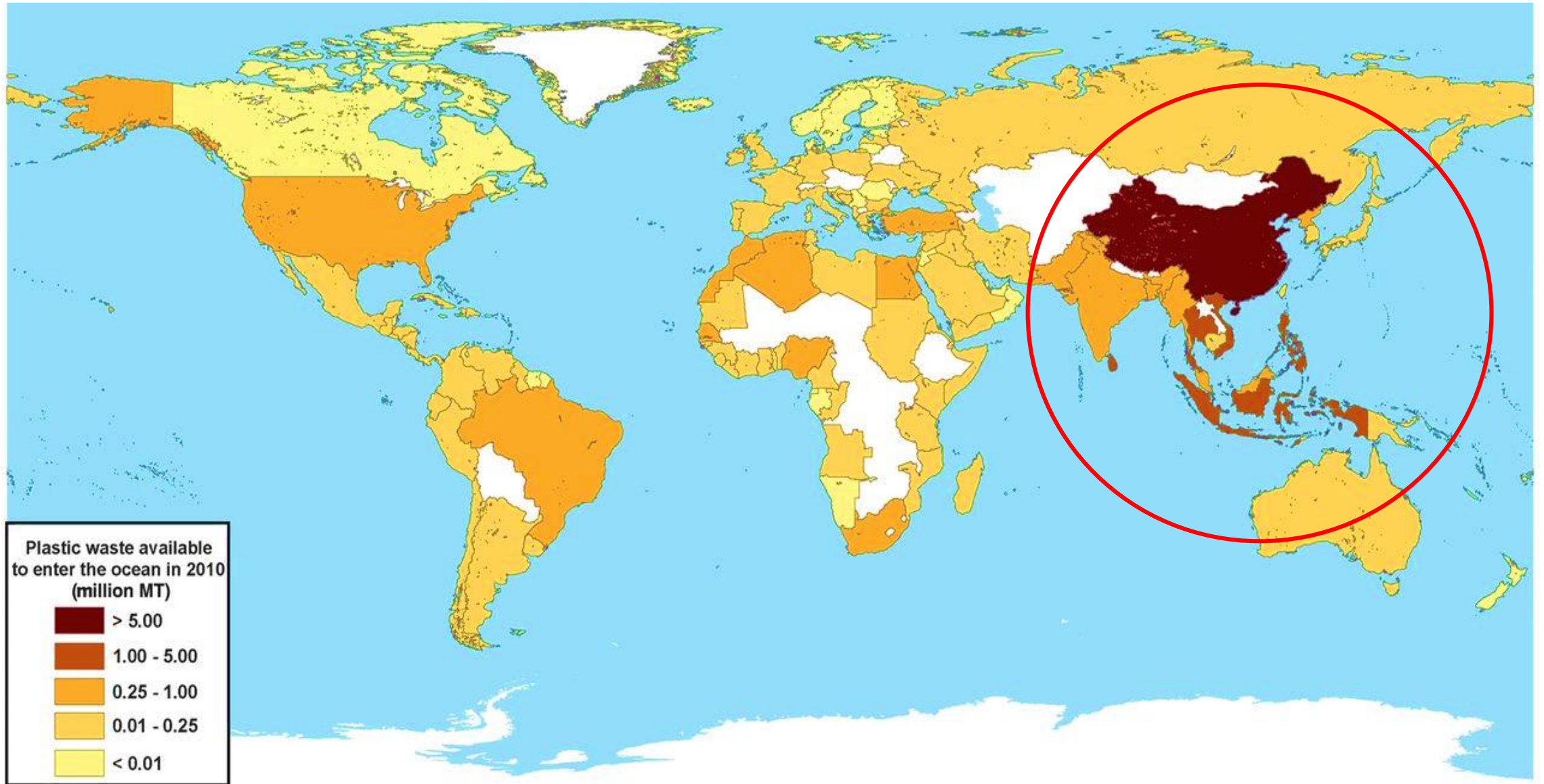# Life Cycle Analysis of Plastic:
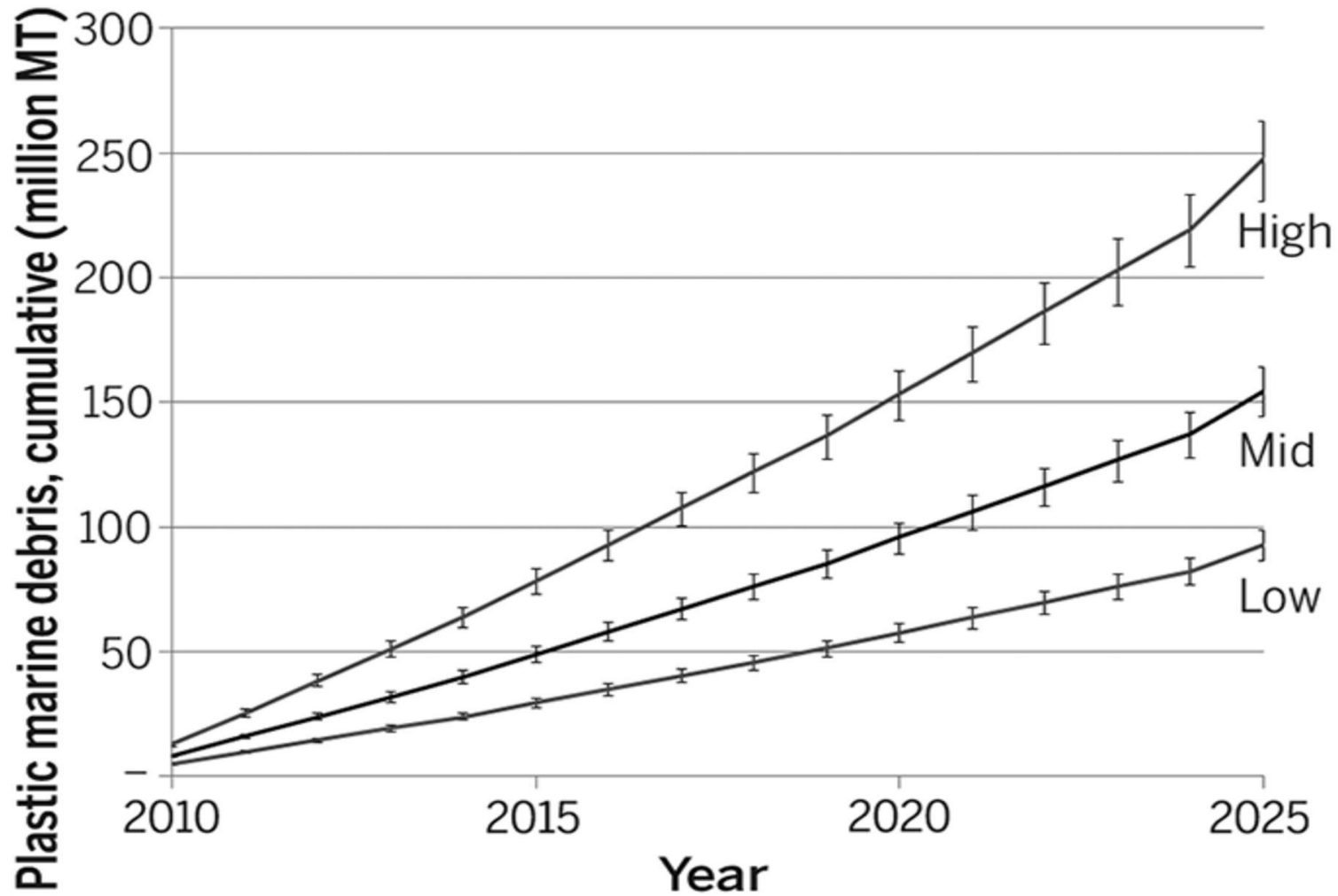## Case Study of Plastic Carrying Bags

Dr. Alvin B. Culaba, Ph.D.

Academician, National Academy of Science and Technology

Professor of Mechanical Engineering, De La Salle University

" *The Philippines is the world's third-largest ocean polluter next to China and Indonesia.*"

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L. (2015). Plastic waste inputs from land into the ocean. Science347(6223): 768-771.

Plastic waste available to enter the ocean in 2010 (million MT)

- > 5.00
- 1.00 - 5.00
- 0.25 - 1.00
- 0.01 - 0.25
- < 0.01

Source: Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L. (2015). *Plastic waste inputs from land into the ocean*. Science347(6223): 768-771.

Forecast of plastic marine debris in million tons by the year **2025**

Source: Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L. (2015). Plastic waste inputs from land into the ocean. Science347(6223): 768-771.

Metro Manila alone spends Seven Billion Pesos a year to dispose of waste – garbage that big corporations are making money with.

March 07, 2019. According to NGO GAIA, "Filipinos use more than 163 million plastic sachet packets, 48 million shopping bags and 45 million thin film bags daily."

Single-use plastic carrying bag is commonly made from Polyethylene which consists of long chains of ethylene monomers. Ethylene is derived from natural gas and petroleum. The polyethylene used in most carrying bags is either low-density or, more often, high-density (HDPE). Color concentrates and other additives are often used to add tint to the plastic. Plastic shopping bags are commonly manufactured by blown film extrusion.

What are Plastics?

Plastics are synthetic polymers consisting of carbon, hydrogen, oxygen, chloride and nitrogen. It is derived from fossil sources such as oil, coal and natural gas.

Examples are polyethylene (PE), polyethylene terephthalate (PET), nylons, polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyurethane (PU). Due to inefficient disposal methods for these materials, they often end up as environment pollutants, posing an ever-increasing ecological threat to all inhabitants of our planet.

Sources of Plastic Material

- Fossil-Based Plastics
  - Fossil- or petrochemical-based plastics utilize fossil feedstock like petroleum and natural gas. About 7% of all petroleum is converted into plastics. Examples of fossil-based plastics are polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polystyrene (PS).

- Bio-Based Plastics/Bioplastics
  - These are defined as "plastics" in which 100% of the carbon is derived from renewable agricultural and forestry resources, such as corn starch, soybean protein and cellulose
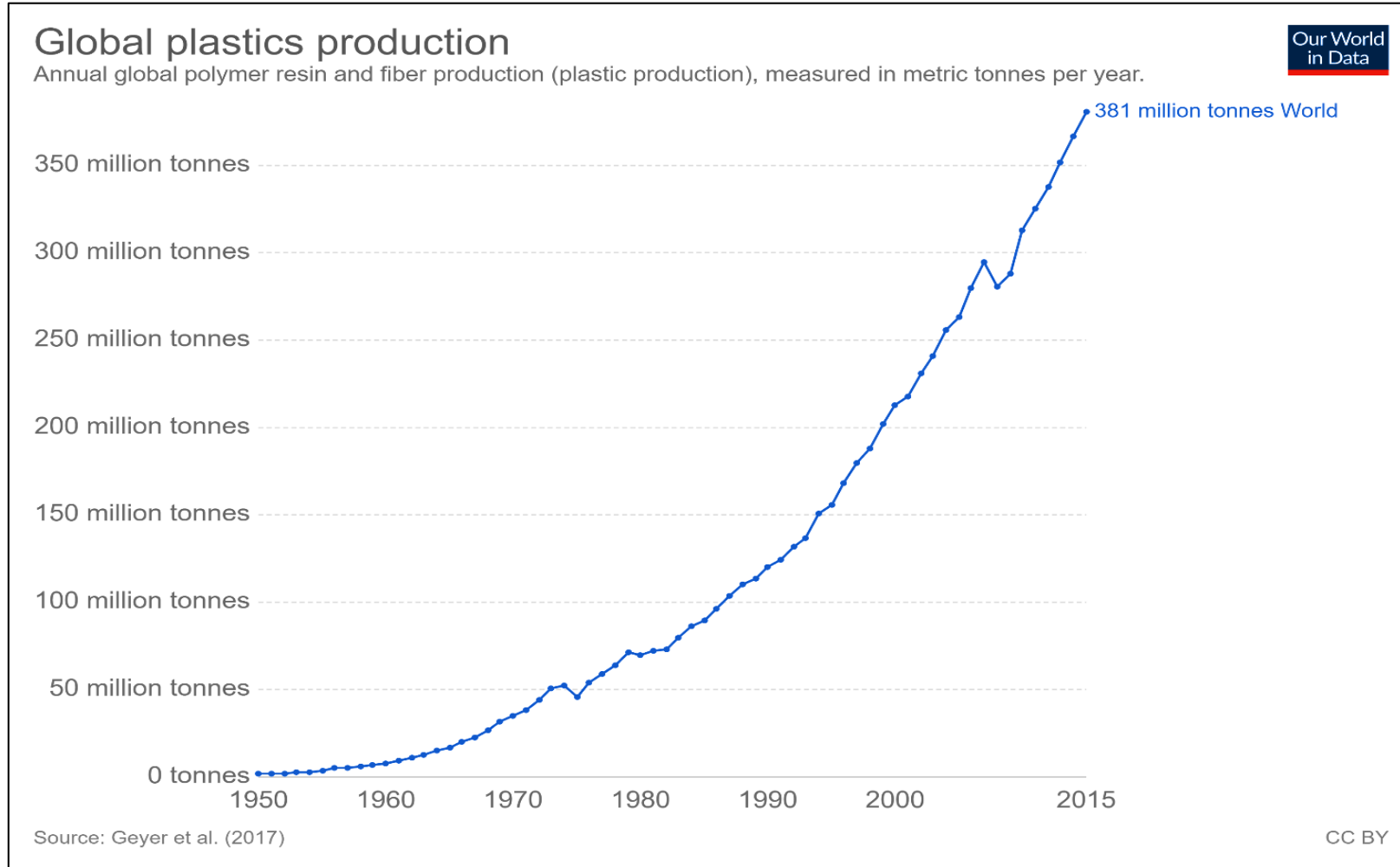
Categories of Plastics

- Thermoplastics
  - These are polymers that do not change their chemical composition when heated and can, therefore, undergo molding multiple times. These include the common plastics polyethylene(PE), polypropylene(PP), polystyrene(PS), polyvinyl chloride(PVC) and polytetrafluoroethylene(PTFE) with molecular weights in the range of 20,000 to 500,000 AMU(atomic mass unit).

