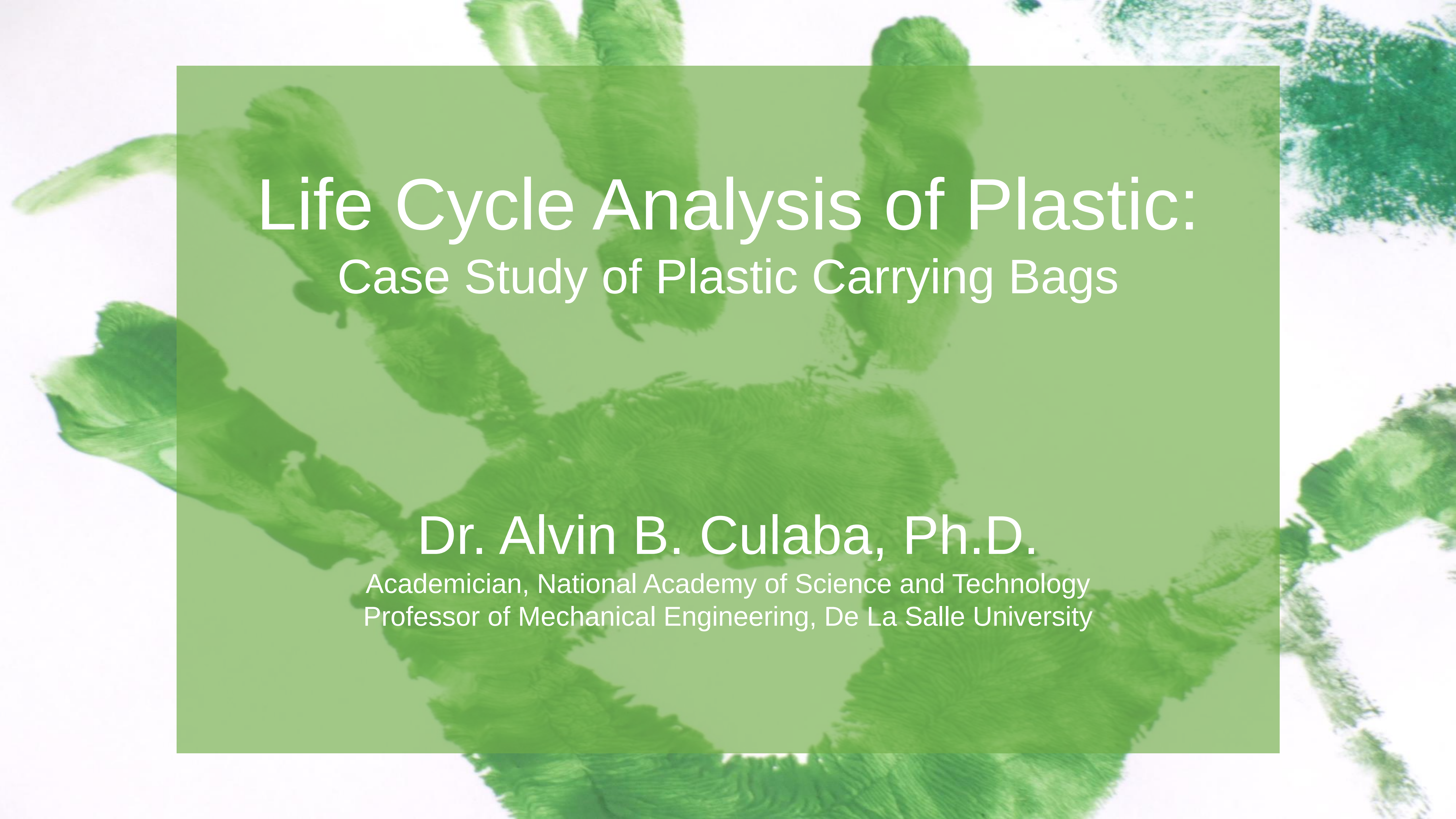


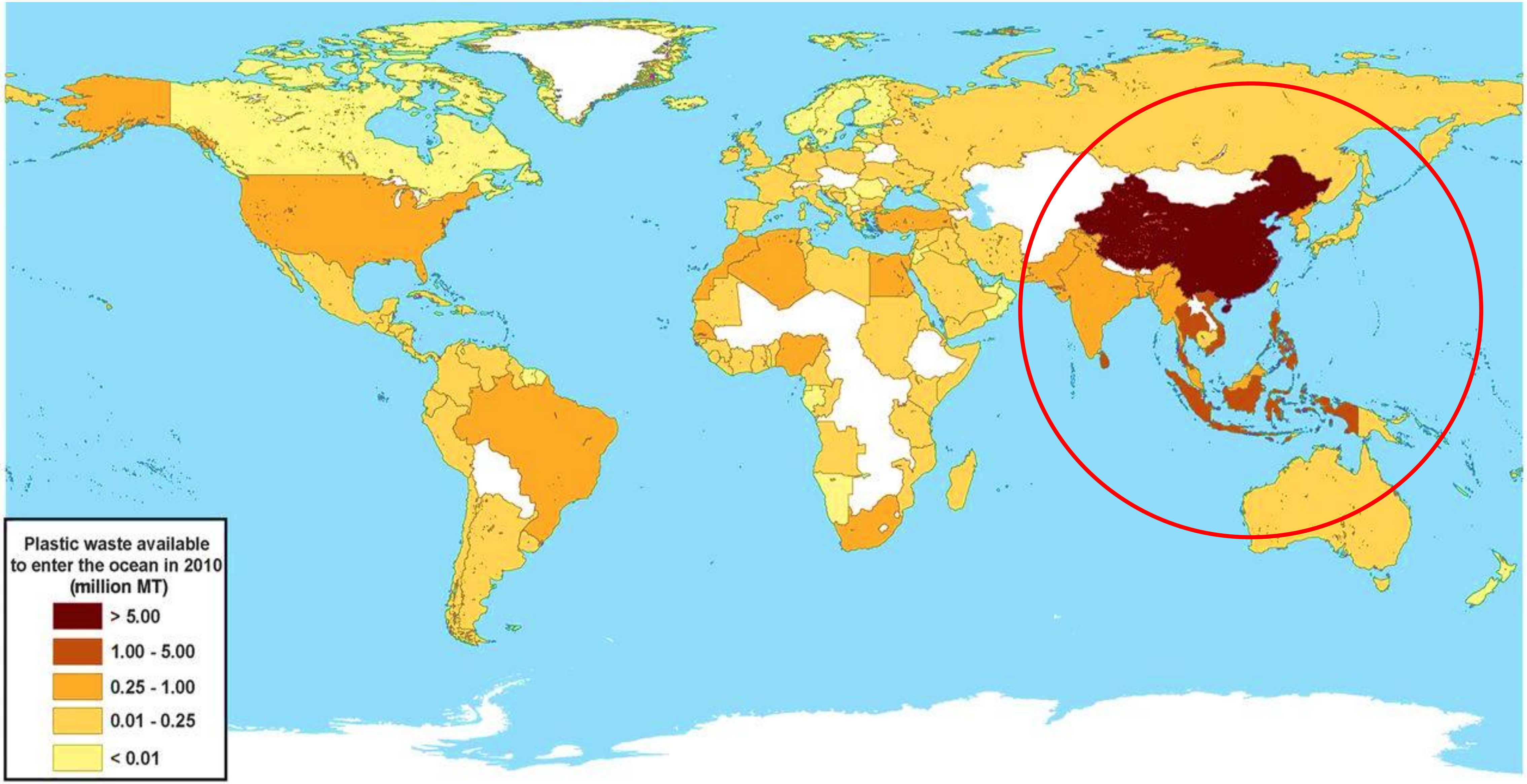
Life Cycle Analysis of Plastic:

Case Study of Plastic Carrying Bags

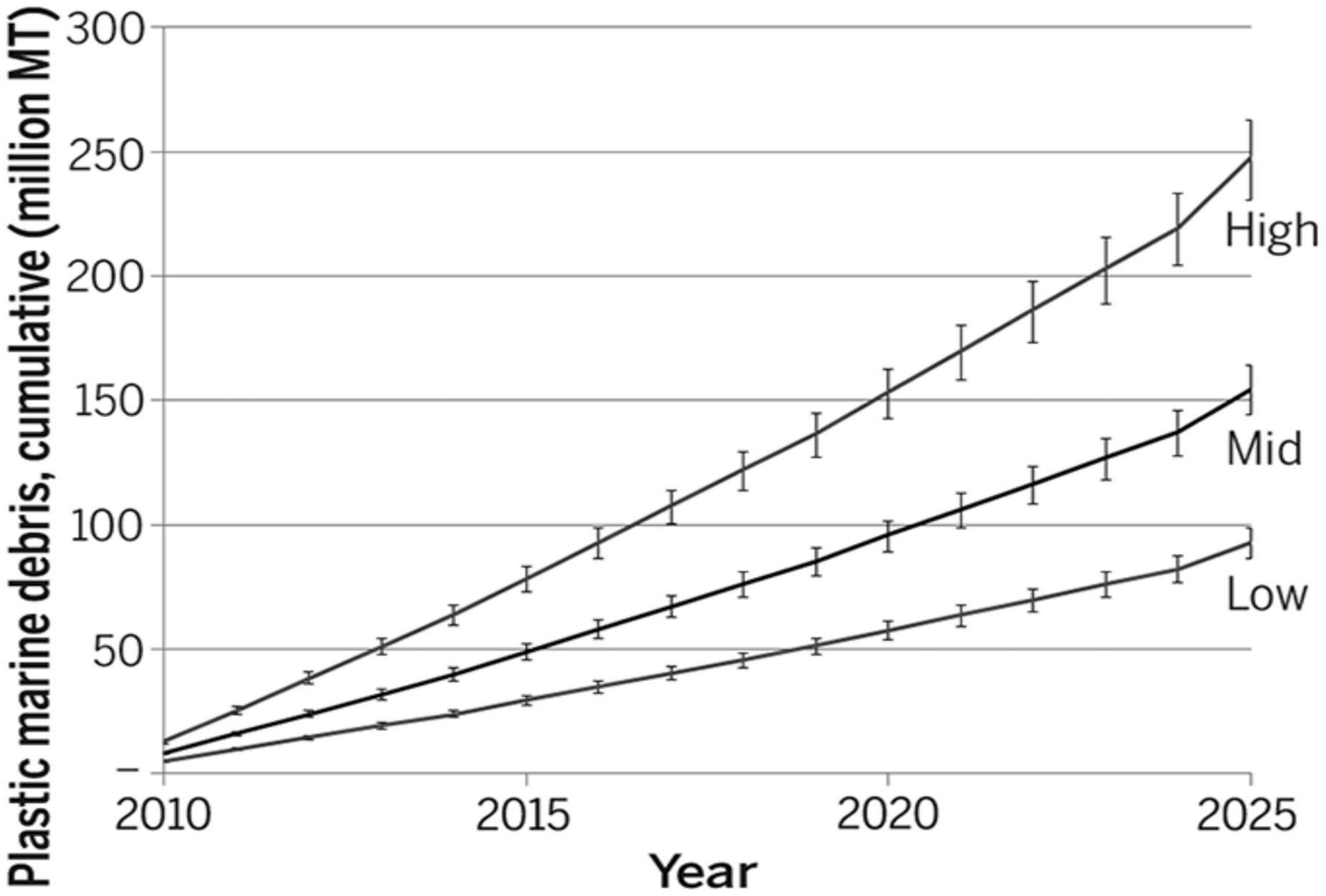
Dr. Alvin B. Culaba, Ph.D.
Academician, National Academy of Science and Technology
Professor of Mechanical Engineering, De La Salle University

" 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.



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.

source: Image by Judgefloro via Wikimedia Commons.

Source: www.scmp.com

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.”

