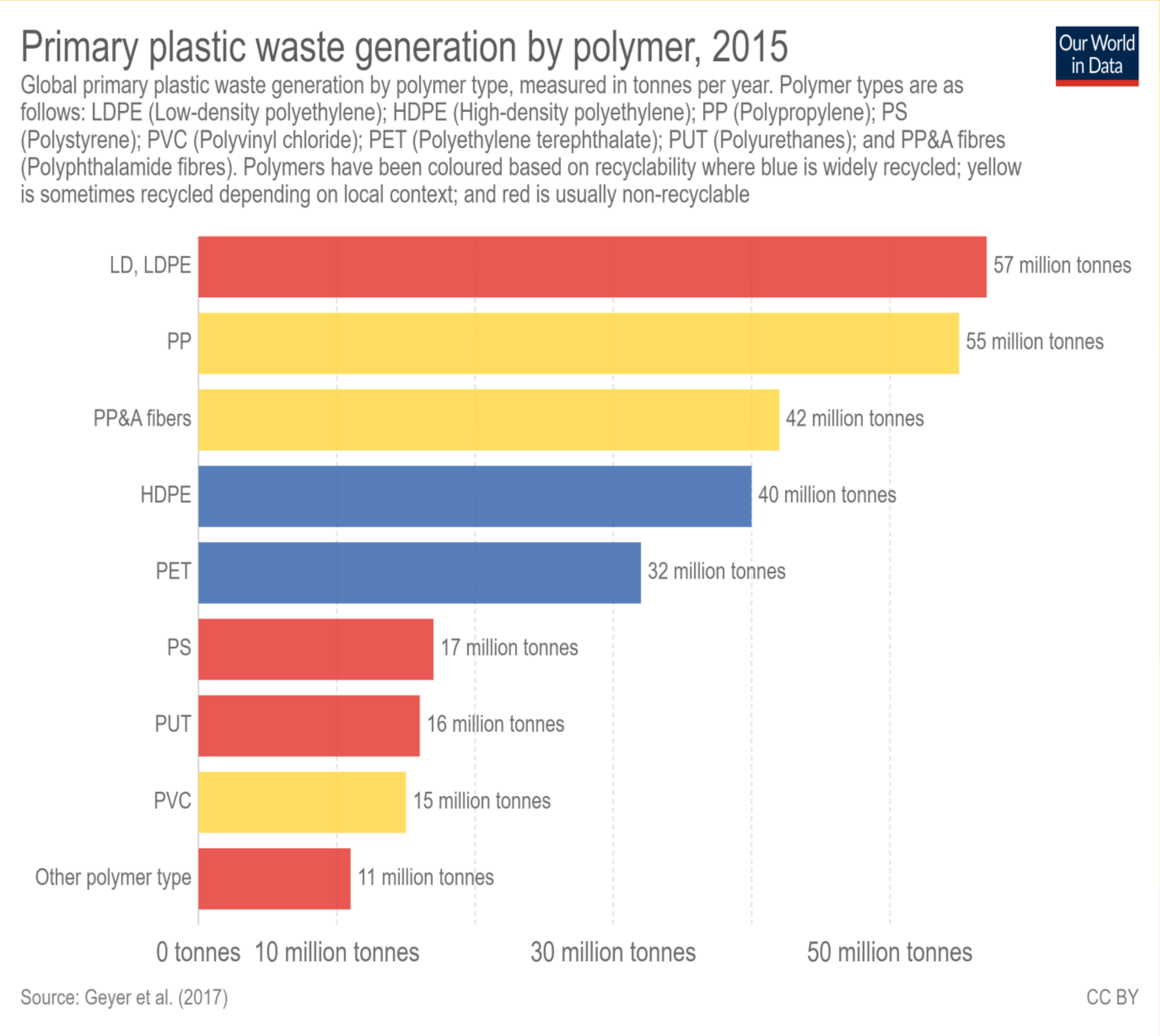

This chart shows the **global primary plastic waste generation by polymer type**, measured in tonnes per year.