- Thermoset Plastics
  - These are polymers that remain solid and can not be melted nor modified. The chemical change here is irreversible, and hence these plastics are not recyclable because they have a highly cross-linked structure, whereas thermoplastics are linear. Examples include phenol-formaldehyde, polyurethanes, etc.
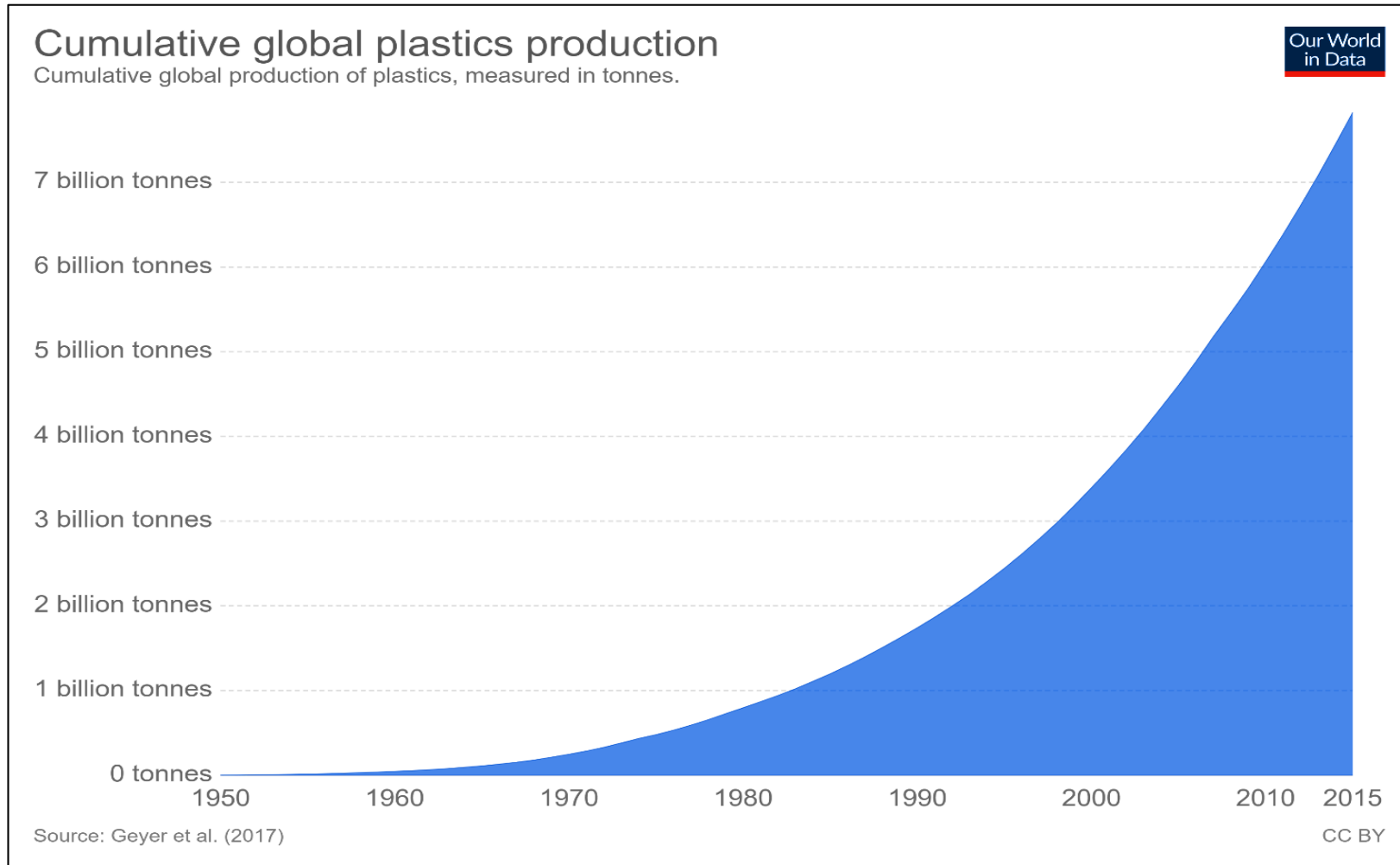
Biodegradable Plastics

- Biodegradable
  - Biodegradable materials can be broken down by microorganisms (bacteria or fungi) into water carbon dioxide (CO_2) and methane (CH_4) and microbial biomass.

- Compostable bioplastics
  - These are bioplastics that are decomposed biologically in a composting process at a similar rate to other compostable materials, without leaving visible toxic remainders. A plastic is designated bio-compostable based on standard measurements of its total biodegradability and disintegration degree, as well as ecological toxicity of its degraded materials.

- ❖ Clarifications
  - Compostable plastics are a subgroup of biodegradable plastics
  - Not all bioplastics are biodegradable

Global Plastics Production

Global plastics production
Annual global polymer resin and fiber production (plastic production), measured in metric tonnes per year.

Our World in Data

381 million tonnes World

350 million tonnes

300 million tonnes

250 million tonnes

200 million tonnes

150 million tonnes

100 million tonnes

50 million tonnes

0 tonnes

1950   1960   1970   1980   1990   2000   2015

Source: Geyer et al. (2017)

CC BY

381 million tons (MT) of plastic was produced in 2015.

Geyer et al. (2017)

Global Plastic Production

Cumulative global plastics production
Cumulative global production of plastics, measured in tonnes.

Our World in Data

- 7 billion tonnes
- 6 billion tonnes
- 5 billion tonnes
- 4 billion tonnes
- 3 billion tonnes
- 2 billion tonnes
- 1 billion tonnes
- 0 tonnes

1950   1960   1970   1980   1990   2000   2010   2015

Source: Geyer et al. (2017)   CC BY

7.81 billion tons of plastics was produced cumulatively in the world as of 2015

Geyer et al. (2017)

Global Plastic Waste by Disposal

Global plastic waste by disposal
Estimated share of global plastic waste by disposal method.

Our World in Data

Recycled

Incinerated

Discarded

Source: Geyer et al. (2017)

CC BY
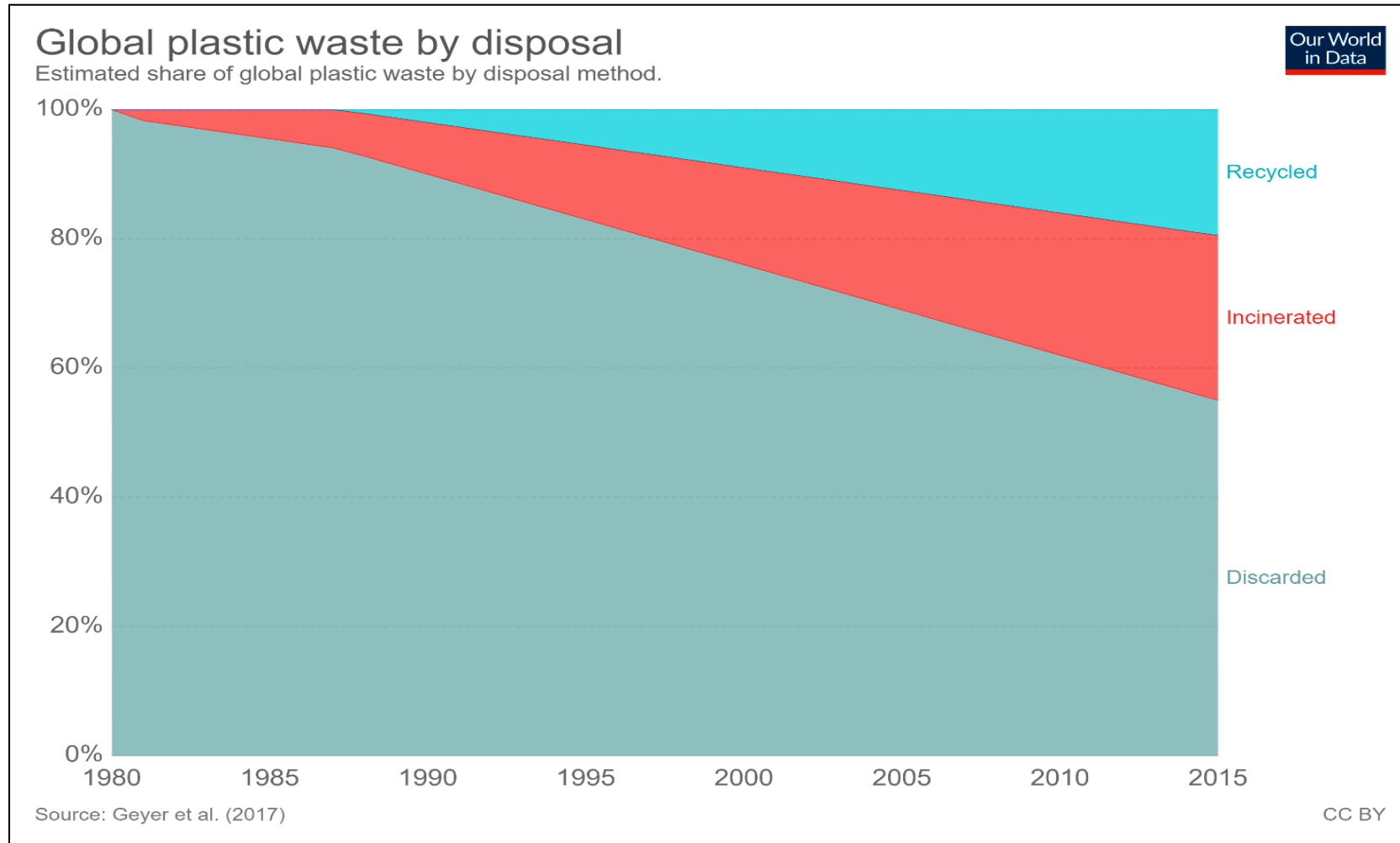
In 2015, plastics were disposed in the following methods