Source: www.no-burn.org

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

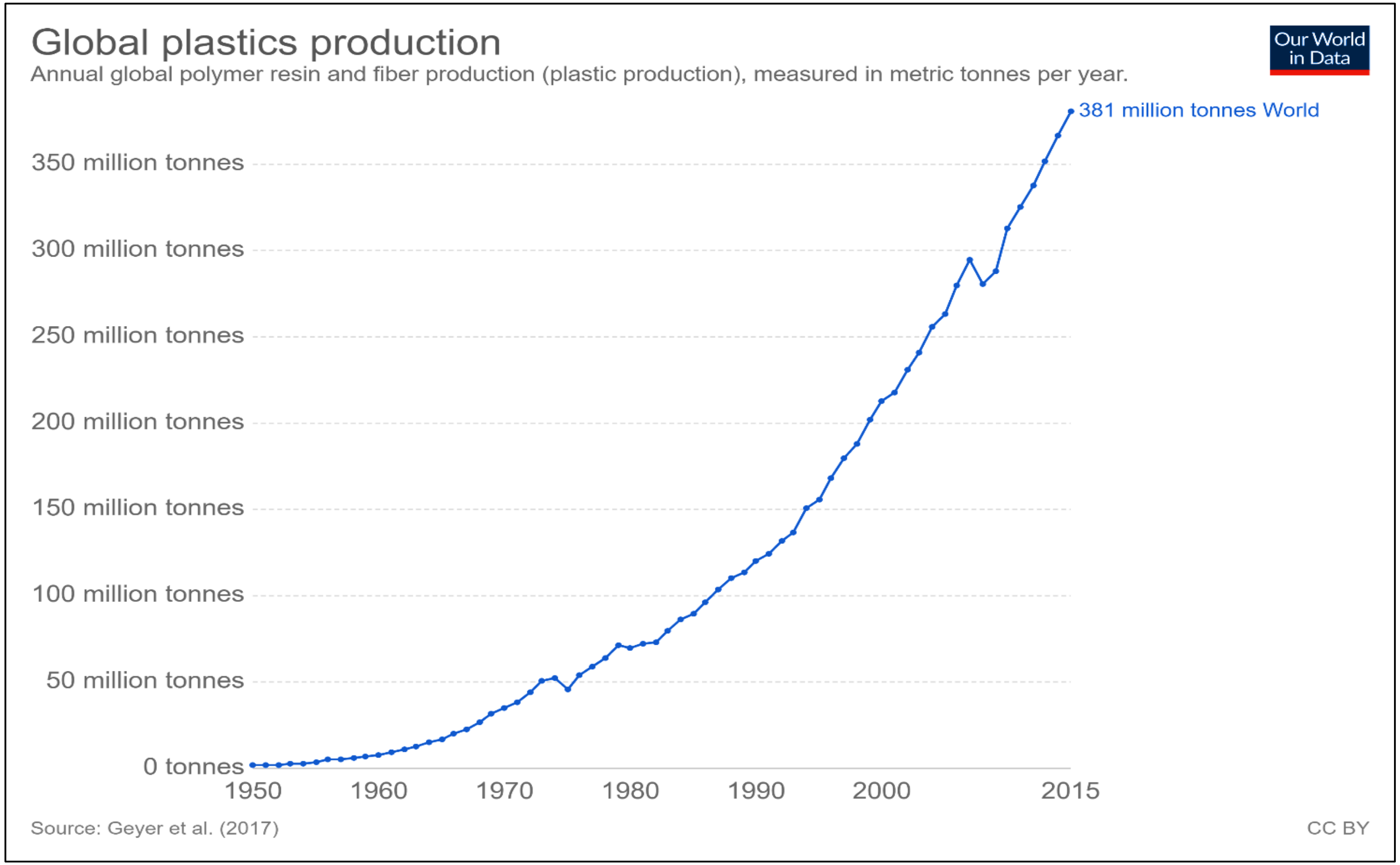
- Biodegradable
  - Biodegradable materials can be broken down by microorganisms (bacteria or fungi) into water carbon dioxide (CO2) and methane (CH4) and microbial biomass.

- 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

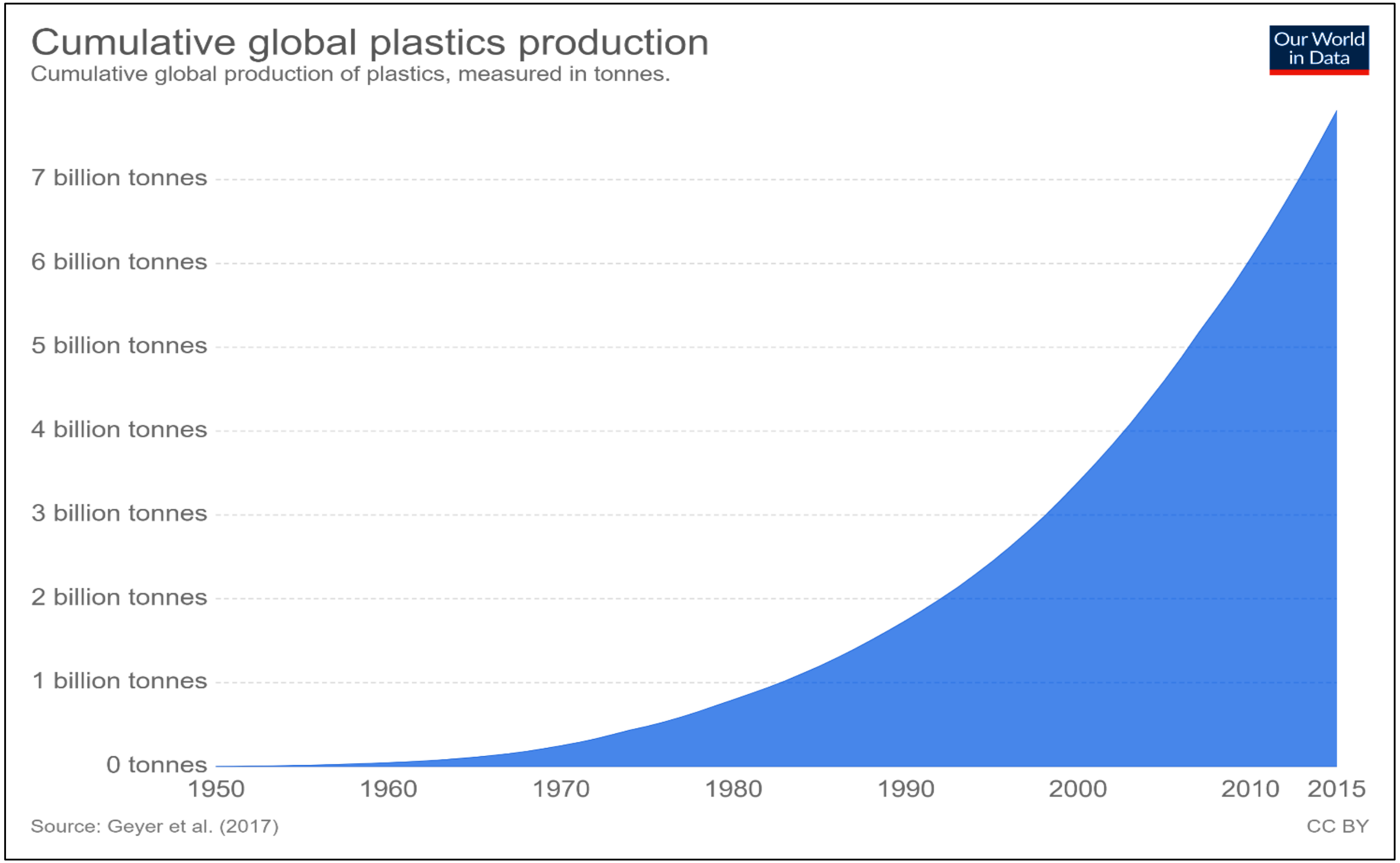
Global Plastics Production



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

Geyer et al. (2017)

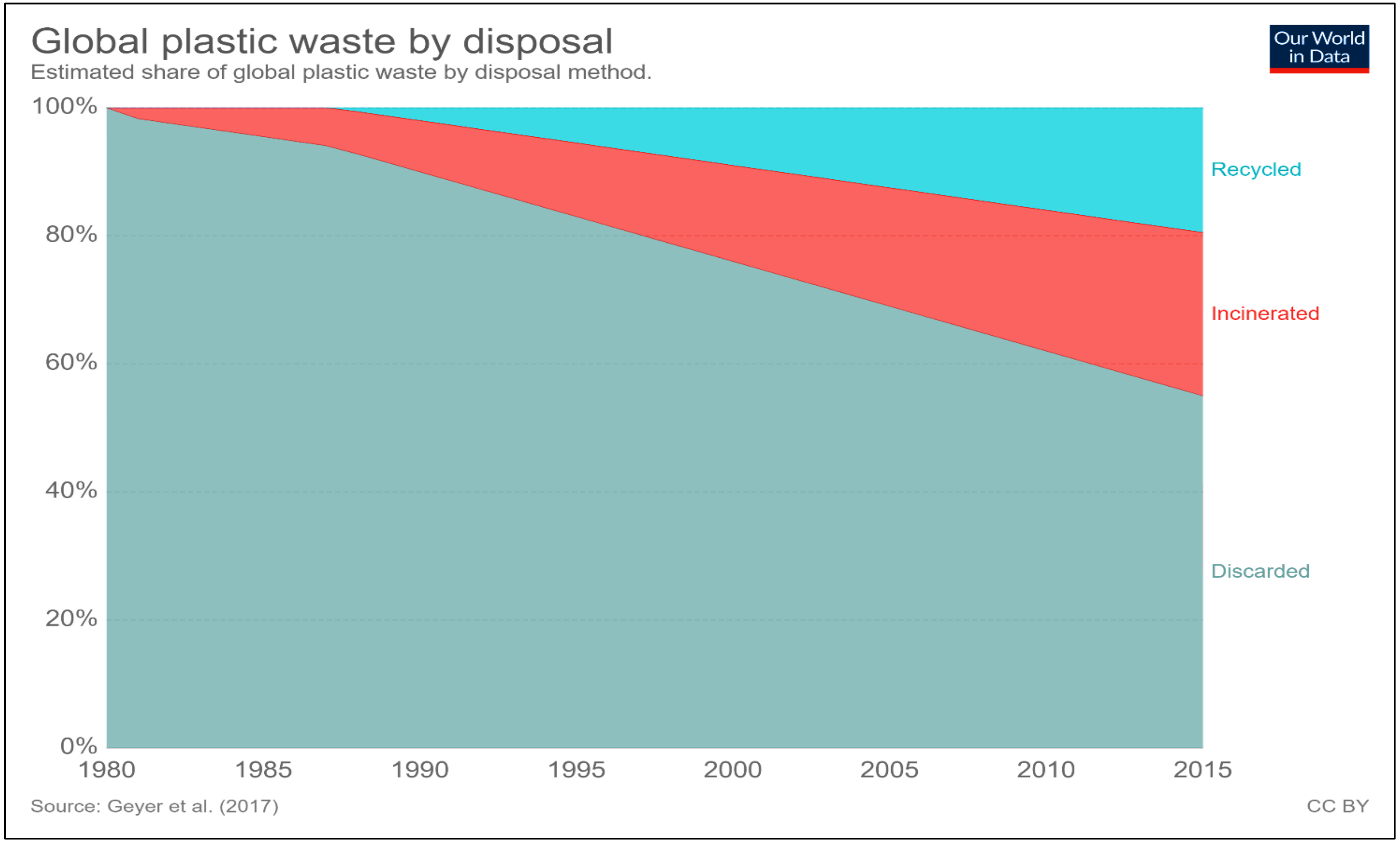
Global Plastic Production



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

Geyer et al. (2017)