Polymers have been coloured based on recyclability, where:

- **blue** is **widely recycled**,
- **yellow** is **sometimes recycled** depending on local context, and
- **red** is usually

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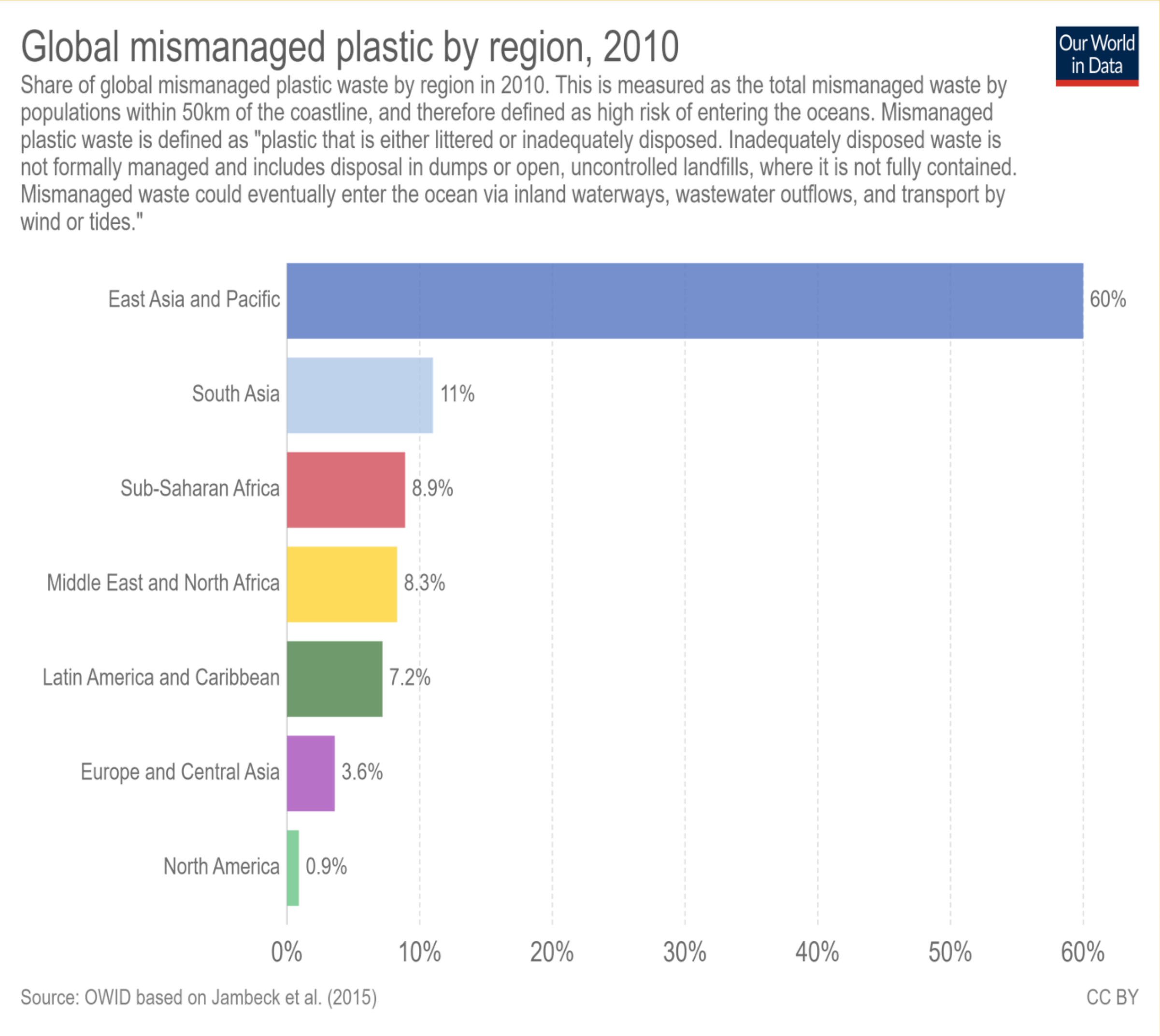
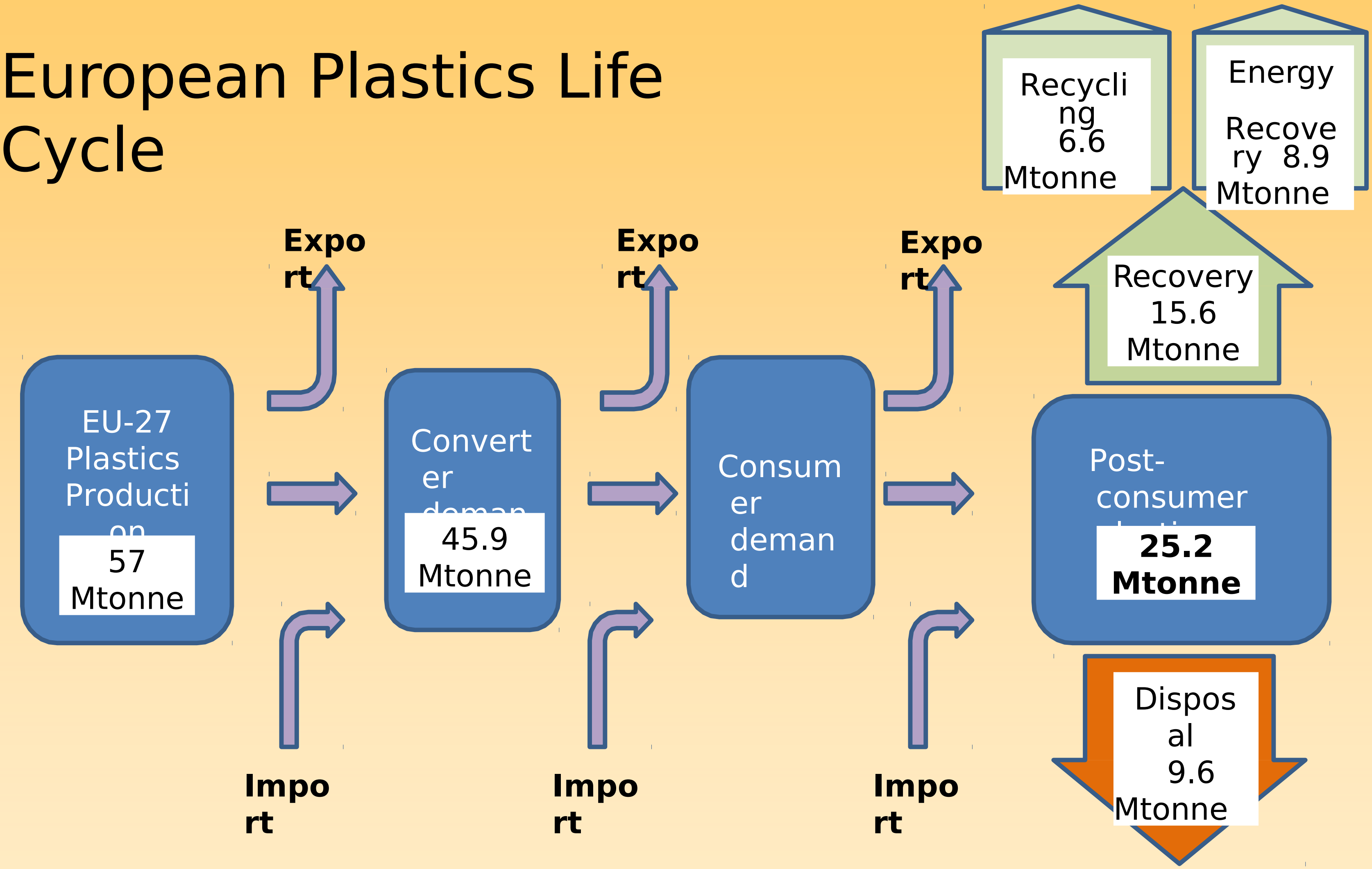