- Discarded (55%)
- Incinerated (25%)
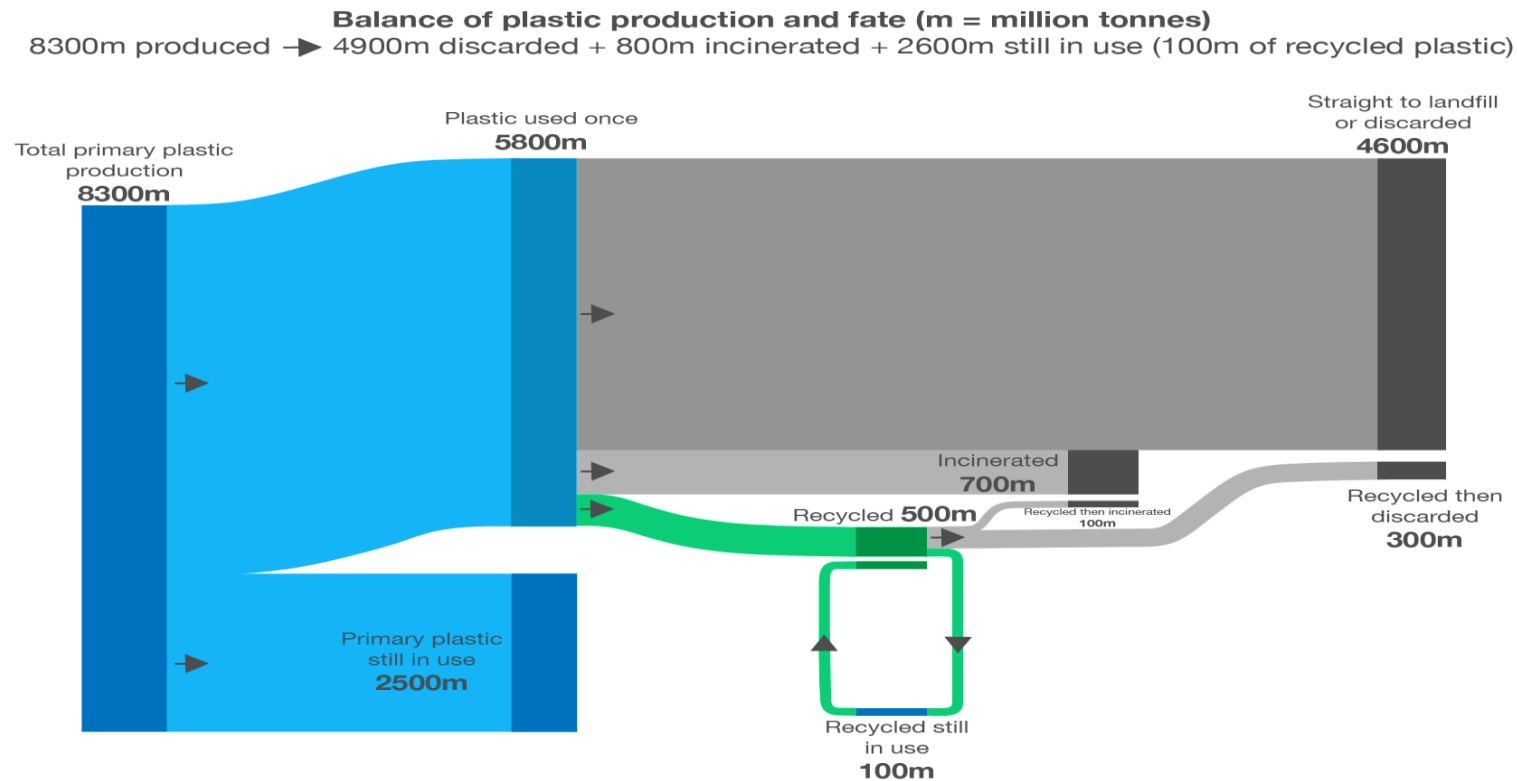- Recycled (20%)

Geyer et al. (2017)

The Fate of Plastics

Global plastic production and its fate (1950-2015)
Global production of polymer resins, synthetic fibres and additives, and its journey through to its ultimate fate (still in use, recycled, incinerated or discarded).
Figures below represent the cumulative mass of plastics over the period 1950-2015, measured in million tonnes.

Our World in Data

Balance of plastic production and fate (m = million tonnes)
8300m produced → 4900m discarded + 800m incinerated + 2600m still in use (100m of recycled plastic)

Plastic used once
5800m

Straight to landfill
or discarded
4600m

Total primary plastic
production
8300m

Incinerated
700m

Recycled 500m

Recycled then incinerated
100m

Recycled then
discarded
300m

Primary plastic
still in use
2500m

Recycled still
in use
100m

Source: based on Geyer et al. (2017). Production, use, and fate of all plastics ever made.
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing. Licensed under CC-BY-SA by Hannah Ritchie and Max Roser (2018).
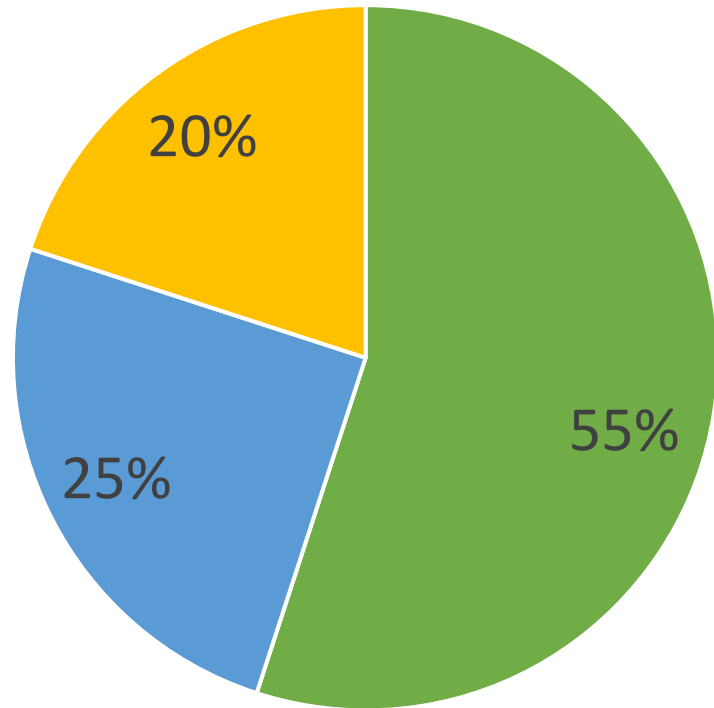
All the plastics produced from 1950 to 2015 went to the following
- Straight to landfill (55%)
- Still in use (30%)
- Incinerated (8%)
- Recycled (6-7%)
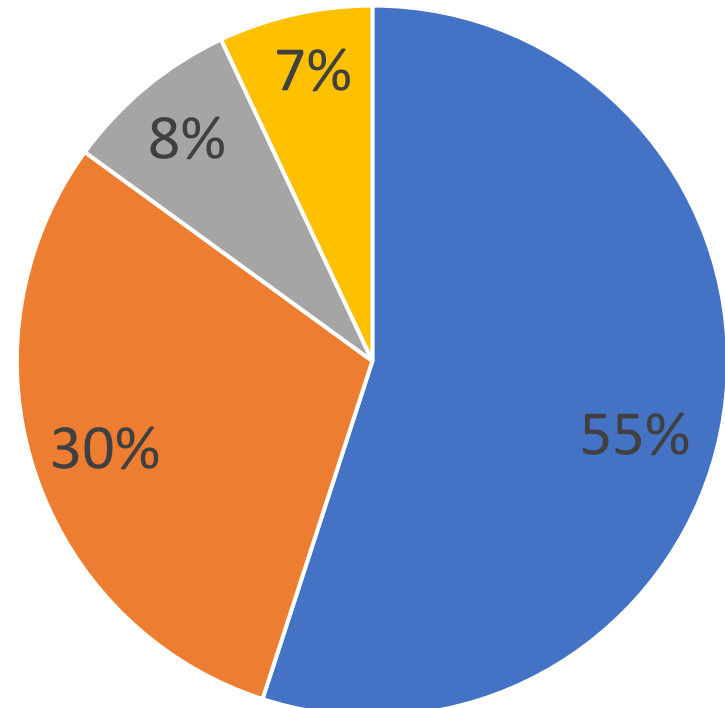
Only 9% of the plastics no longer in used was recycled.

Geyer et al. (2017)

Disposal Method and Fate of Plastics Summary

Plastic Production by Industrial Sector

Primary plastic production by industrial sector, 2015
Primary global plastic production by industrial sector allocation, measured in tonnes per year.

Our World in Data

Sector	Tonnes
Packaging	146 million tonnes
Building and Construction	65 million tonnes
Other sector	59 million tonnes
Textiles	47 million tonnes
Consumer & Institutional Products	42 million tonnes
Transportation	27 million tonnes
Electrical/Electronic	18 million tonnes
Industrial Machinery	3 million tonnes

Source: Geyer et al. (2017)   CC BY
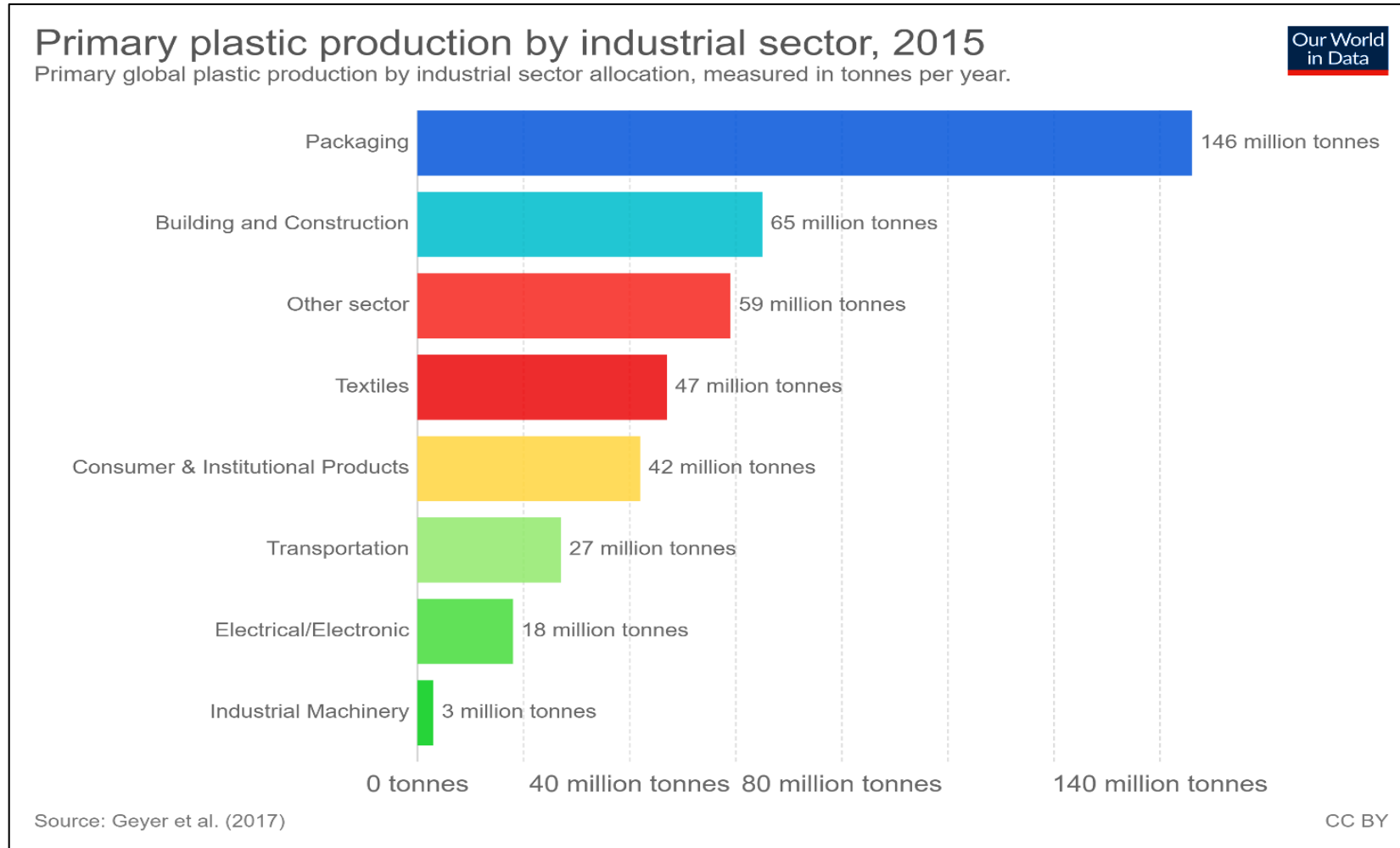
Packaging is leading at 146 million tons in 2015

Geyer et al. (2017)

Plastic Waste Generation by Industrial Sector

Plastic waste generation by industrial sector, 2015
Global plastic waste generation by industrial sector, measured in tonnes per year.

Our World in Data

Sector	Amount
Packaging	141 million tonnes
Other sector	42 million tonnes
Textiles	38 million tonnes
Consumer & Institutional Products	37 million tonnes
Transportation	17 million tonnes
Electrical/Electronic	13 million tonnes
Building and Construction	13 million tonnes
Industrial Machinery	1 million tonnes

0 tonnes   40 million tonnes   80 million tonnes   140 million tonnes

Source: Geyer et al. (2017)   CC BY

Packaging is leading at 141 million tons in 2015 in waste generation

Geyer et al. (2017)

Global Mismanaged Plastics by Region

Global mismanaged plastic by region, 2010

Share of global mismanaged plastic waste by region in 2010. This is measured as the total mismanaged waste by populations within 50km of the coastline, and therefore defined as high risk of entering the oceans. Mismanaged plastic waste is defined as "plastic that is either littered or inadequately disposed. Inadequately disposed waste is not formally managed and includes disposal in dumps or open, uncontrolled landfills, where it is not fully contained. Mismanaged waste could eventually enter the ocean via inland waterways, wastewater outflows, and transport by wind or tides."