Global Plastic Waste by Disposal

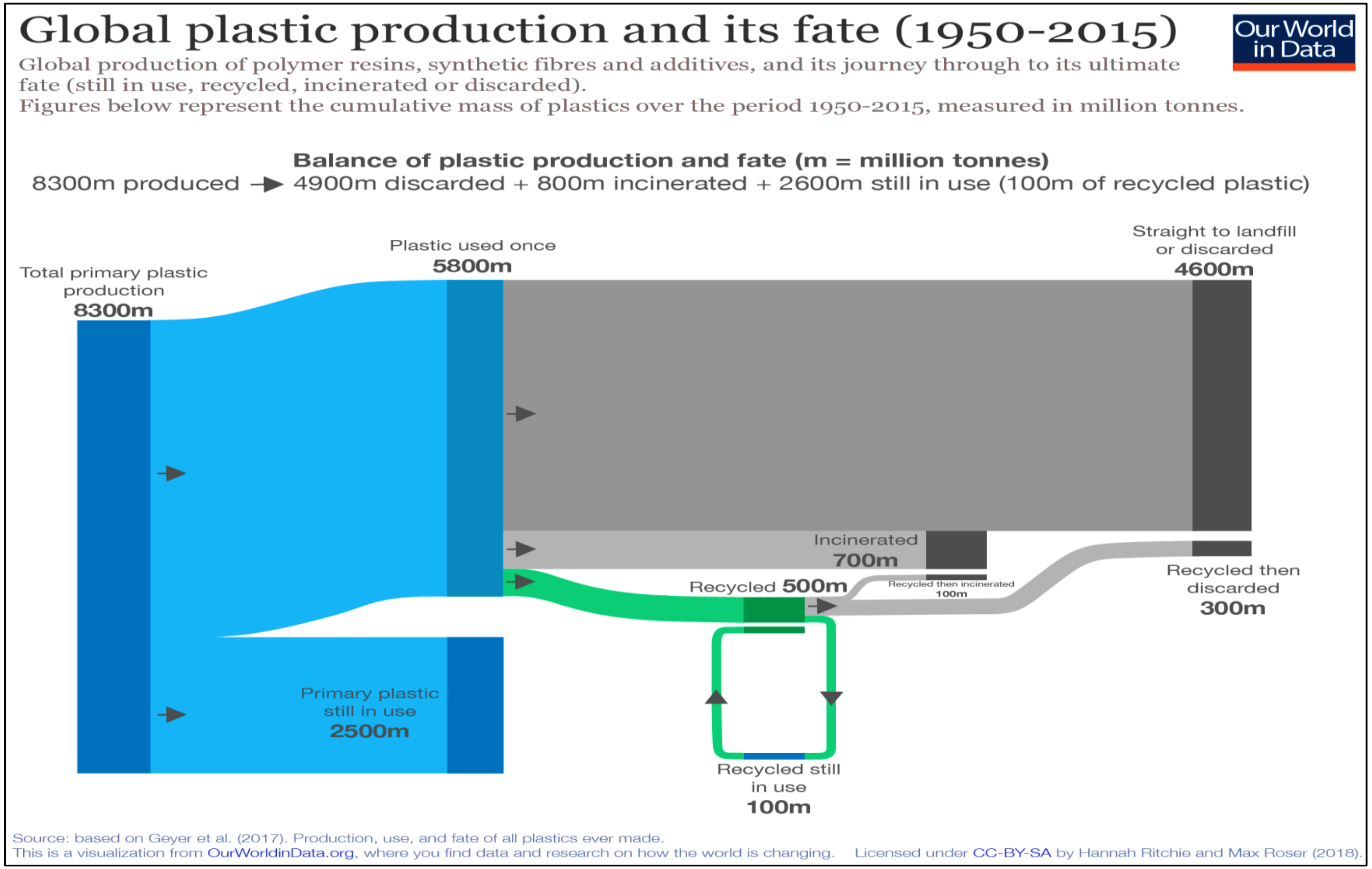


In 2015, plastics were disposed in the following methods

- 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.

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

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).

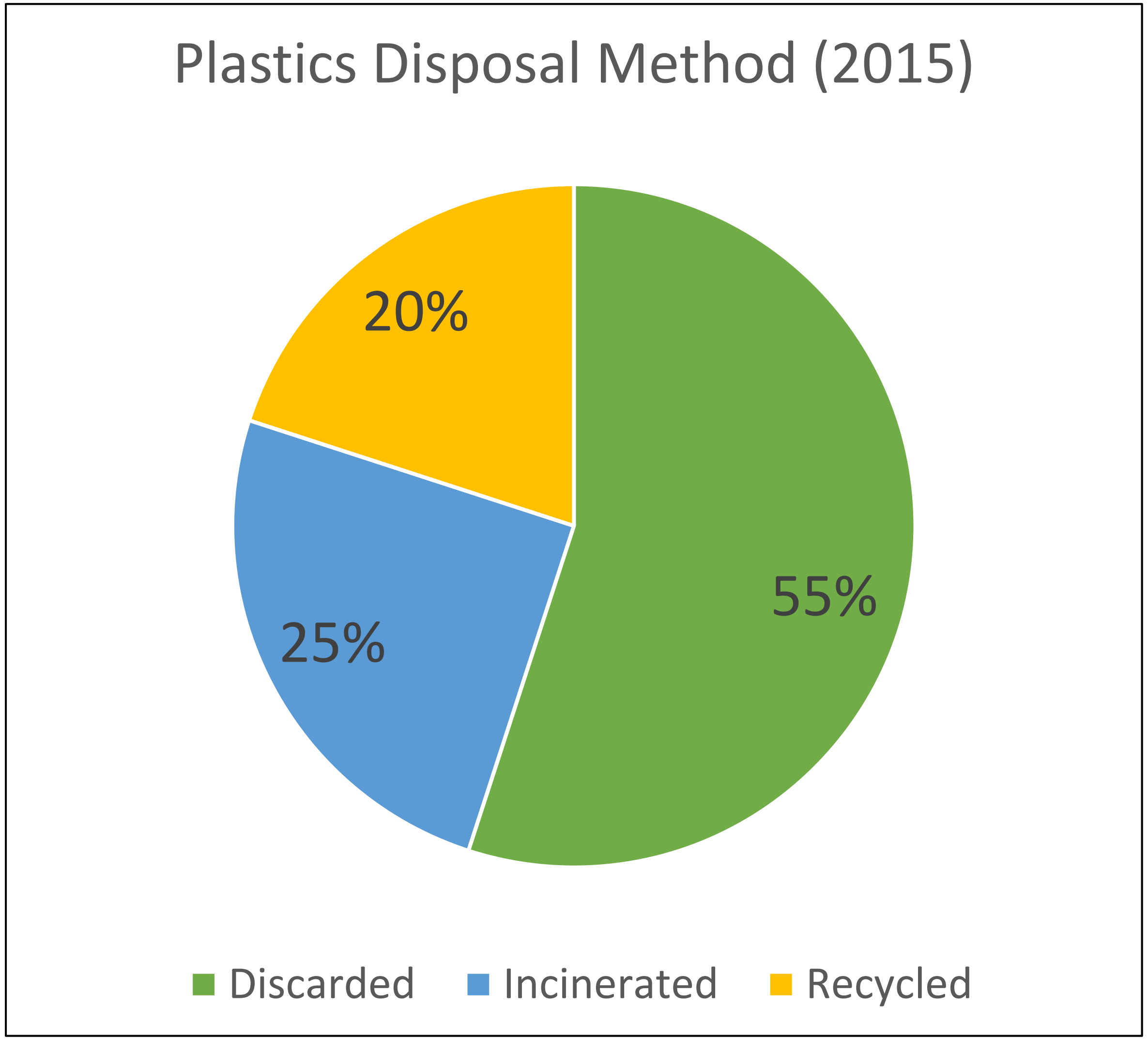
All the plastics produced from 1950 to 2015 went to the following

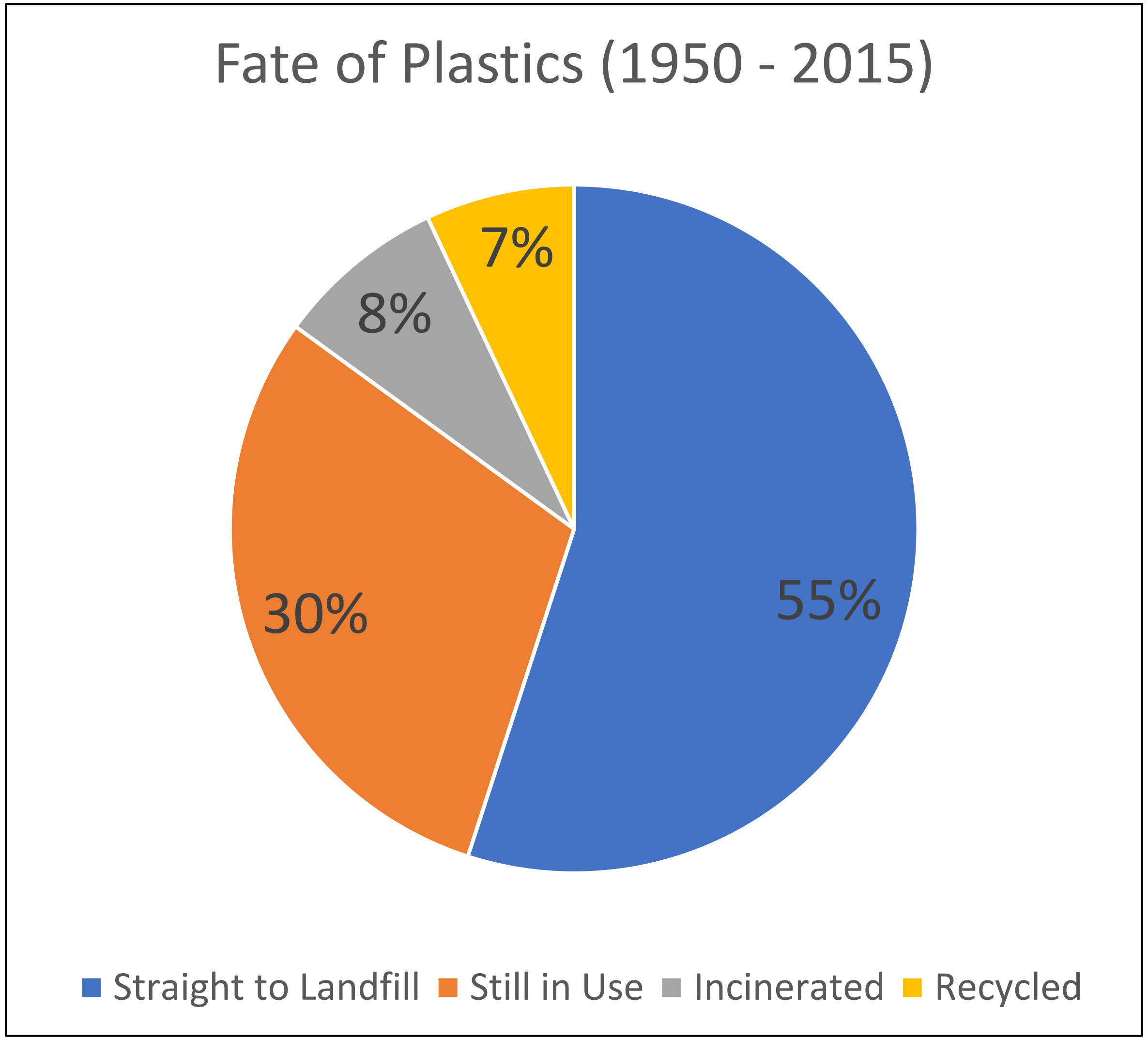
- Straight to landfill (55%)
- Still in use (30%)
- Incinerated (8%)
- Recycled (6-7%)

Only 9% of the plastics no longer in used was recycled.