If all countries had effective waste management, **mismanaged plastic waste** could be reduced by 80%.

For comparison: total mismanaged waste from North America & Europe was less than 5%.

Even a complete plastic ban across the richest countries would have a relatively small impact at the global scale.

European Plastics Life Cycle



Non-Recyclable Plastic Waste as Energy Source

- ✓ An **effective system** for managing **non-recyclable plastic waste** must be **techno-economically**, **environmentally**, and **socially** sound.

- ✓ A range of **waste-to-energy** technologies are now well-known for exploiting the potential of **non-recyclable plastic waste** as an **energy** source, varying from **basic** systems to more **advanced** conversion processes.

- ✓ The conversion of **non-recyclable plastic waste** to **energy** is based on three main routes: **thermochemical**, **biochemical**, and **physicochemical**.

- ✓ **Non-recyclable plastic waste** is an excellent **feedstock** for **thermochemical** conversion technologies, due to their significant **heating value**.

- ✓ A **study** by the Columbia University Earth Engineering Center showed the **LHV** (Lower Heating Value) of **non-**

Non-Recyclable Plastic Waste as Energy Source

- Currently, there is a few published research pertaining to work done on the **techno-economic**, **environmental**, and **social** outcomes of **non-recyclable plastic waste** processed via **thermochemical** conversion technologies based on their associated characteristics.

- This **research** attempts to provide a new perspective on the ***Energy Recovery Evaluation of Thermochemical Conversion Technologies for Non-Recyclable Plastic Waste*** by applying the **multicriteria method PROMETHEE II, based on three different weighting strategies**.

Thermochemical Conversion

The **method** of **thermochemical conversion** includes **thermal** decomposition of **non-recyclable plastic waste** to generate either **heat** or **petroleum** or **gas**.

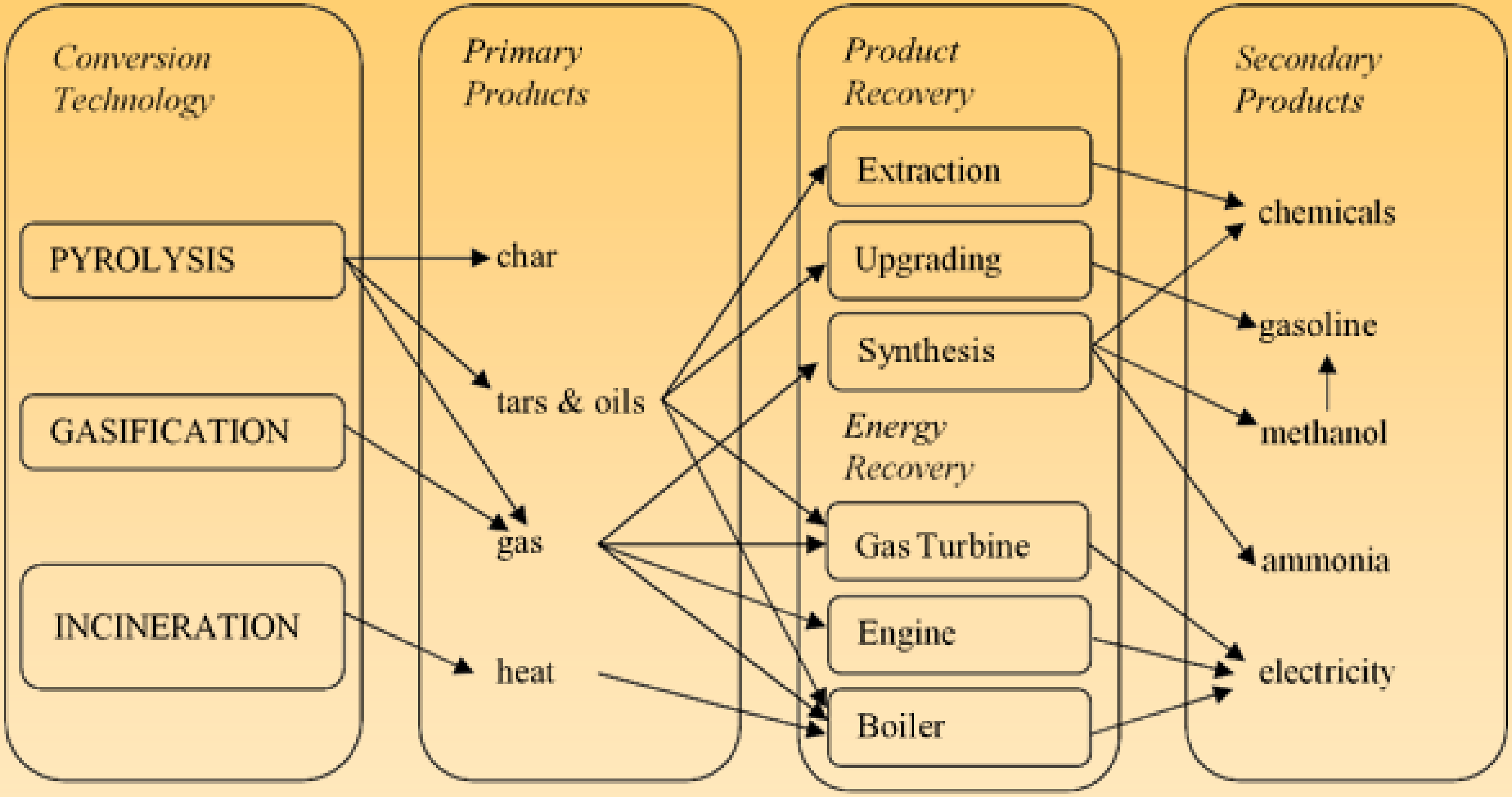
Thermochemical conversion is **best** aligned to **feedstock** with **reduced humidity** and is usually **less selective** for **materials**.