Our World in Data

Region	Share
East Asia and Pacific	60%
South Asia	11%
Sub-Saharan Africa	8.9%
Middle East and North Africa	8.3%
Latin America and Caribbean	7.2%
Europe and Central Asia	3.6%
North America	0.9%

Source: OWID based on Jambeck et al. (2015)   CC BY

East Asia has the biggest share of mismanaged plastics at **60%** in 2010.

Jambeck et al. (2015)

Top Ocean-Polluting Countries

The Countries Polluting The Oceans The Most

Annual metric tons of mismanaged plastic waste and total amount ending up in global waters*

■ Mismanaged plastic waste   ● Plastic marine debris

Country	Mismanaged plastic waste	Plastic marine debris
China	8.80m	3.53m
Indonesia	3.20m	1.29m
Philippines	1.90m	0.75m
Vietnam	1.80m	0.73m
Sri Lanka	1.60m	0.64m
Egypt	1.00m	0.39m
Thailand	1.00m	0.41m
Malaysia	0.90m	0.37m
Nigeria	0.90m	0.34m
Bangladesh	0.80m	0.31m
Brazil	0.50m	0.19m
United States	0.30m	0.11m
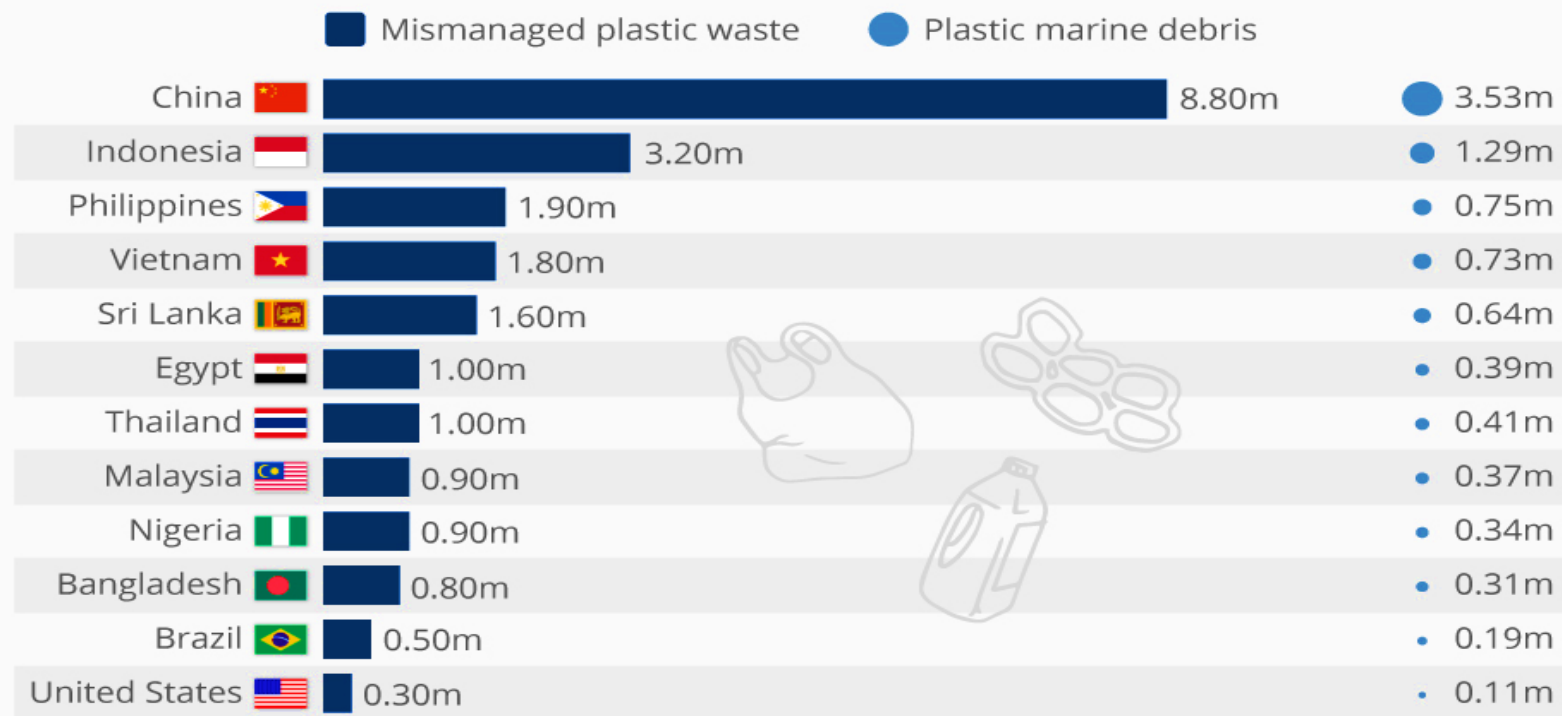
* Generated in 2010 (selected countries)
@StatistaCharts   Source: The Wall Street Journal

statista

The Philippines is among top ocean polluting countries with a total of **1.9 million metric tons** of mismanaged plastic wastes and **750, 000 metric tons** of plastic marine debris

Jambeck et al. (2015)

Plastic Ocean input from Top 20 Rivers

Plastic ocean input from top 20 rivers, 2015

Plastic input to the ocean from the top 20 polluting rivers across the world. Shown is the given river, its location, and estimated annual input of plastic to the oceans in tonnes.

River	Plastic input
Yangtze (China)	333,000 tonnes
Ganges (India, Bangladesh)	115,000 tonnes
Xi (China)	73,900 tonnes
Huangpu (China)	40,800 tonnes
Cross (Nigeria, Cameroon)	40,300 tonnes
Amazon (Brazil, Peru, Colombia, Ecuador)	38,900 tonnes
Brantas (Indonesia)	38,900 tonnes
Pasig (Philippines)	38,800 tonnes
Irrawaddy (Myanmar)	35,300 tonnes
Solo (Indonesia)	32,500 tonnes
Mekong (Thailand, Cambodia, Laos, China, Myanmar, Vietnam)	22,800 tonnes
Imo (Nigeria)	21,500 tonnes
Dong (China)	19,100 tonnes
Serayu (Indonesia)	17,100 tonnes
Magdalena (Colombia)	16,700 tonnes
Tamsui (Taiwan)	14,700 tonnes
Zhujiang (China)	13,600 tonnes
Hanjiang (China)	12,900 tonnes
Progo (Indonesia)	12,800 tonnes
Kwa Ibo (Nigeria)	11,900 tonnes

0 tonnes   150,000 tonnes   300,000 tonnes

Source: Lebreton et al. (2017)   CC BY

Pasig river is one top 20 polluting rivers around the world.

Pasig river's annual plastic input to the oceans is around **38,800 tons**.

Lebreton et al. (2018)

Other Facts on Plastic Bags

- Around **100, 000 marine animals** are killed each year due to plastic bags.

- Around **46, 000 plastic pieces** are found in every square mile of ocean.

- **4.3 billion gallons of crude oil** used each year for plastic bag production.

- Around **1 trillion** single use plastic bags are used every year.

- It takes around **1000 years** for 1 plastic bag to fully degrade.

- Total of **3.5 million tons** of plastic bags are discarded every year.

Life Cycle Assessment (LCA)

"LCA is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements."

Source: (SETAC, 1993)

Components of LCA

- Goal & Scope Definition (ISO 14041)

- Inventory Analysis (ISO 14041)

- Impact Assessment (ISO 14042)

- Interpretation (ISO 14043)

Manufacturing

Raw Materials Extraction

Distribution

Use

Reuse/Recycling

Final Disposal
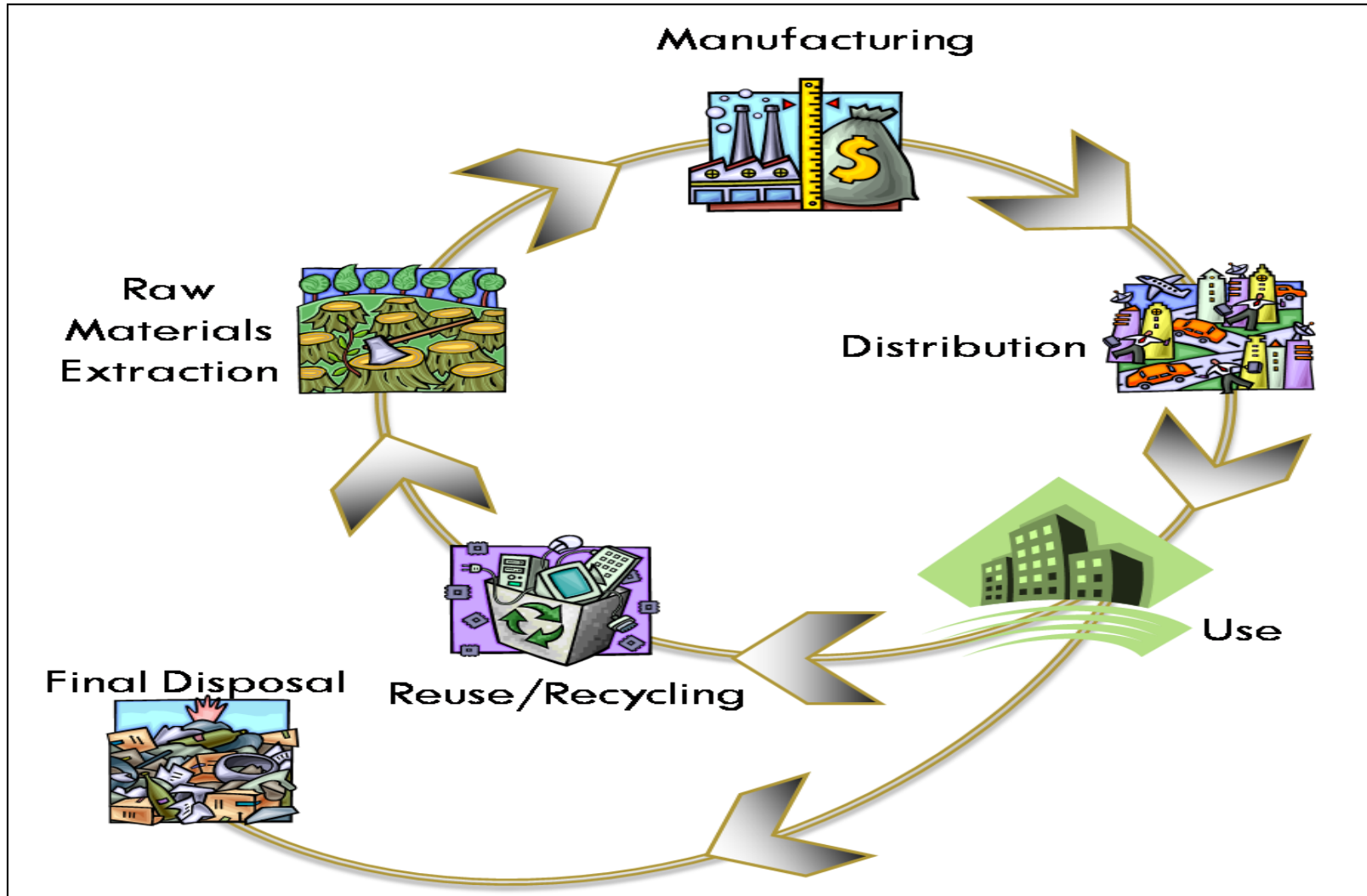
Product Life Cycle:
A Cradle-to-Grave Analysis

Material extraction → Material processing → Manufacturing → Use → Waste management
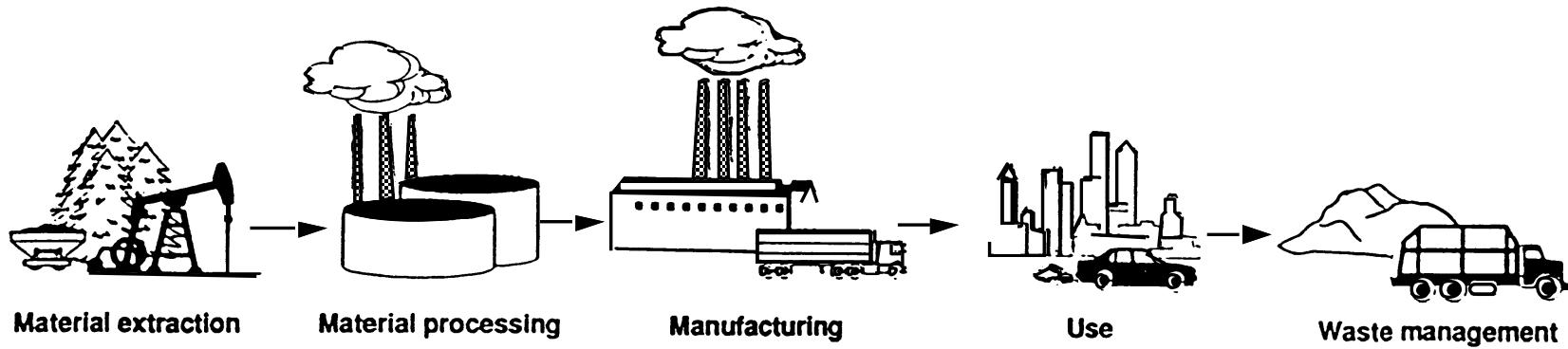
A paradigm that provides a holistic picture of an entire product system covering resources extraction, material processing, transportation, manufacturing, distribution, use, disposal and reuse/recycling.