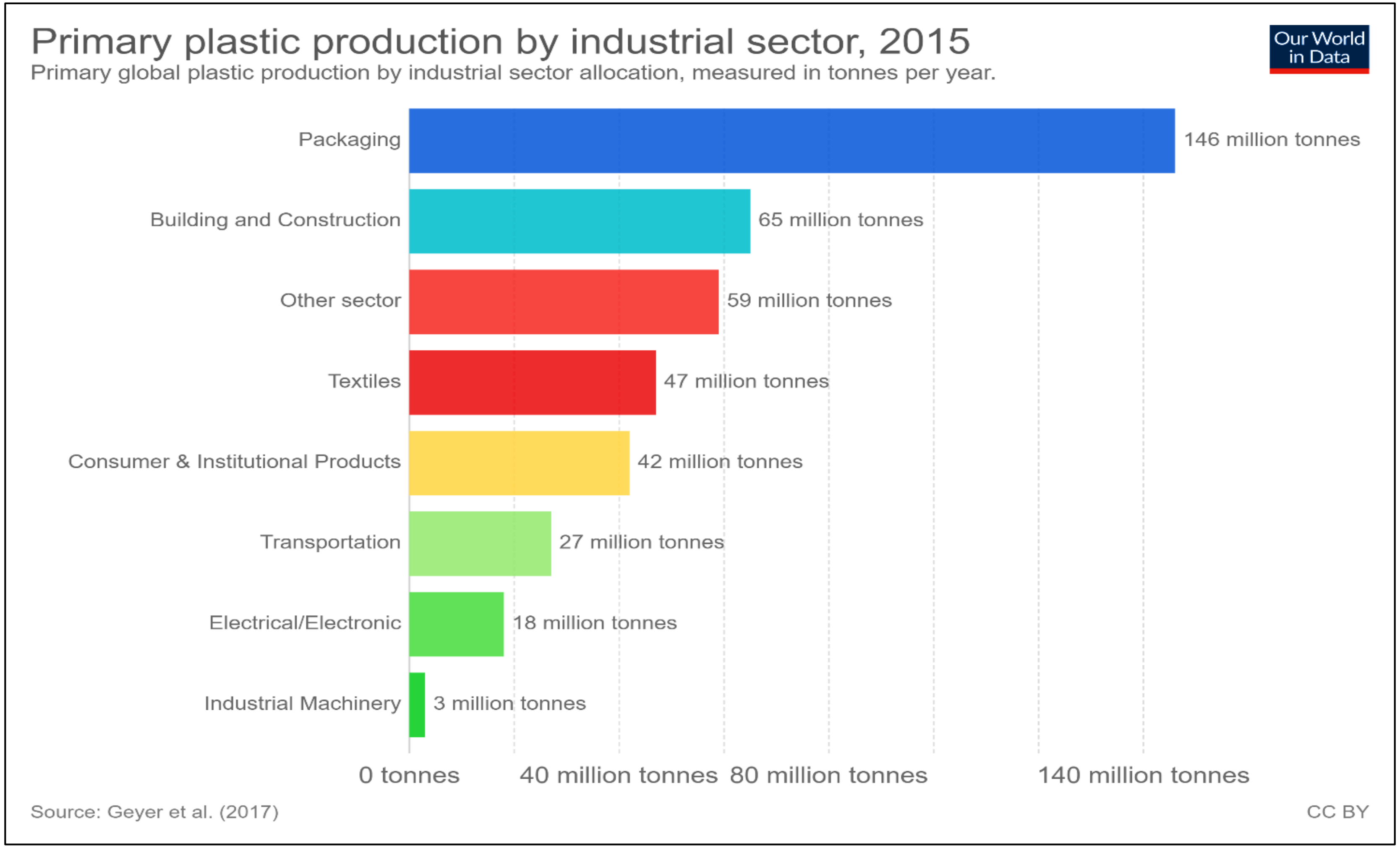
Geyer et al. (2017)

Disposal Method and Fate of Plastics Summary





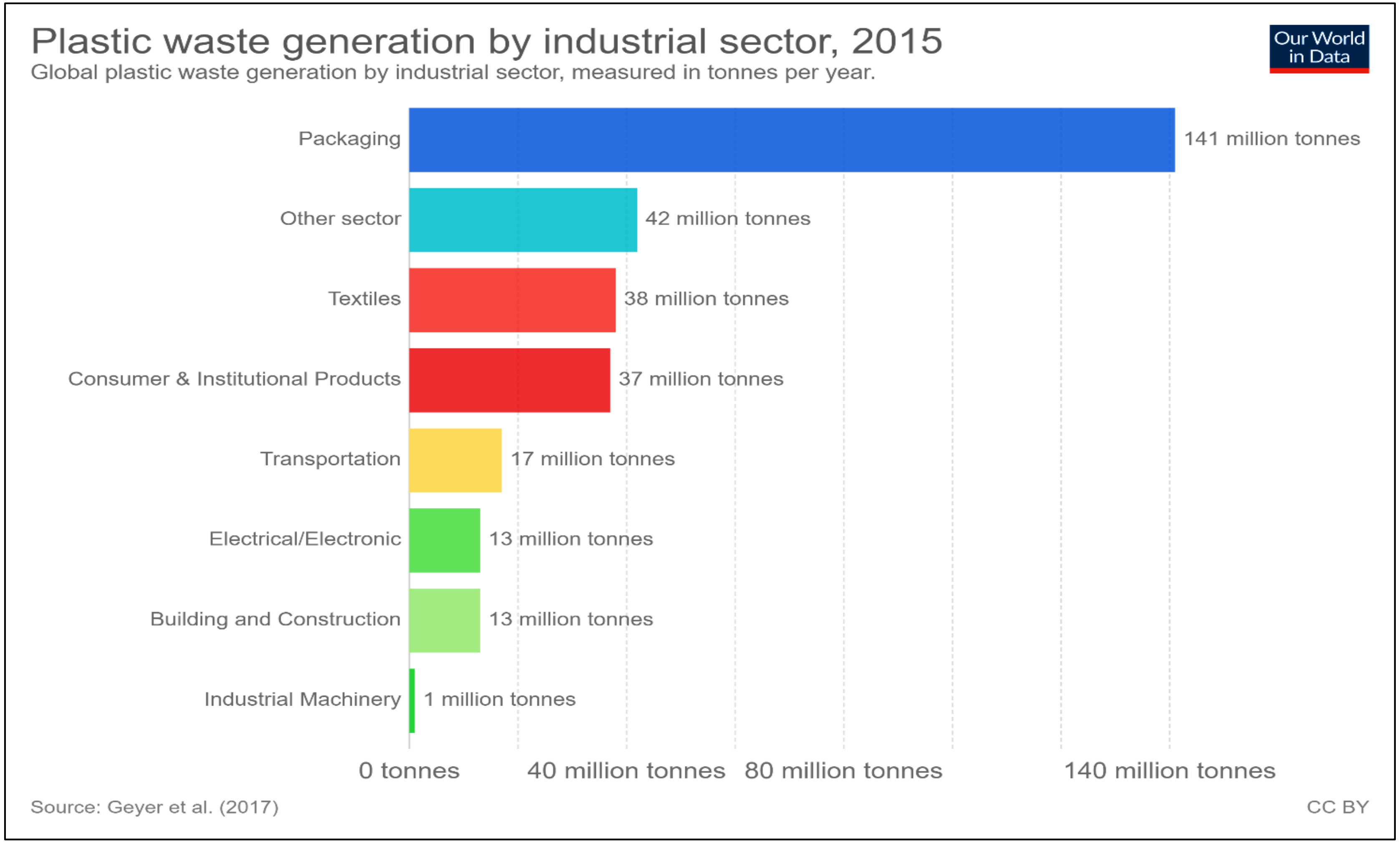
Plastic Production by Industrial Sector



Packaging is leading at 146 million tons in 2015

Geyer et al. (2017)

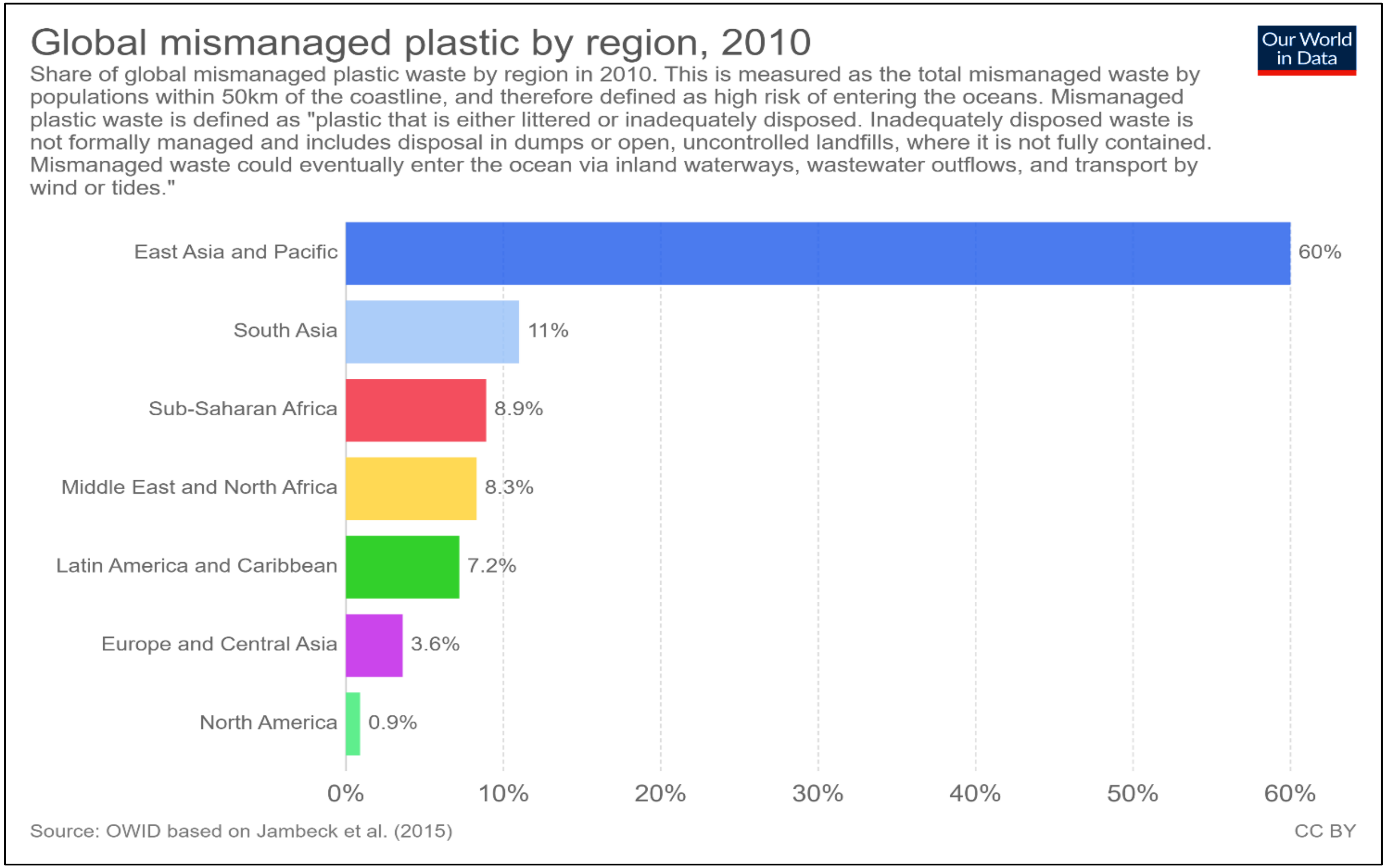
Plastic Waste Generation by Industrial Sector