Gasification, **pyrolysis**, and **incineration** are the primary technological choices in this category.

Gasification can be **defined** as the **thermochemical** conversion—by the **supply** of a **gasifying agent—**of a solid **carbon-based material** into a **fuel gas**.

Pyrolysis is a **thermochemical** reaction which involves the **molecular** breakdown of **larger** molecules into **smaller** molecules in the **presence** of **heat** and in the **absence** of **oxygen**.

Thermochemical Conversion



Thermochemical Conversion Processes & Products

Evaluation Process

The multicriteria method, **PROMETHEE II** (Preference Ranking Organization Method for Enrichment Evaluation), has been selected.

It is well adapted to problems where a finite number of alternatives are to be ranked considering several conflicting criteria.

Criteria: According to the literature review the most frequentl

- **Capital Cost (Economic criterion)**
- **Technological Complexity (Technological criterion)**
- **Public Acceptability (Social criterion)**
- **Diversion from landfill (Environmental criterion)**
- **Energy produced (kWh/ton) (Technological criterion)**

Criteria

- The values obtained for each criterion are shown in the following Table.

- The values are selected through literature review.

- For simplification, in the present study, the indifference threshold has been ignored, and the V-type preference equation has been used for the quantitative criteria. [illegible] used

Criteria		Pyrolysis	Gasification	Incineration
Capital Cost	**C1**	Very high	High	Very high
Technological Complexity	**C2**	Very high	Very high	High
Public acceptability	**C3**	Medium	Very high	Low
Diversion from landfill	**C4**	100%	100%	70%
Energy produced	**C5**	660	660	585

Weighting of Criteria

- Weighting of criteria is carried out according to the hierarchical ranking of criteria, Simos approach.
- The weights of the criteria have been elicited from interviews with stakeholders.
- The following policy scenarios have been developed:

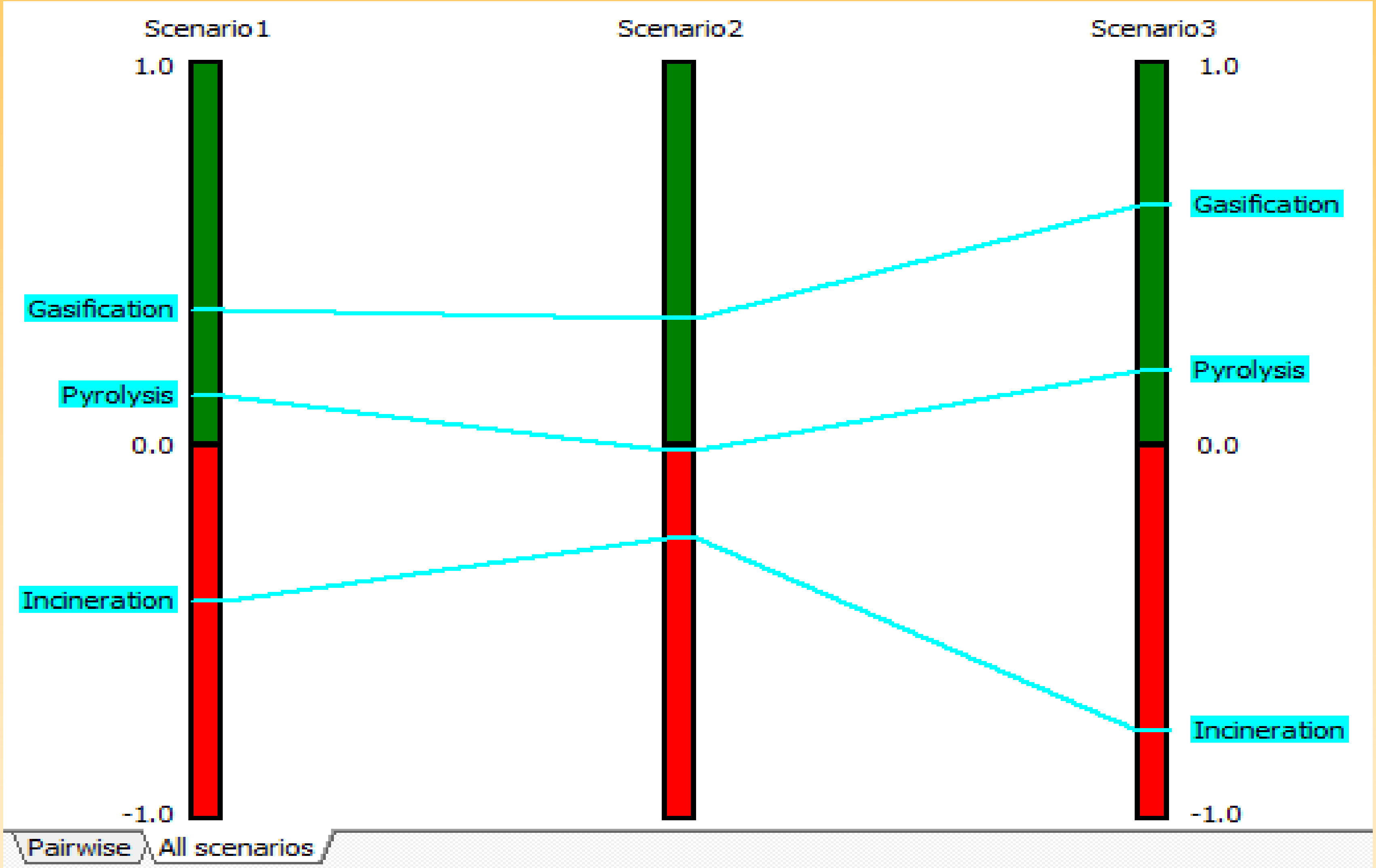
  - ✓ ***Scenario 1:*** *A preference is given in the environmental aspect, and in a second level in technological aspect.*
  - ✓ ***Scenario 2:*** *A preference towards the technological criteria.*
  - ✓ ***Scenario 3:*** *A preference is given in the environmental and social impact at the same time.*

Alternative Scenarios

It is obvious that the environmental criterion, “Diversion from landfill” and the criterion “Energy produced” are in the preferences of stakeholders as the most important in all the examined Scenarios

Criteria		Scenario 1	Scenario 2	Scenario 3
Capital Cost	**C1**	13%	21%	8%
Technological Complexity	**C2**	24%	31%	8%
Public acceptability	**C3**	4%	4%	33%
Diversion from landfill	**C4**	35%	13%	33%
Energy produced	**C5**	24%	31%	20%

Results


Scenario1
Scenario2
Scenario3
1.0
0.0
-1.0
1.0
0.0
-1.0
Gasification
Pyrolysis
Incineration
Gasification
Pyrolysis
Incineration
Pairwise
All scenarios

Conclusions

- ✓ Based on the currently available information and data; the outcome of this **Multiple Criteria Decision Analysis** of **decision options** demonstrates that **Gasification** provides the most significant improvement in **net energy recovery rates**, mitigates **greenhouse gas emissions**, and is widely accepted by the **public**.
- ✓ **Gasification** is consistent with the **principles** of **Sustainable Materials Management** and a more **Circular Economy**.
- ✓ With high contents of **carbon** and **hydrogen** in **non-recyclable plastic waste**, **thermal** degradation processes at an elevated temperature can lead to the production of value-added **electricity**, **hydrocarbon fuels**, and **chemical products**.
- ✓ The **selected criteria** fall into the most **crucial axes** for the evaluation of Thermochemical Conversion Technologies for Non-Recyclable Plastic Waste.
- ✓ **Further research** will focus on the multicriteria assessment of the other technologies, biochemical and

Thank you for your attention!