E   w/e   E   w/e   E   w/e   E   E

Raw Materials Acquisition → Product Processing & Manufacture → Marketing and Distribution → Consumption and Use → Waste Management   Final Disposal

Energy

Materials

Product Reuse

Material Recycle

Alternative Routes for Sustainability

Energy Recovery

E: energy in
e: energy out
w: waste discharge

Source: Culaba & Purvis, 1999
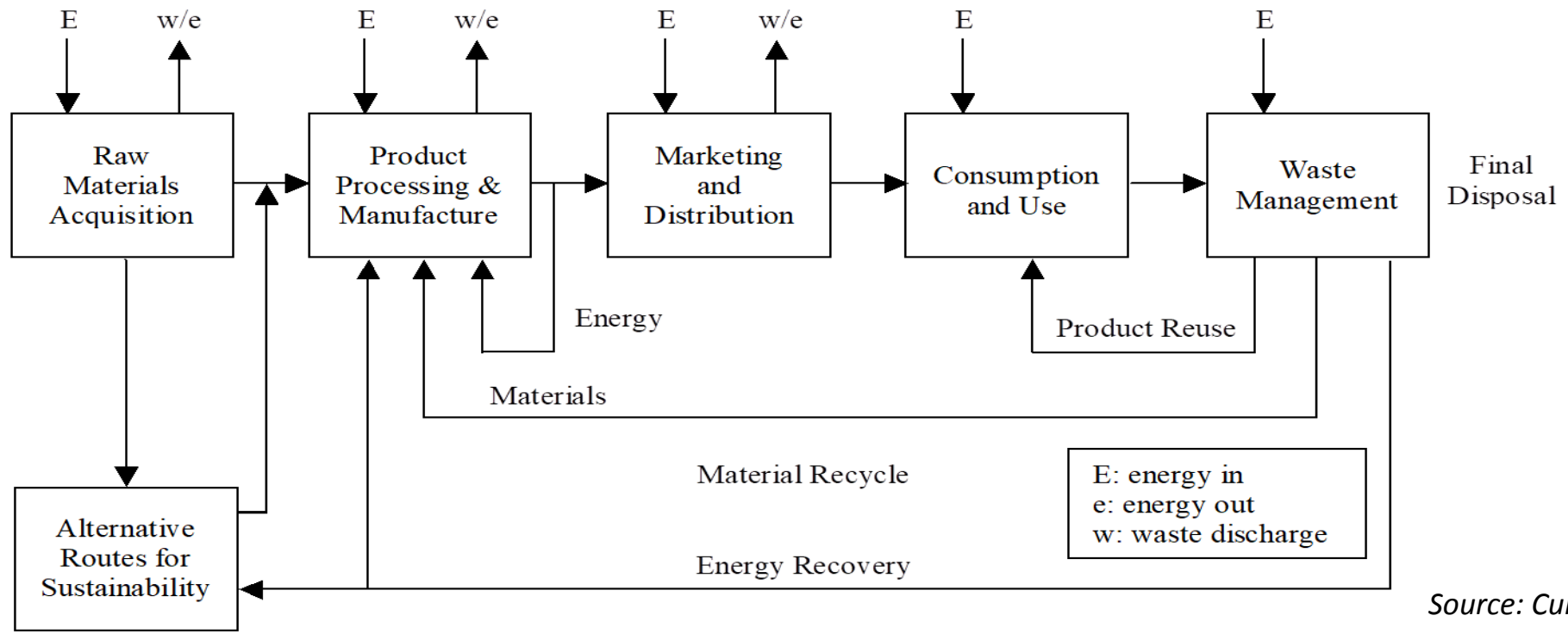
Life Cycle Impact Assessment

- Classification: What specific impacts (e.g., global warming, acid rain) do the material and energy flows contribute to?

- Characterization: How much do the M&E flows contribute to these impacts?

- Valuation: How much does each impact category contribute to over-all damage?
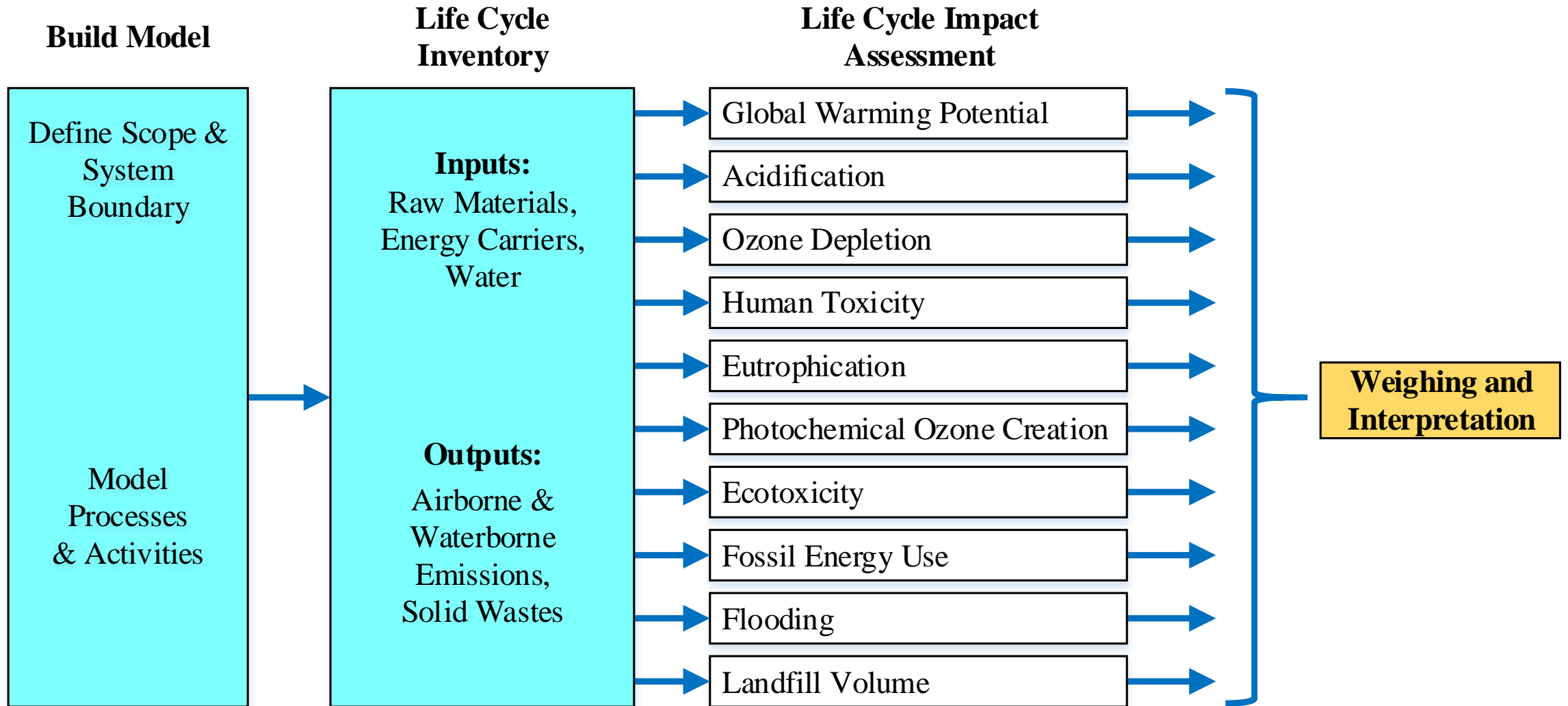
Impact Area	Reference Unit	Description
Global Warming Potential	kg CO_2-eq	This impact is related to the continued rise in the average temperature of the earth's climatic system. This is also concerned with climate change and the greenhouse effect.
Ozone Depletion	kg CFC11-eq	This is the environmental impact related to the thinning of the ozone layer caused by ozone depleting substances emitted by different forms of human activities. The depletion of ozone in the stratosphere makes it ineffective to screen out much of the UV rays from the sun and can cause serious damages to plants, animals, and humans.
Acidification	m^2	This impact is associated with the apparent decrease in the pH level of terrestrial and aquatic ecosystems caused by releases of hydrogen cations (or protons) from acidifying substances which leads to damages in ecosystem populations. This is measured in terms of the land area of an ecosystem with exceeded limits of acidification.
Ozone Formation	person.ppm.h	This impact category is related to the photochemical ozone creation potential. In the ground level, ozone acts as a secondary pollutant formed by a highly-complex reaction between sunlight, NOx and volatile organic compounds (VOCs) including methane. At certain concentrations, ozone causes damages to vegetation and human health.

Eutrophication	kg N-eq	This impact category covers the negative effects of excess nutrients, particularly Nitrogen present in soil (terrestrial eutrophication) or turbidity-causing nutrients in water (aquatic eutrophication) which are, in turn, caused by present atmospheric input of nutrients, from human and industrial activities. These imbalances in nutrients cause changes in species composition as adaptation becomes advantageous to a limited number of species
Human Toxicity	person	This is the impact to the level of functional state of a person to adequately cope with his/her daily activities by the absence of diseases and impairment. This is also the impact factor which can represent the social aspect of sustainable production.
Ecotoxicity	m^3	A combination of the words ecology and toxicity, this impact factor refers to the potential for physical stressors (whether biological, chemical or physical) to affect ecosystems
Fossil Energy Use	MJ	This impact factor quantifies the fossil fuel used in terms of energy equivalent