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

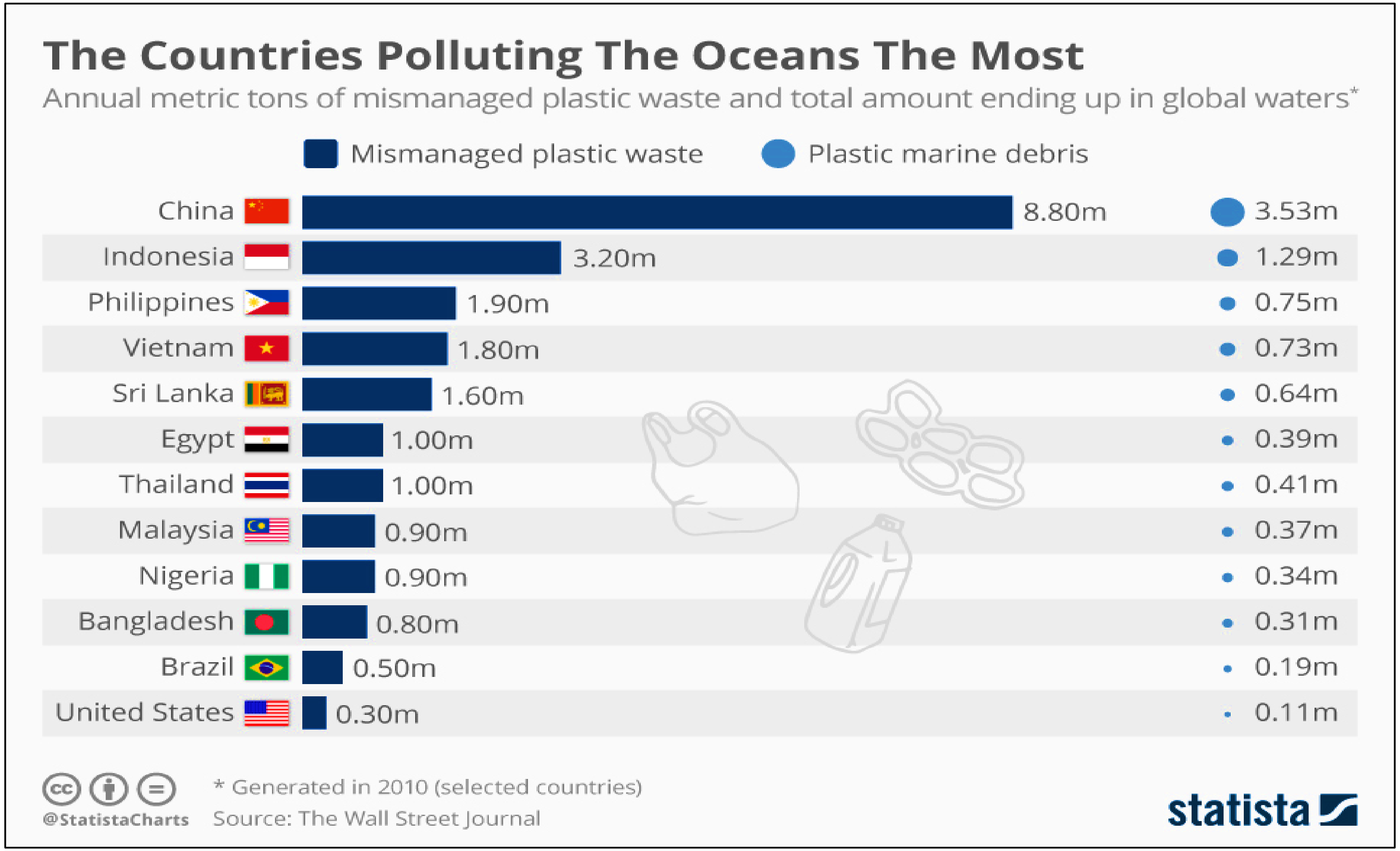
Share of global mismanaged plastic waste by region in 2010. This is measured as the total mismanaged waste by populations within 50km of the coastline, and therefore defined as high risk of entering the oceans. Mismanaged plastic waste is defined as "plastic that is either littered or inadequately disposed. 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."

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

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

Jambeck et al. (2015)

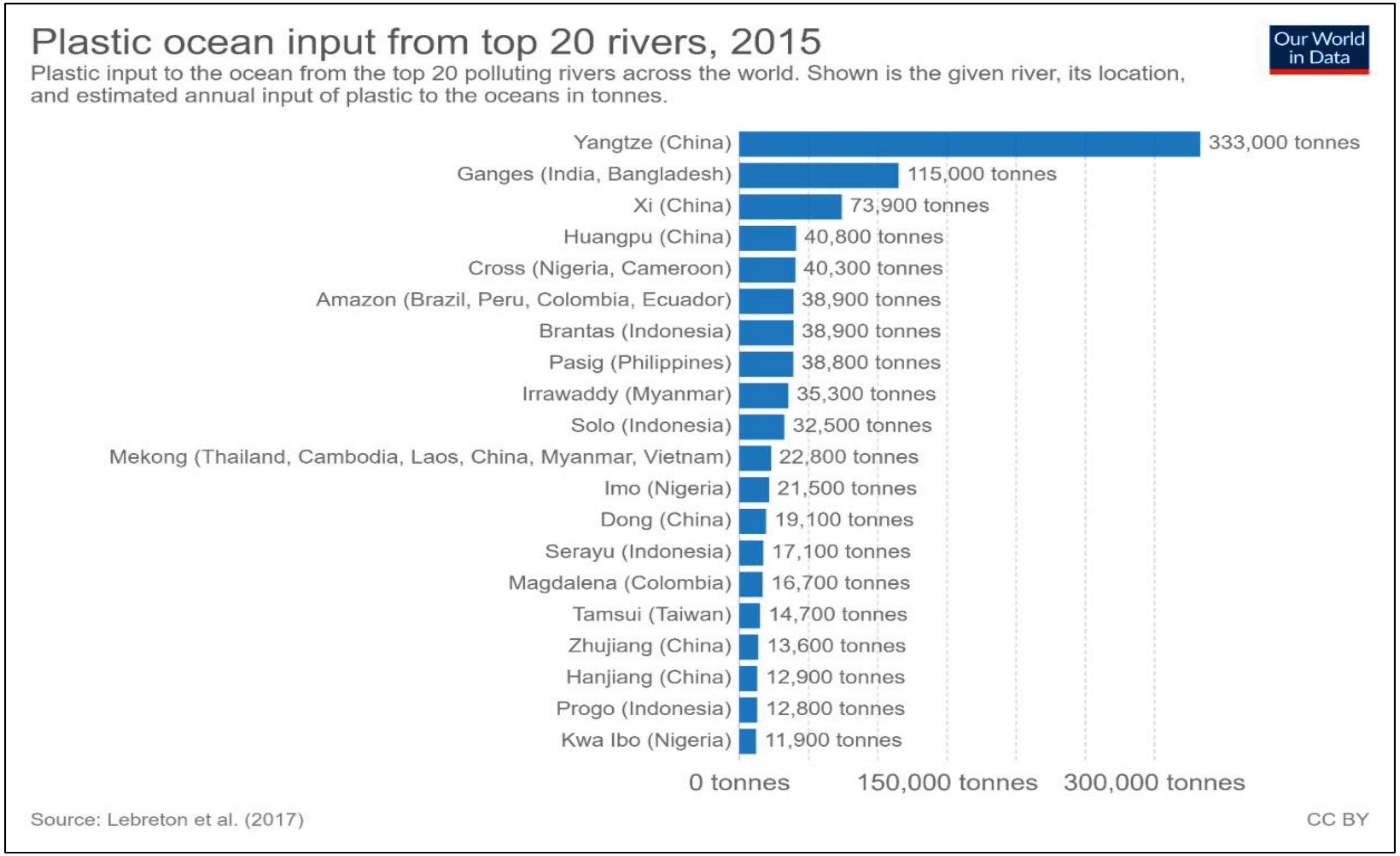
Top Ocean-Polluting Countries



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.

Source: Lebreton et al. (2017)

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.

Source: Greener Ideal (2018)

Life Cycle Assessment (LCA)

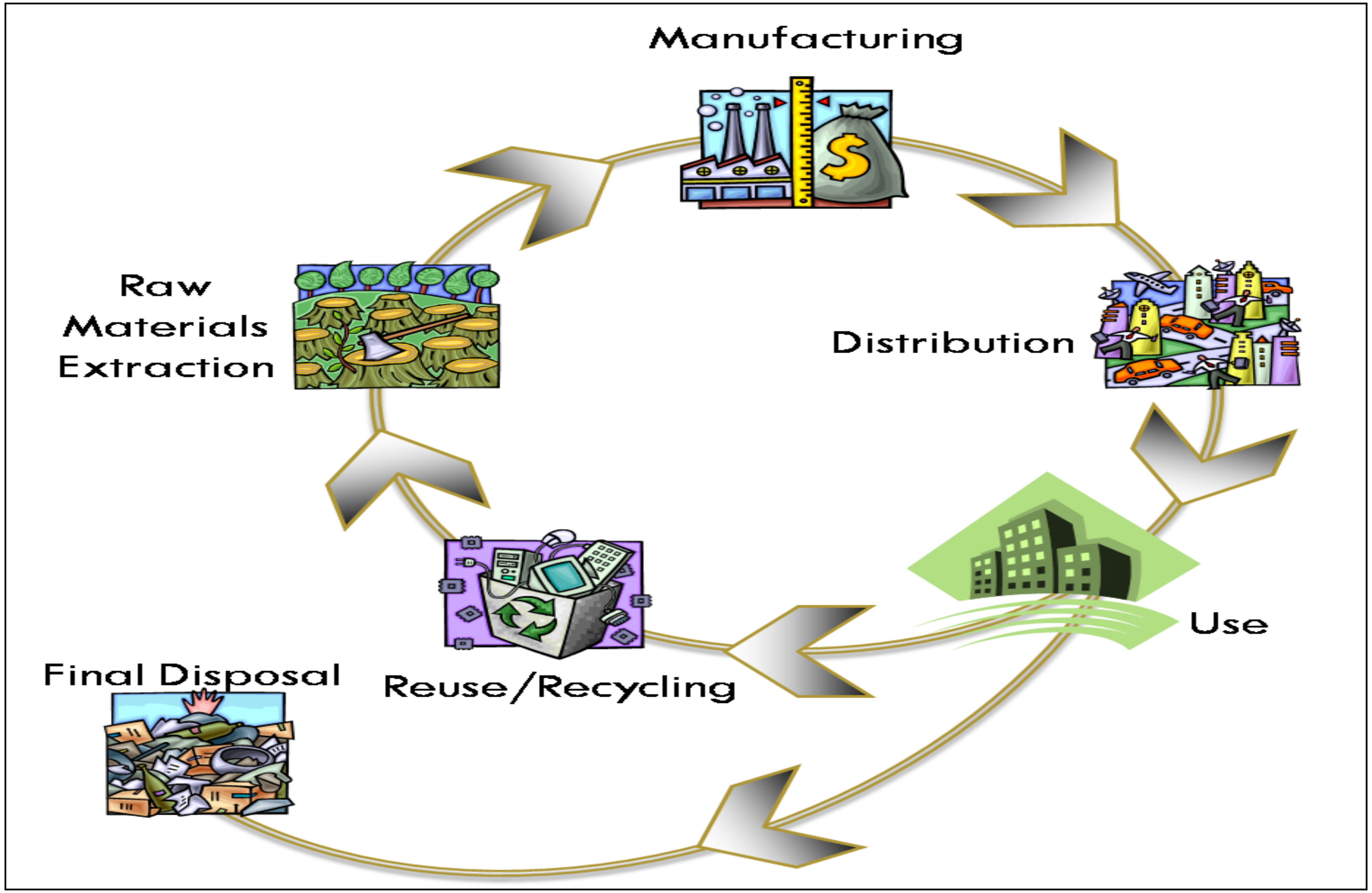
> "LCA is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements."

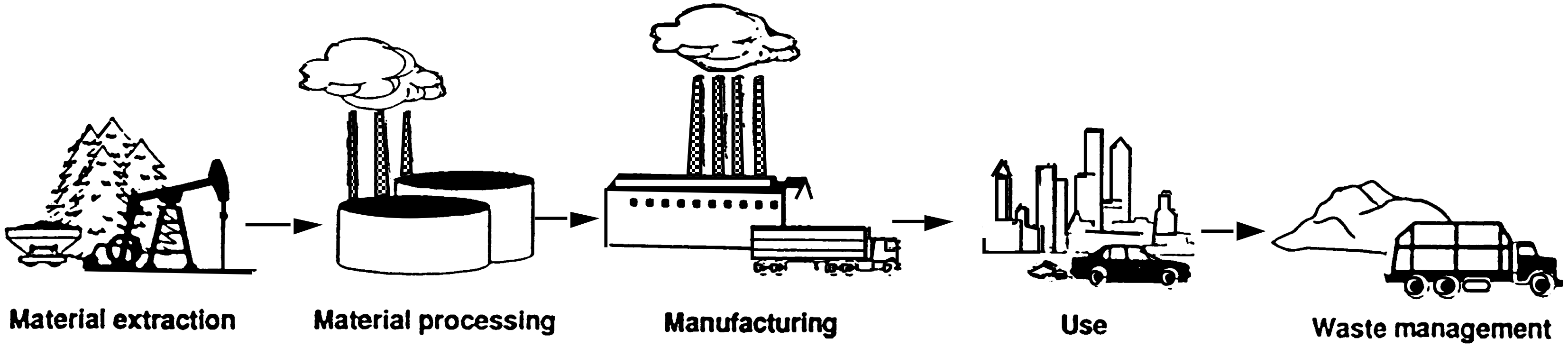
Source: (SETAC, 1993)

Components of LCA

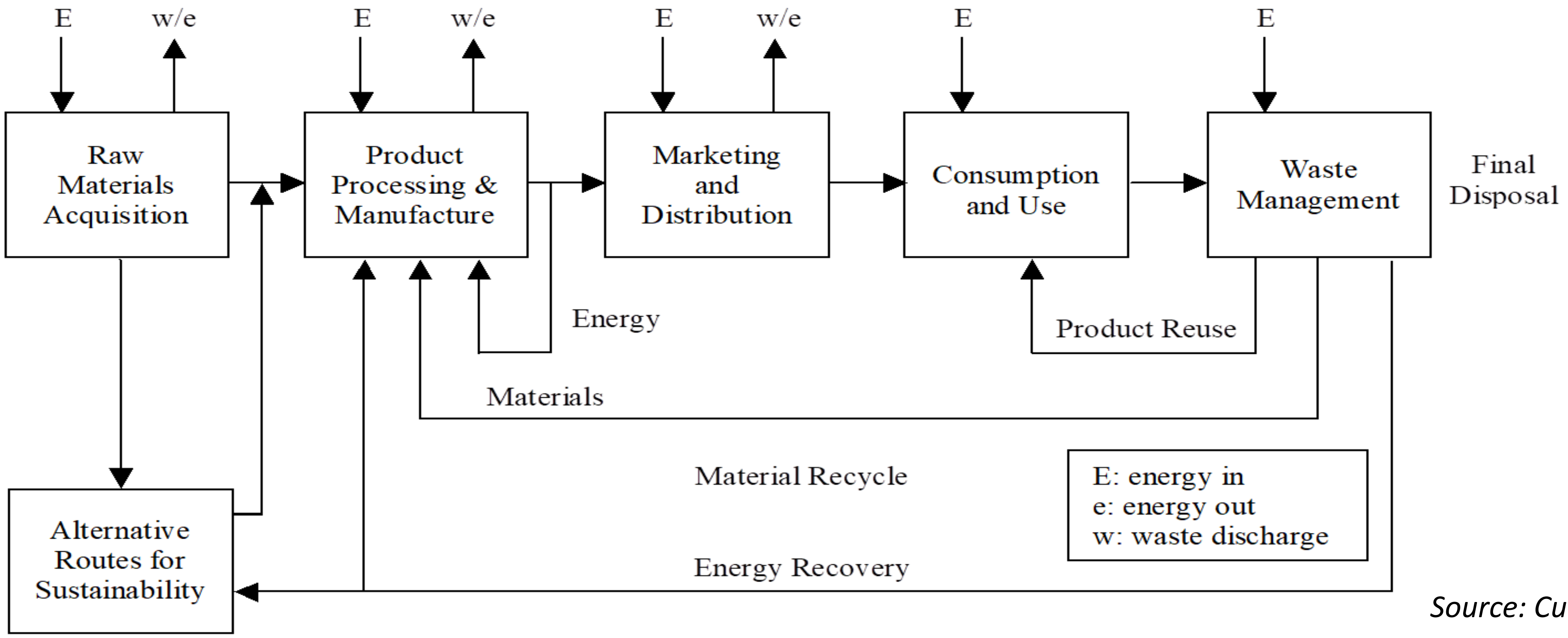
- Goal & Scope Definition (ISO 14041)
- Inventory Analysis (ISO 14041)
- Impact Assessment (ISO 14042)
- Interpretation (ISO 14043)

Product Life Cycle: A Cradle-to-Grave Analysis





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

Product Reuse

Materials

Material Recycle

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

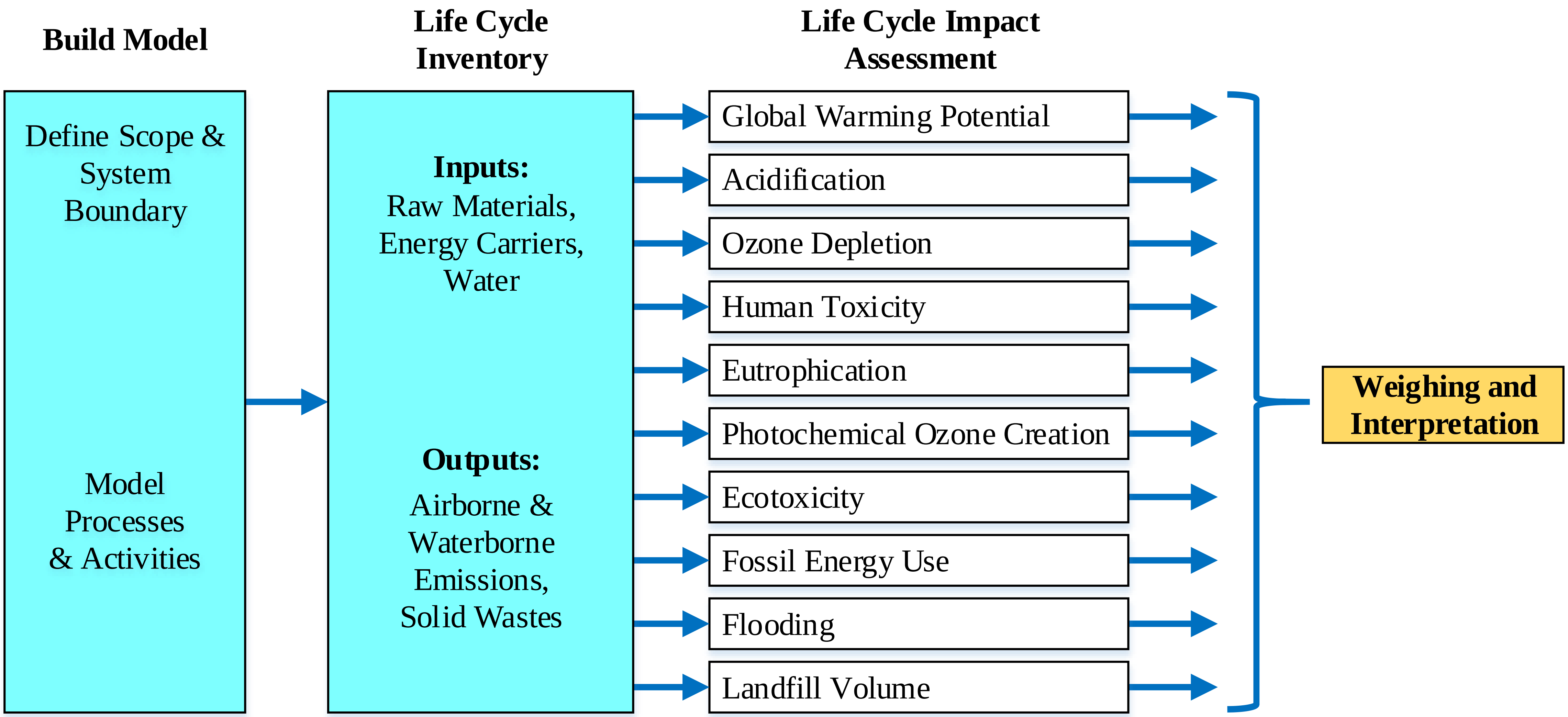
Energy Recovery

Alternative Routes for Sustainability

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?


Build Model

Define Scope & System Boundary

Model Processes & Activities

Life Cycle Inventory

Inputs:
Raw Materials, Energy Carriers, Water

Outputs:
Airborne & Waterborne Emissions, Solid Wastes

Life Cycle Impact Assessment

- Global Warming Potential
- Acidification
- Ozone Depletion
- Human Toxicity
- Eutrophication
- Photochemical Ozone Creation
- Ecotoxicity
- Fossil Energy Use
- Flooding
- Landfill Volume

Weighing and Interpretation

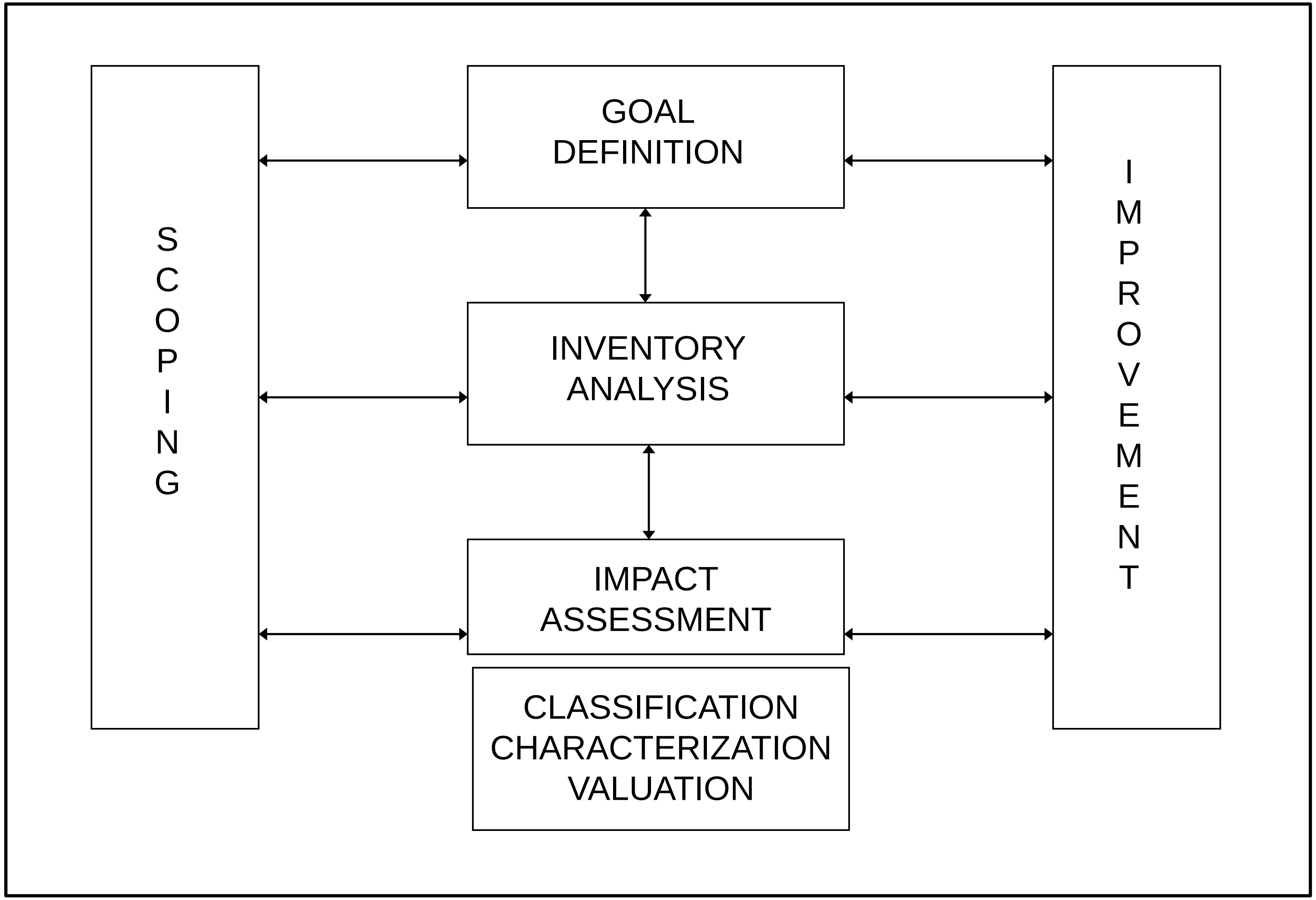
Impact Area	Reference Unit	Description
Global Warming Potential	kg CO_2-eq	This impact is related to the continued rise in the average temperature of the earth's climatic system. This is also concerned with climate change and the greenhouse effect.
Ozone Depletion	kg CFC11-eq	This is the environmental 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



SCOPING

GOAL DEFINITION

INVENTORY ANALYSIS

IMPACT ASSESSMENT

CLASSIFICATION
CHARACTERIZATION
VALUATION

IMPROVEMENT

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:

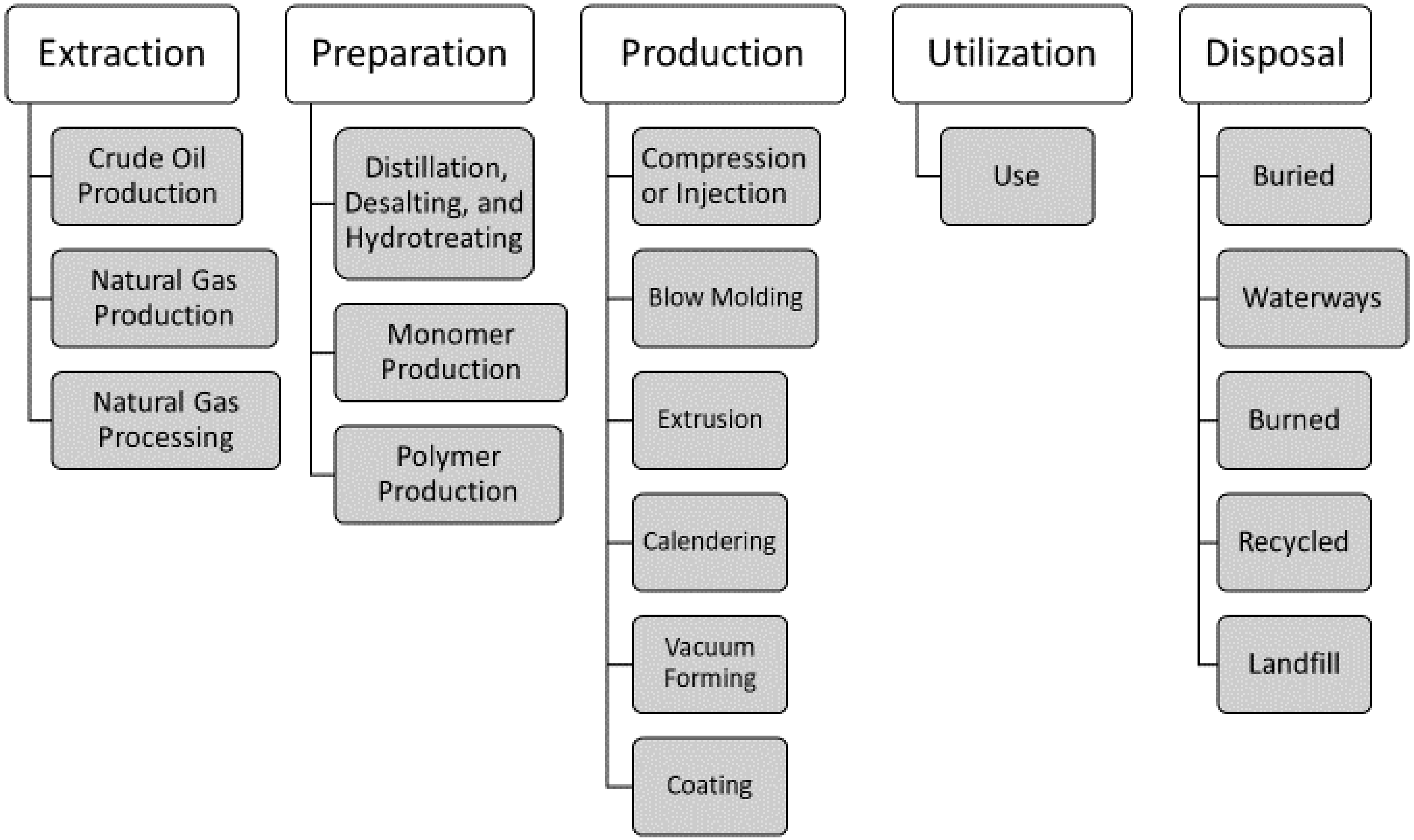
Case Study of Plastic Carrying Bags

- To determine the environmental performance of the production of plastic carrying bags. The bag is made of high density polyethylene (HDPE).

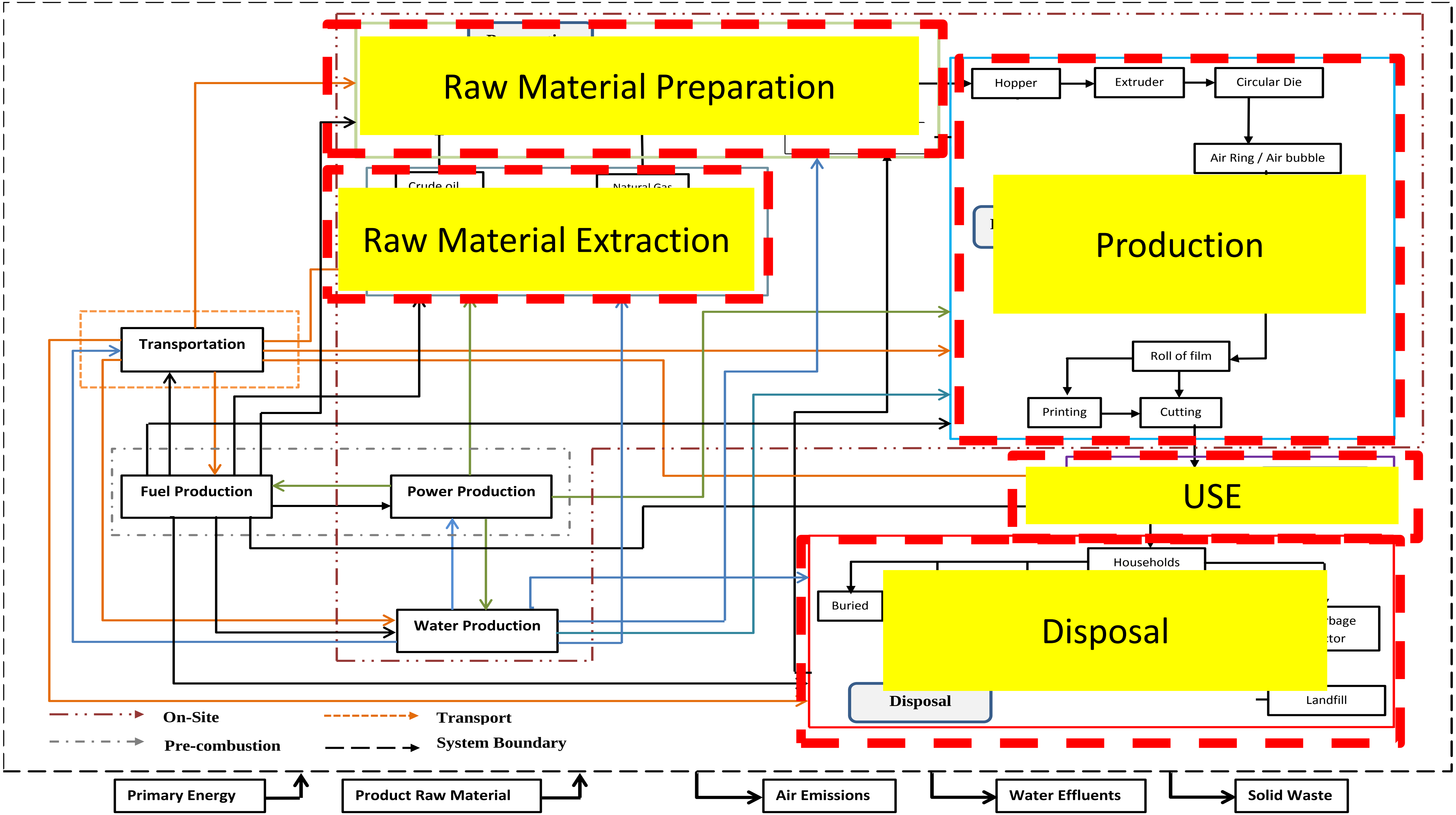
- Functional Unit: 1000 kg of carrying plastic bags produced.

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

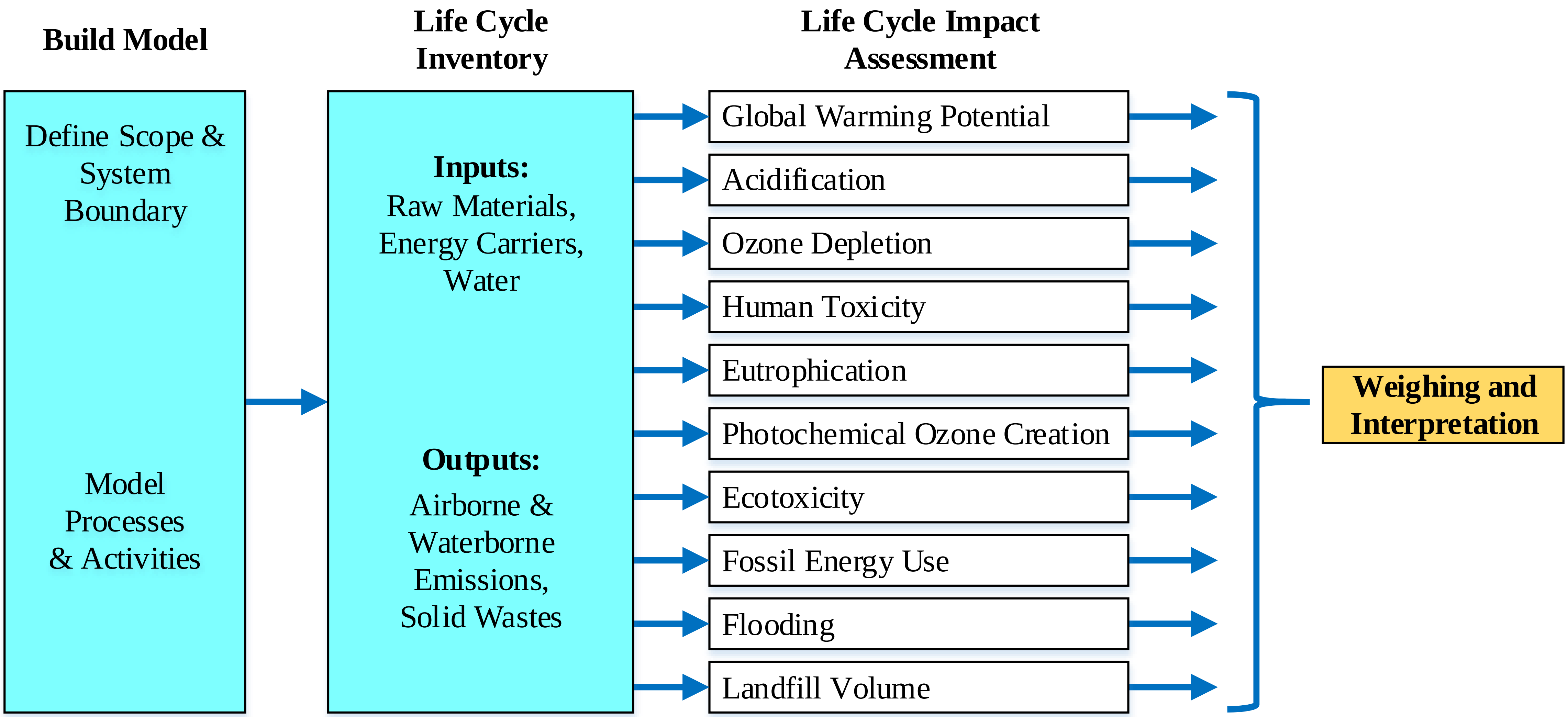

Raw Material Preparation
Hopper
Extruder
Circular Die
Air Ring / Air bubble
Crude oil
Natural Gas
Raw Material Extraction
Production
Roll of film
Printing
Cutting
Transportation
Fuel Production
Power Production
Water Production
USE
Households
Buried
Disposal
bage
tor
Disposal
Landfill
On-Site
Transport
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	-	-	10[illegible]8	1005	-	-	-
Refined Petroleum Products	kg	-	-	-	-	186	-	-
Processed Natural Gas	kg	-	-	-	-	830	-	-
Olefins (Ethylene)	kg	-	[illegible]	[illegible]	-	[illegible]	990	[illegible]
Water	liters	-	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]
Polyethylene resins	kg	-	[illegible]	[illegible]	-	[illegible]	[illegible]	1005
Ink	Kg	-	[illegible]	[illegible]	-	-	-	65
colorants	kg	-	[illegible]	[illegible]	-	-	-	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