Life Cycle Interpretation

- What do the results mean?
- Have high-impact areas or *hot spots* been identified?
- Has a *best environmental option* (BEO) been identified?
- Is further in-depth evaluation necessary?
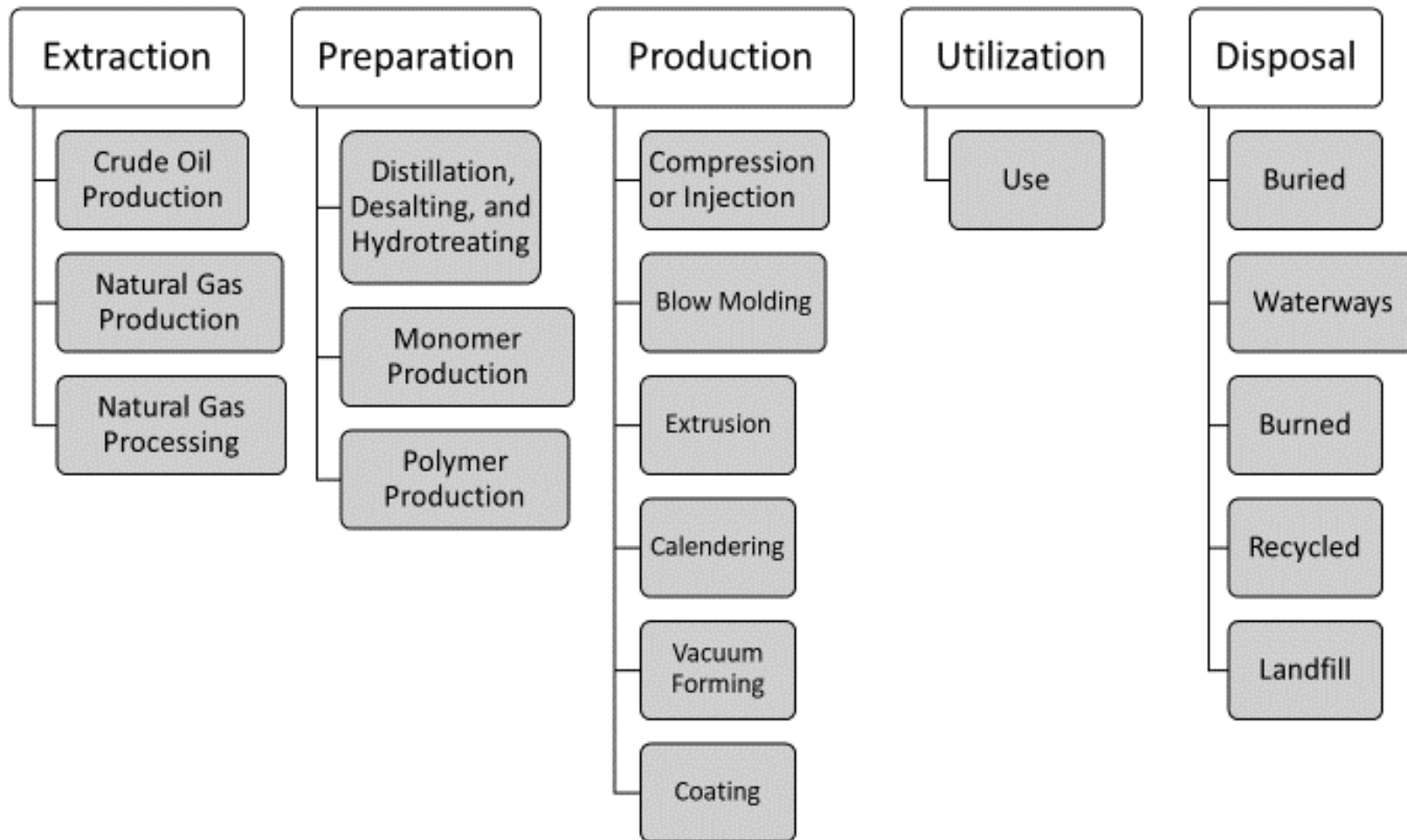
Interaction of LCA Components
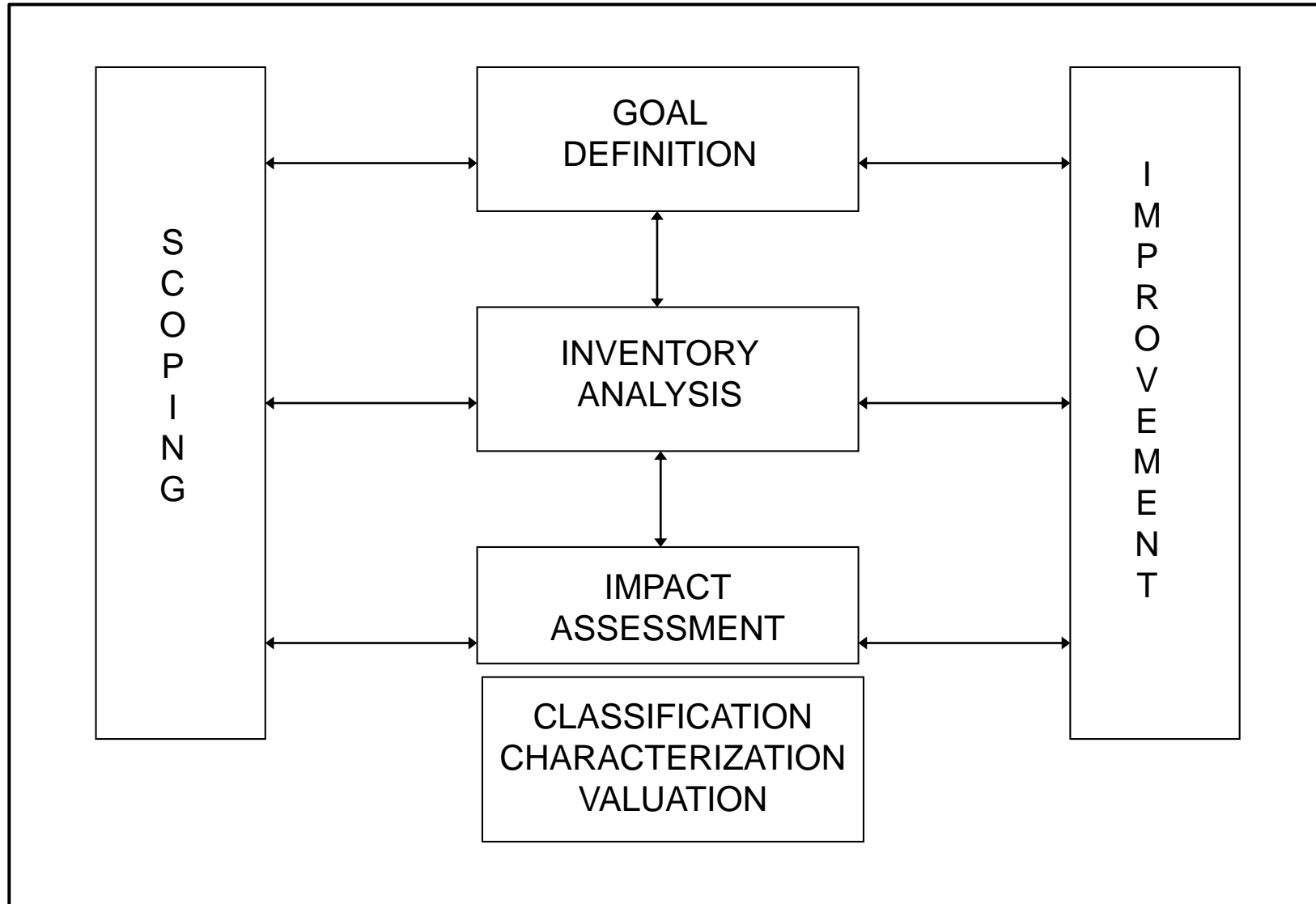
Why is LCA important?

- LCA gives an indication of total environmental impacts
- LCA can reveal environmental impacts that are overlooked in conventional assessments
- LCA gives a true measure of environmental performance
- Rationalizes the structure of a decision-support mechanism that considers the interaction of both environmental and productivity parameters.

Life Cycle Analysis of Plastic:
Case Study of Plastic Carrying Bags
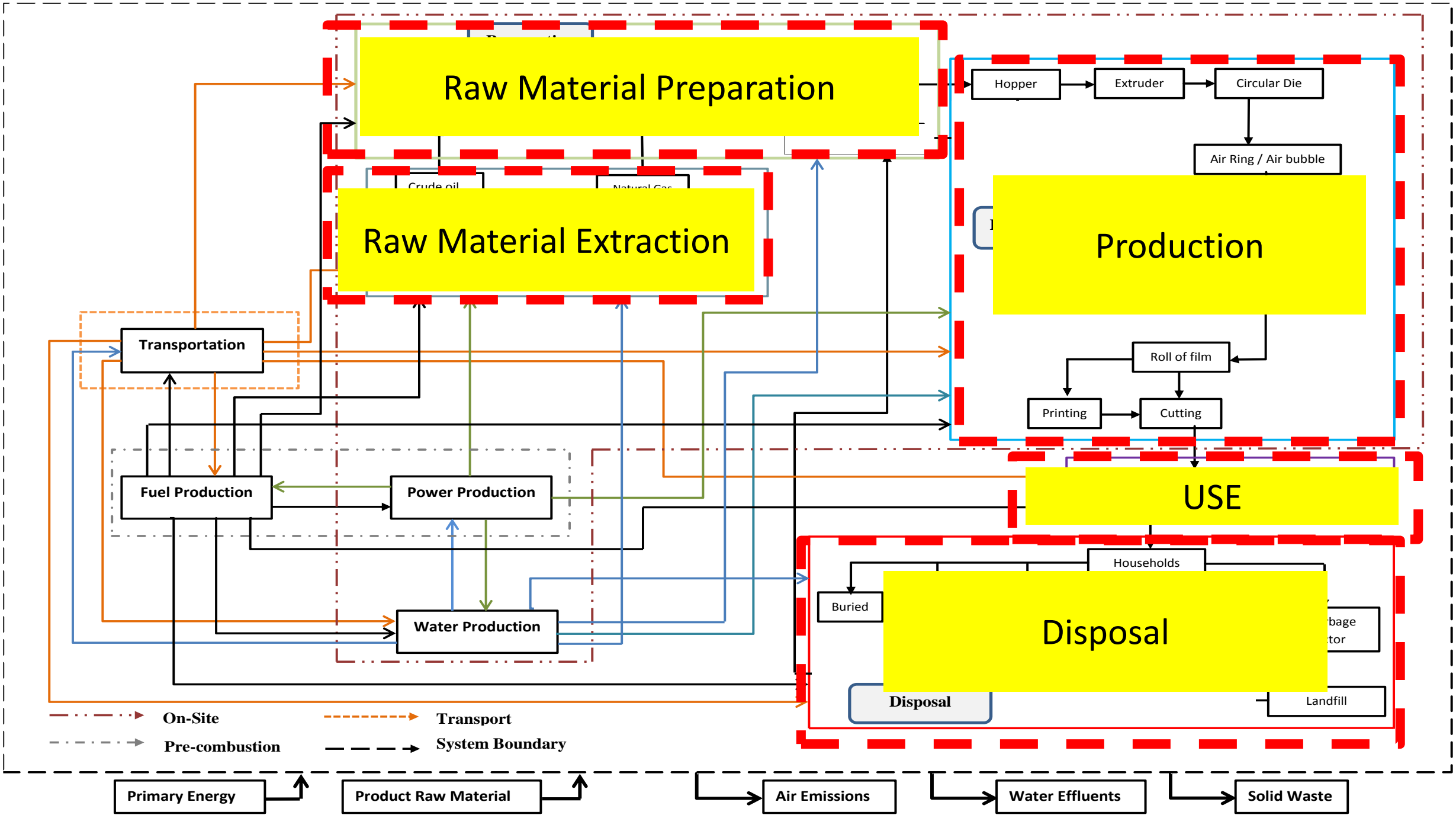
To determine the environmental performance of the production of plastic carrying bags. The bag is made of high density polyethylene (HDPE).

Functional Unit: 1000 kg of carrying plastic bags produced.
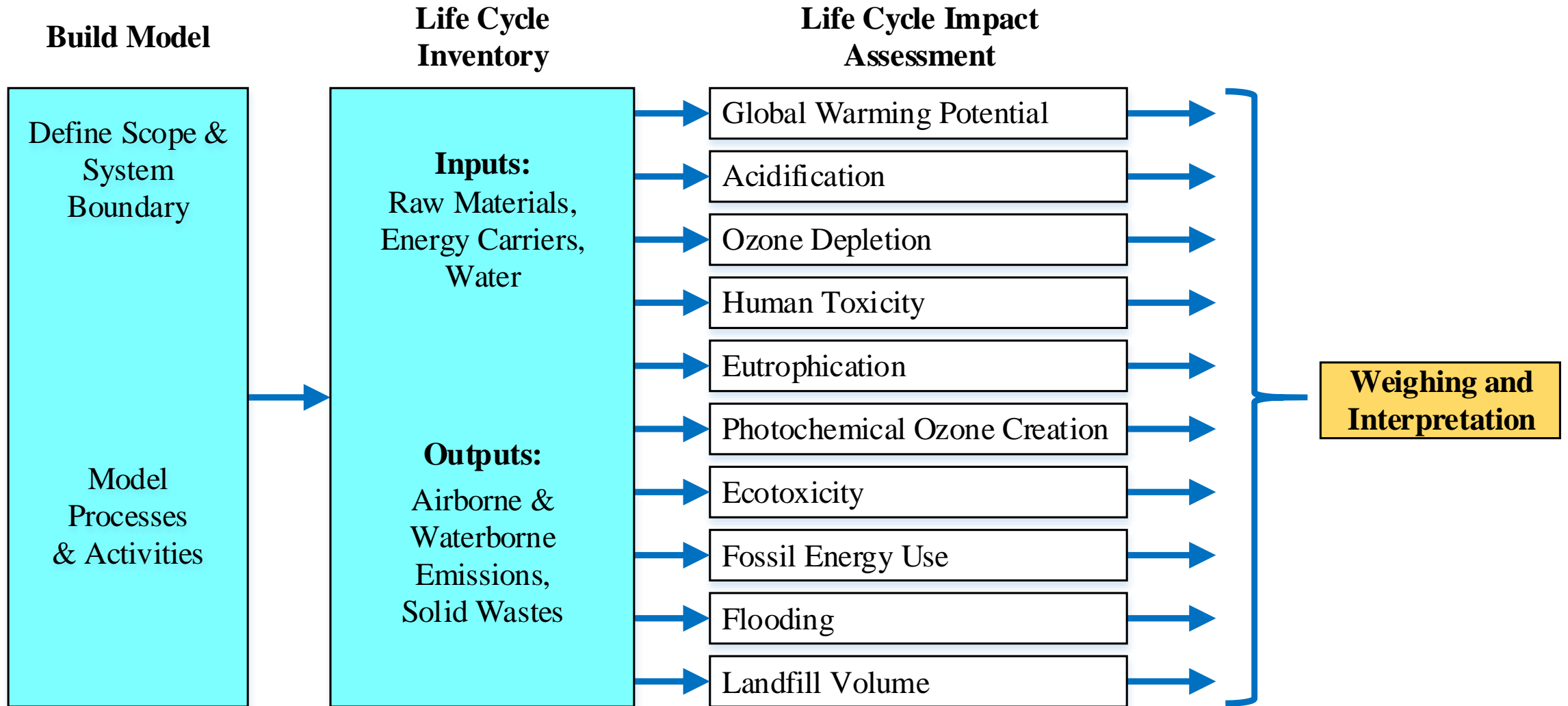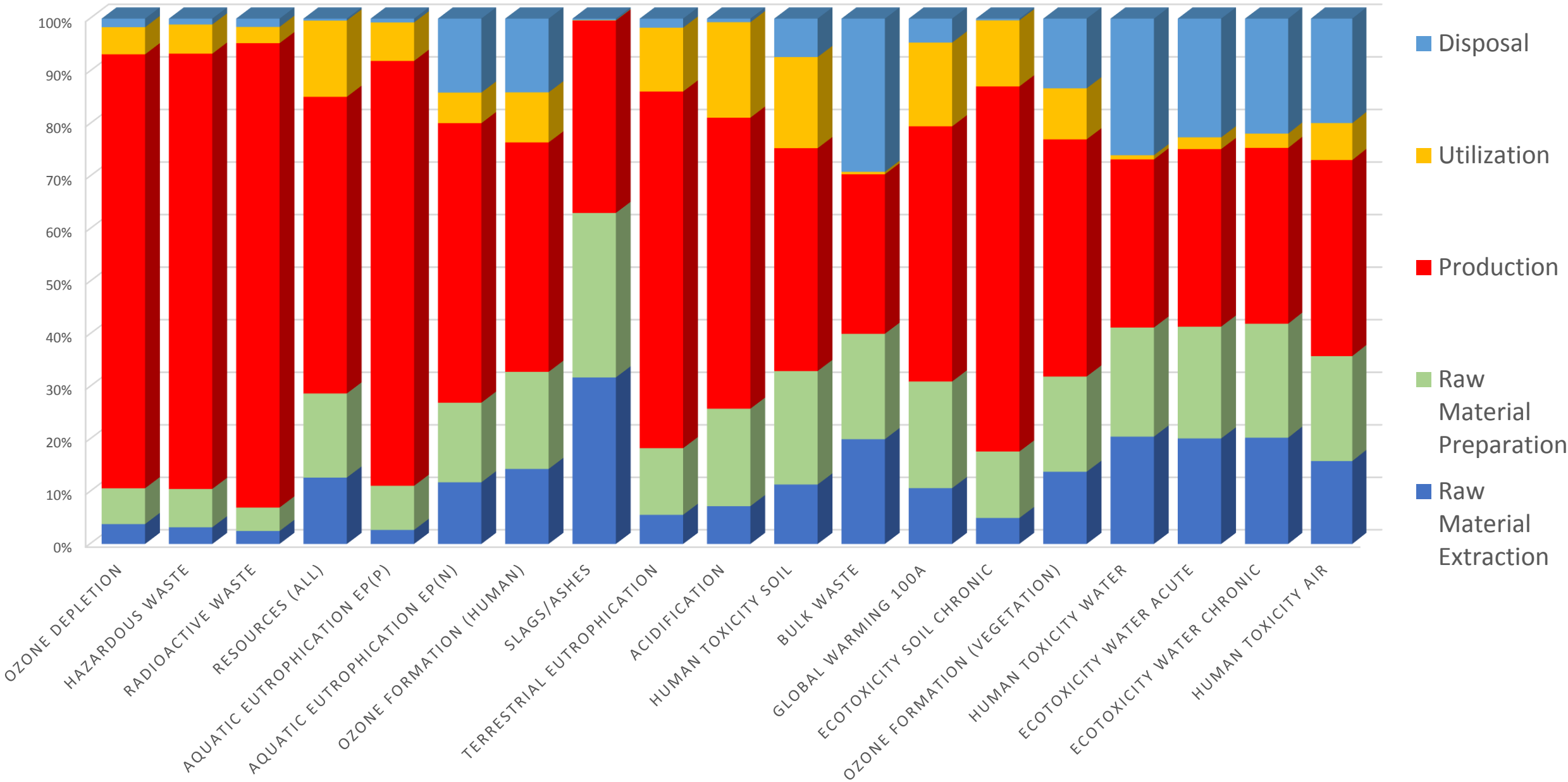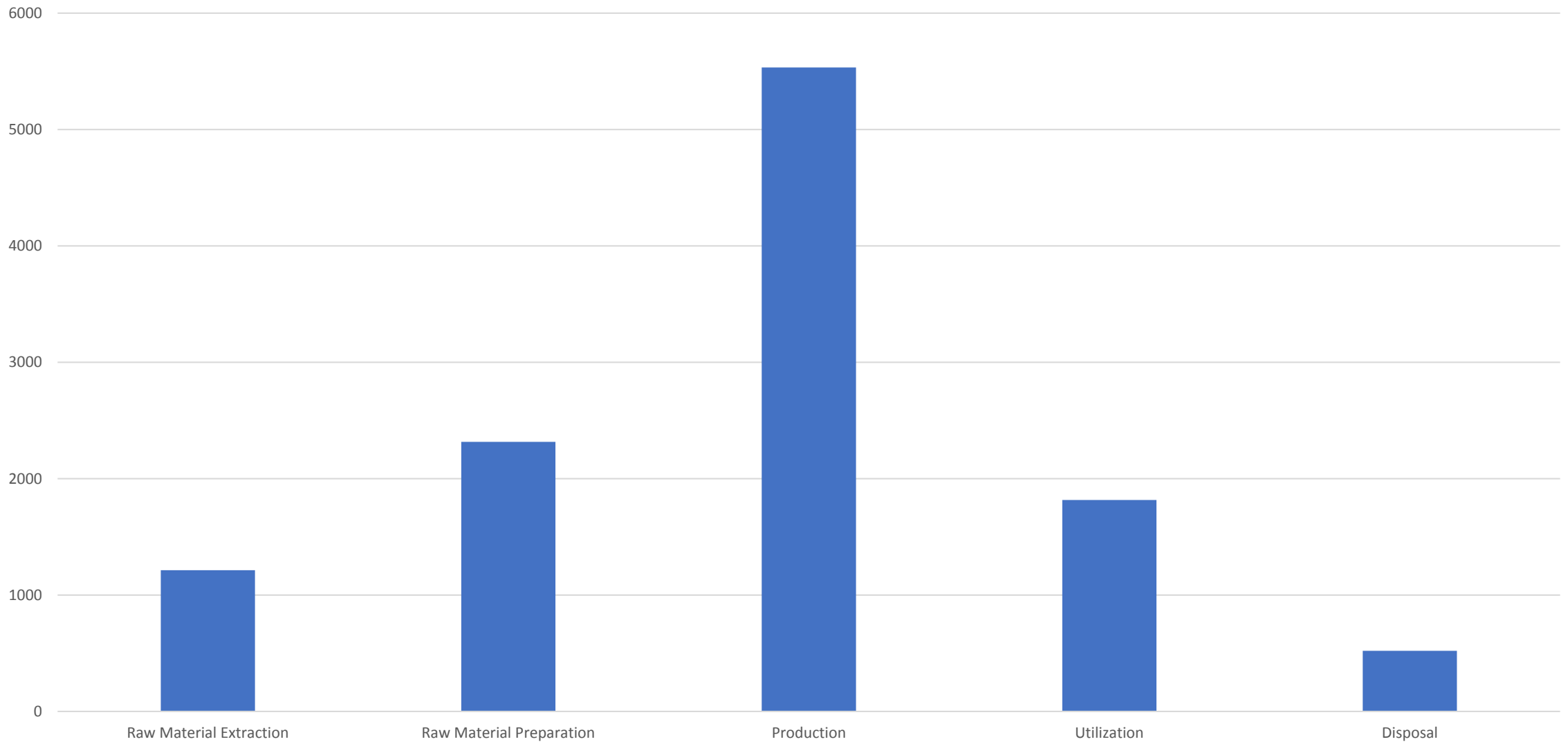
LCA Framework

Cradle-to-grave approach

Extraction
- Crude Oil Production
- Natural Gas Production
- Natural Gas Processing

Preparation
- Distillation, Desalting, and Hydrotreating
- Monomer Production
- Polymer Production

Production
- Compression or Injection
- Blow Molding
- Extrusion
- Calendering
- Vacuum Forming
- Coating

Utilization
- Use

Disposal
- Buried
- Waterways
- Burned
- Recycled
- Landfill

Raw Material Preparation

Raw Material Extraction

Production

Hopper → Extruder → Circular Die

Circular Die → Air Ring / Air bubble

Roll of film

Printing → Cutting

Crude oil   Natural Gas

Transportation

USE

Fuel Production → Power Production

Water Production

Disposal

Households

Buried

Landfill

Disposal

On-Site   Transport

Pre-combustion   System Boundary

Primary Energy   Product Raw Material   Air Emissions   Water Effluents   Solid Waste

	Units	Crude Oil Extraction	Petroleum Refining	Natural Gas Extraction	Natural Gas Processing	Ethylene Production	Polyethylene Production	Plastic Bag Production
Output Product		Crude Oil	Refined Petroleum	Natural Gas	Processed Natural Gas	Olefins (Ethylene)	Polyethylene	Plastic bags
Reference Flow	kg	1000	1000	1000	1000	1000	1000	1000
Input								
Crude oil	kg	1035	1018	-	-	-	-	-
Natural Gas	kg	-	-	1018	1005	-	-	-
Refined Petroleum Products	kg	-	-	-	-	186	-	-
Processed Natural Gas	kg	-	-	-	-	830	-	-
Olefins (Ethylene)	kg	-	-	-	-	-	990	-
Water	liters	-			-			
Polyethylene resins	kg	-			-		-	1005
Ink	Kg	-			-	-	-	65
colorants	kg	-			-	-	-	60
Process Energy Input								
Electricity	kWh	39	143	39	21.3	78.8	178	1501.5
Natural gas	cu.m.	32.8	11.1	32.8	34.6	142	35.5	-
Residual oil	liters	0.80	27.2	0.80	0.050	-	6.01	-
Distillate/Diesel oil	liters	1.29	-	1.29	0.050	0.079	-	-
Gasoline	liters	0.68	-	0.68	0.048	0.091	-	-
LPG	liters	-	1.15	-	-	-	0.038	-
Recovered Energy	MJ	-	-	-	-	29	-	-
Maintenance oil	Kg	-	-	-	-	-	-	0.0075
Lube oil	kg	-	-	-	-	-	-	0.1
Transportation Energy								
Diesel Combination truck	liters	-	1.2	-	0.44	-	-	-
Diesel Rail	liters	-	0.18	-	0.10	-	-	-
Diesel Barge	liters	0.0025	0.49	-	-	-	-	-
Residual Oil Barge	liters	0.0083	1.64	-	-	-	-	-
Diesel Ocean Freight	liters	2.33	-	-	-	-	-	-
Residual Oil Ocean Freight	liters	21.00	-	-	-	-	-	-
Natural Gas Pipeline	cu.m.	-	-	-	21.5	-	-	-

Raw Material Extraction

Production

Preparation

PERCENT OF LIFE CYCLE STAGES IN EACH IMPACT CATEGORY

Legend:
- Disposal
- Utilization
- Production
- Raw Material Preparation
- Raw Material Extraction

Categories (x-axis):
OZONE DEPLETION, HAZARDOUS WASTE, RADIOACTIVE WASTE, RESOURCES (ALL), AQUATIC EUTROPHICATION EP(P), AQUATIC EUTROPHICATION EP(N), OZONE FORMATION (HUMAN), SLAGS/ASHES, TERRESTRIAL EUTROPHICATION, ACIDIFICATION, HUMAN TOXICITY SOIL, BULK WASTE, GLOBAL WARMING 100A, ECOTOXICITY SOIL CHRONIC, OZONE FORMATION (VEGETATION), HUMAN TOXICITY WATER, ECOTOXICITY WATER ACUTE, ECOTOXICITY WATER CHRONIC, HUMAN TOXICITY AIR

Global warming 100a

	Raw Material Extraction	Raw Material Preparation	Production	Utilization	Disposal

Acidification

Ozone depletion
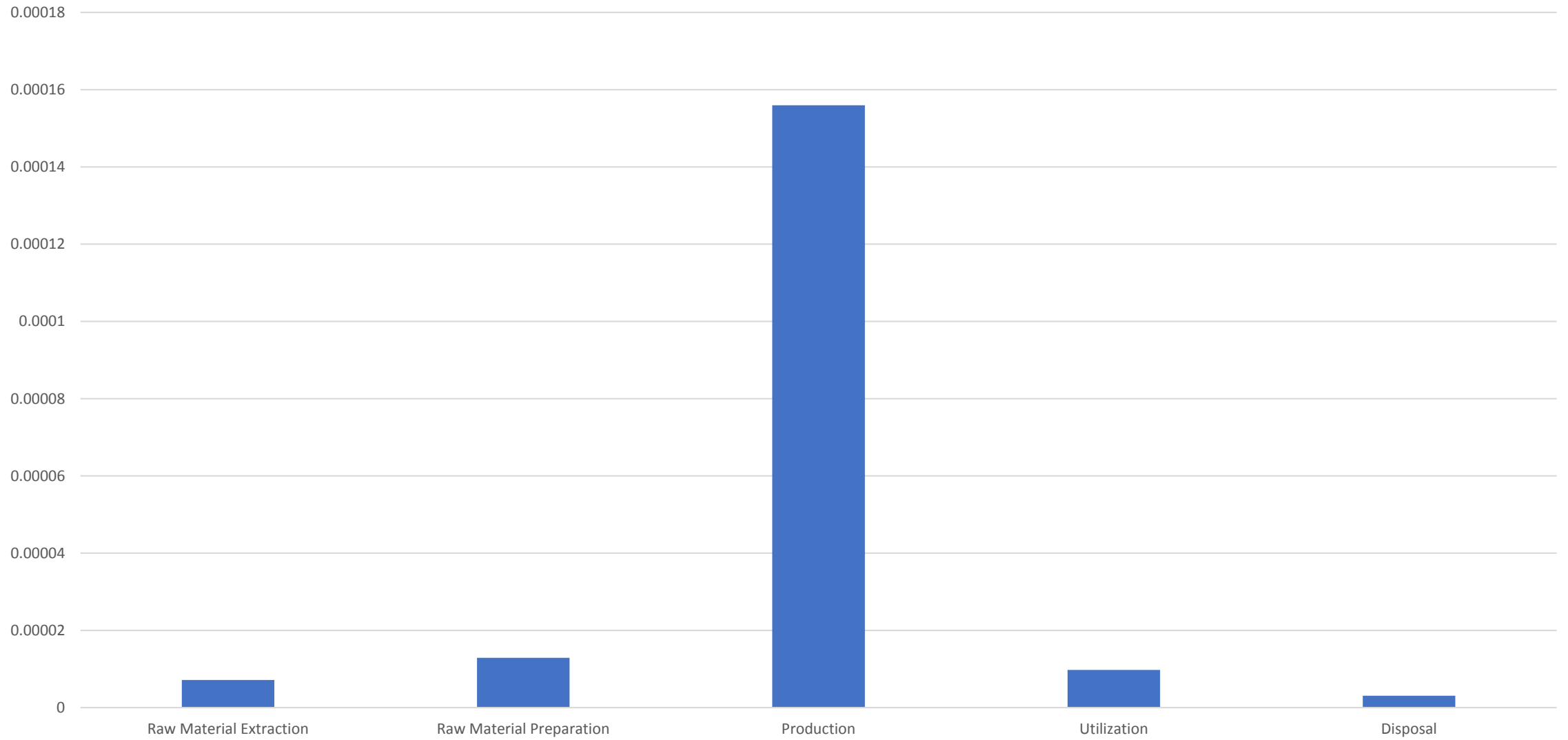
Single Score

Single score allows you to easily compare the environmental impact of different products or scenarios, or stage in the life cycle. It is much easier to explain a single score for environmental impact than it is to explain 3 to 18 different scores per product or scenario.

All environmental impact scores are converted with a single unit and then added to determine a single score amount.
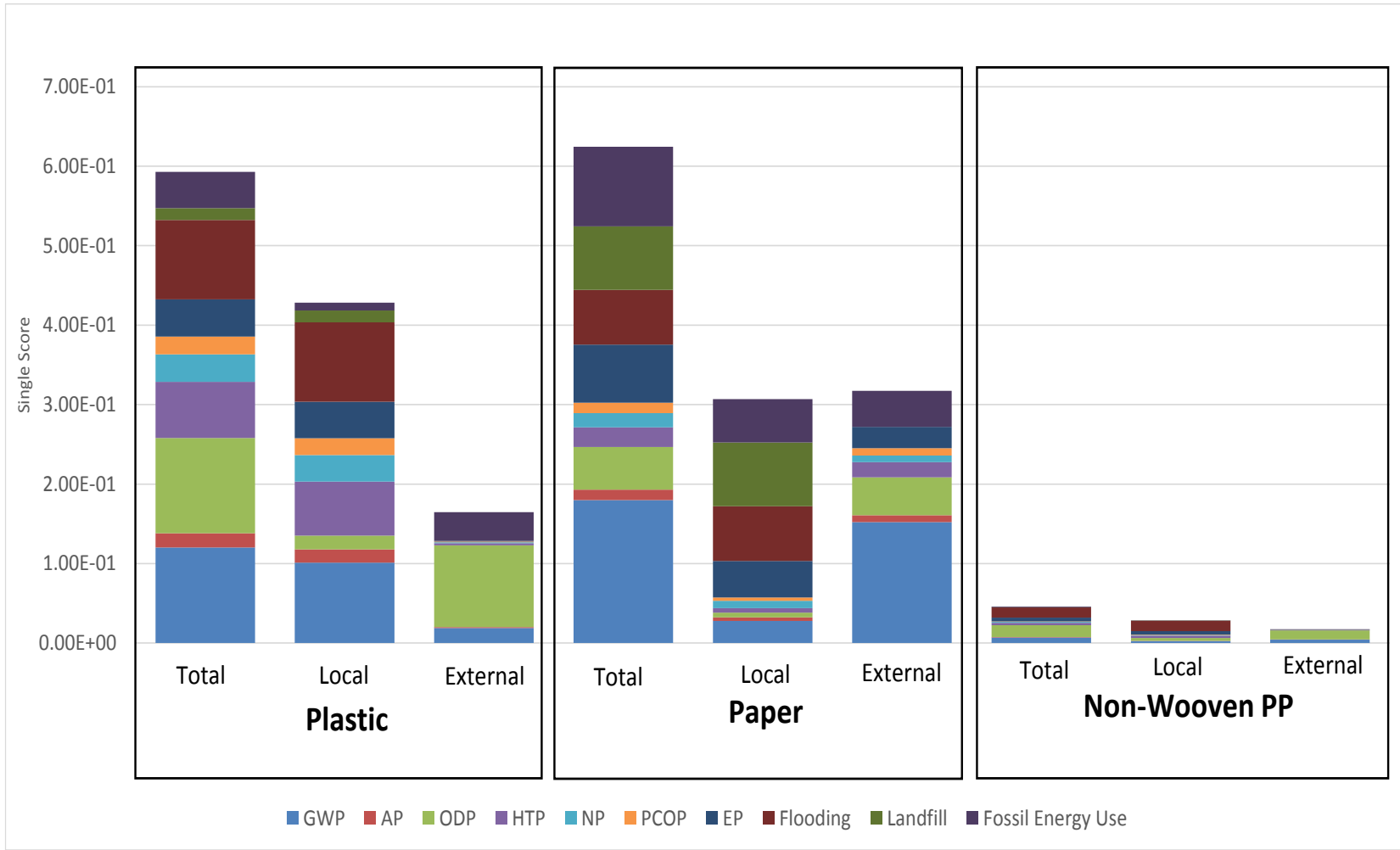
Single Score
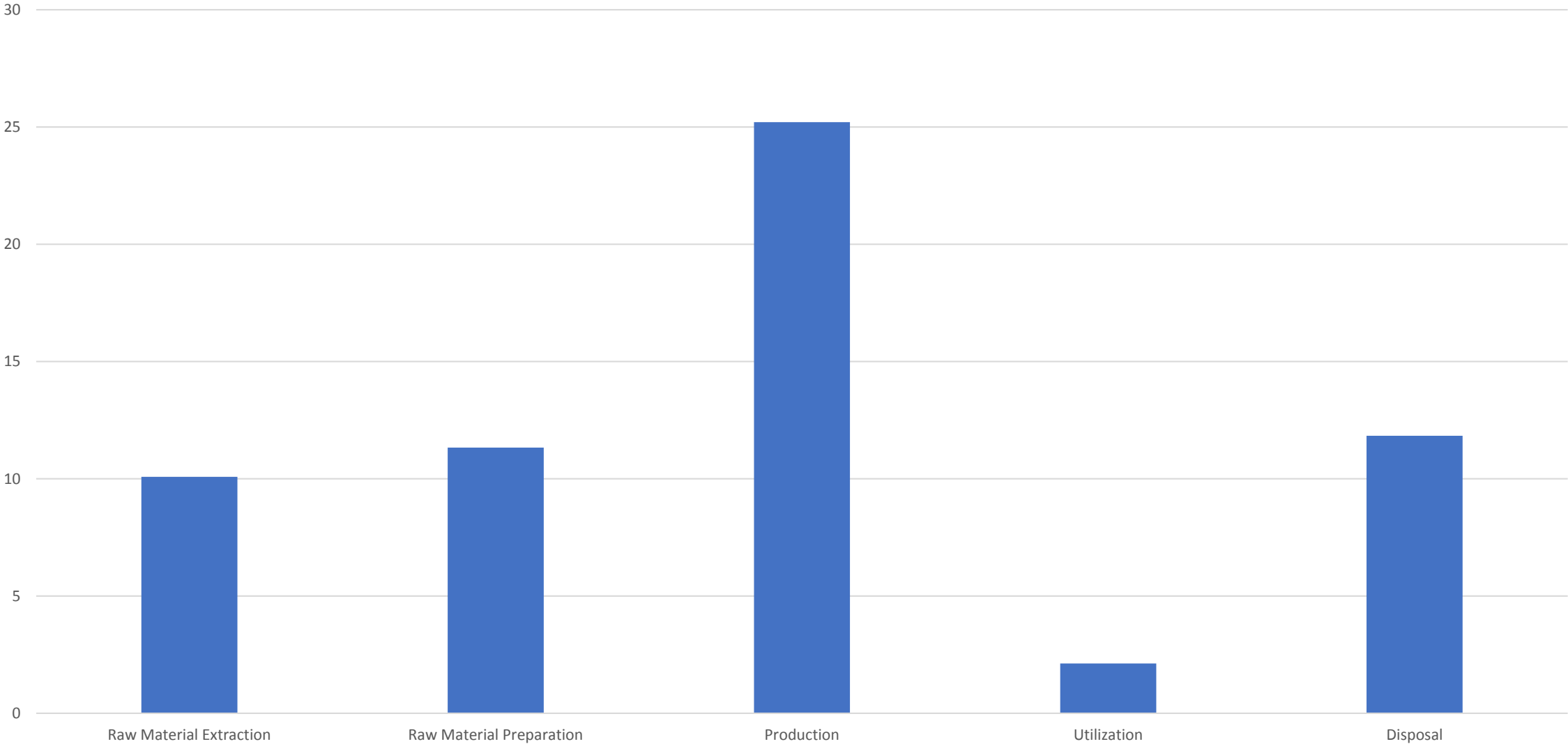
Conclusion

- Production stage has the biggest damage among the life cycle stages of producing single-use plastic carrying bags.
- It is encouraged to adapt to reusable bags.

Conclusion

Based from a study (Biona, 2017), **Reusable bags** has considerably less environmental impact compared to plastic bags and paper bags.

Source: Biona, 2017

Sources

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- Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., ... & Noble, K. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports, 8(1), 4666. Available at: https://www.nature.com/articles/s41598-018-22939-w.

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