Build Model

Define Scope &
System
Boundary

Model
Processes
& Activities

**Life Cycle
Inventory**

Inputs:
Raw Materials,
Energy Carriers,
Water

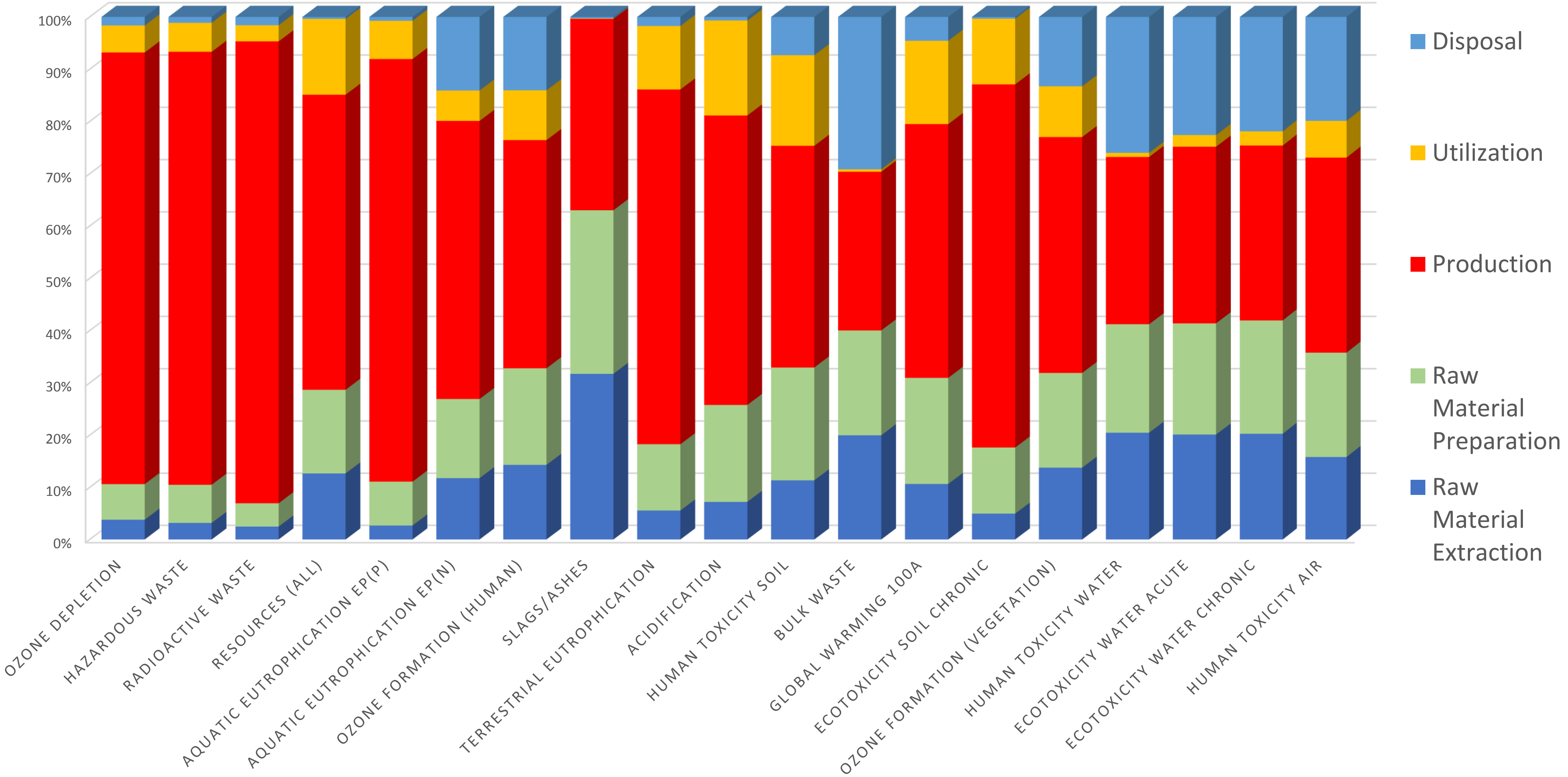
Outputs:
Airborne &
Waterborne
Emissions,
Solid Wastes

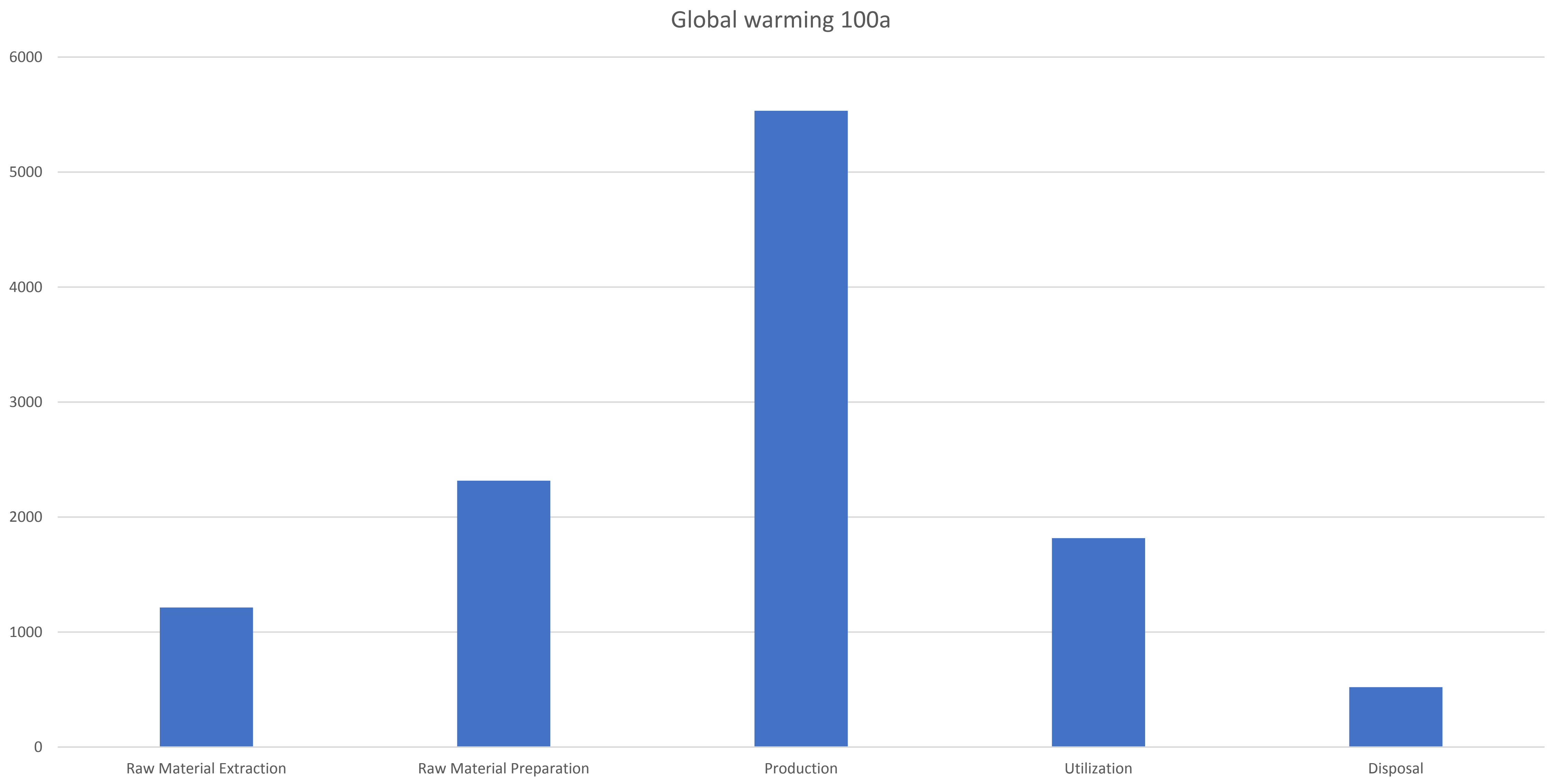
**Life Cycle Impact
Assessment**

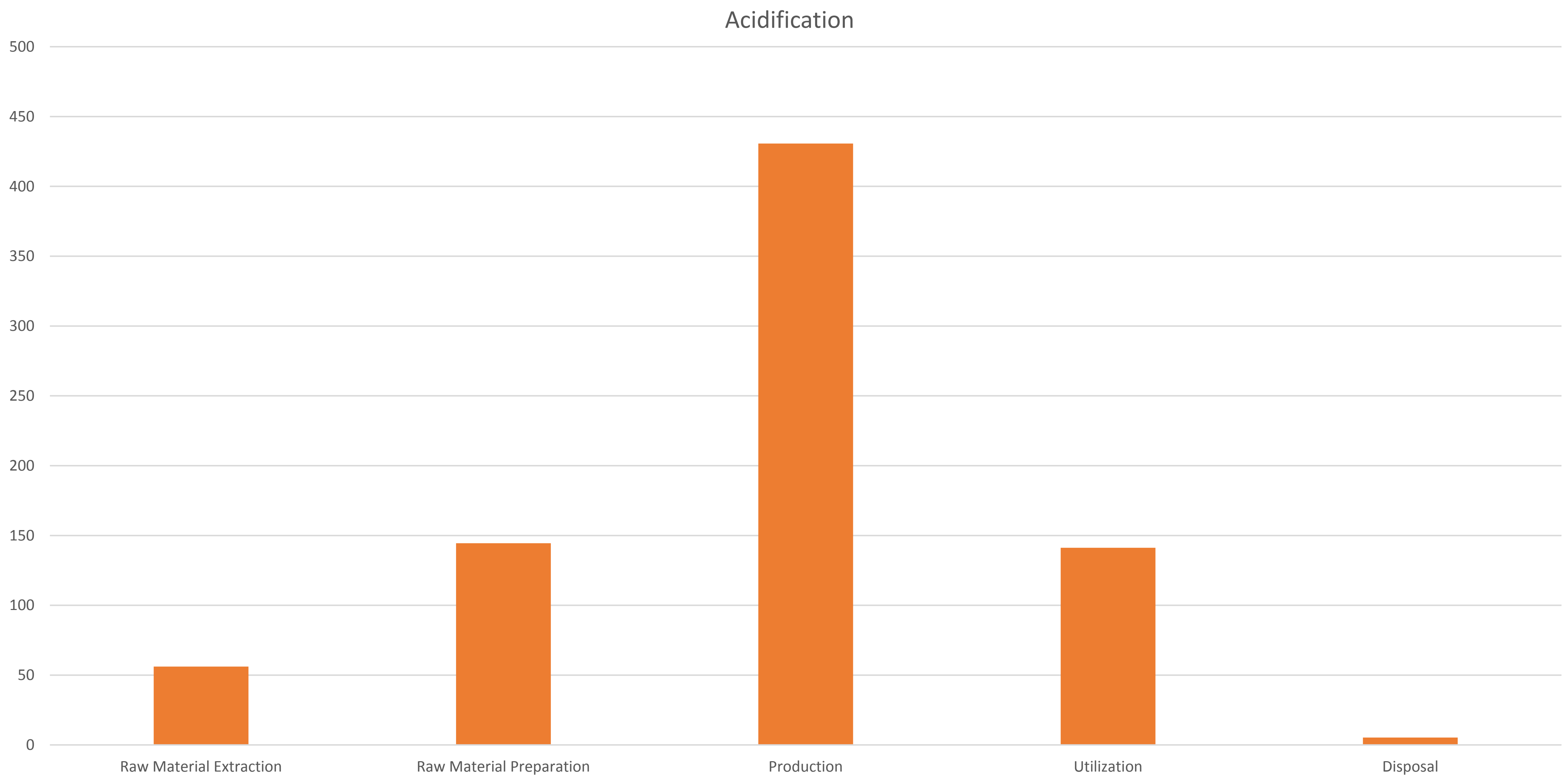
- Global Warming Potential
- Acidification
- Ozone Depletion
- Human Toxicity
- Eutrophication
- Photochemical Ozone Creation
- Ecotoxicity
- Fossil Energy Use
- Flooding
- Landfill Volume

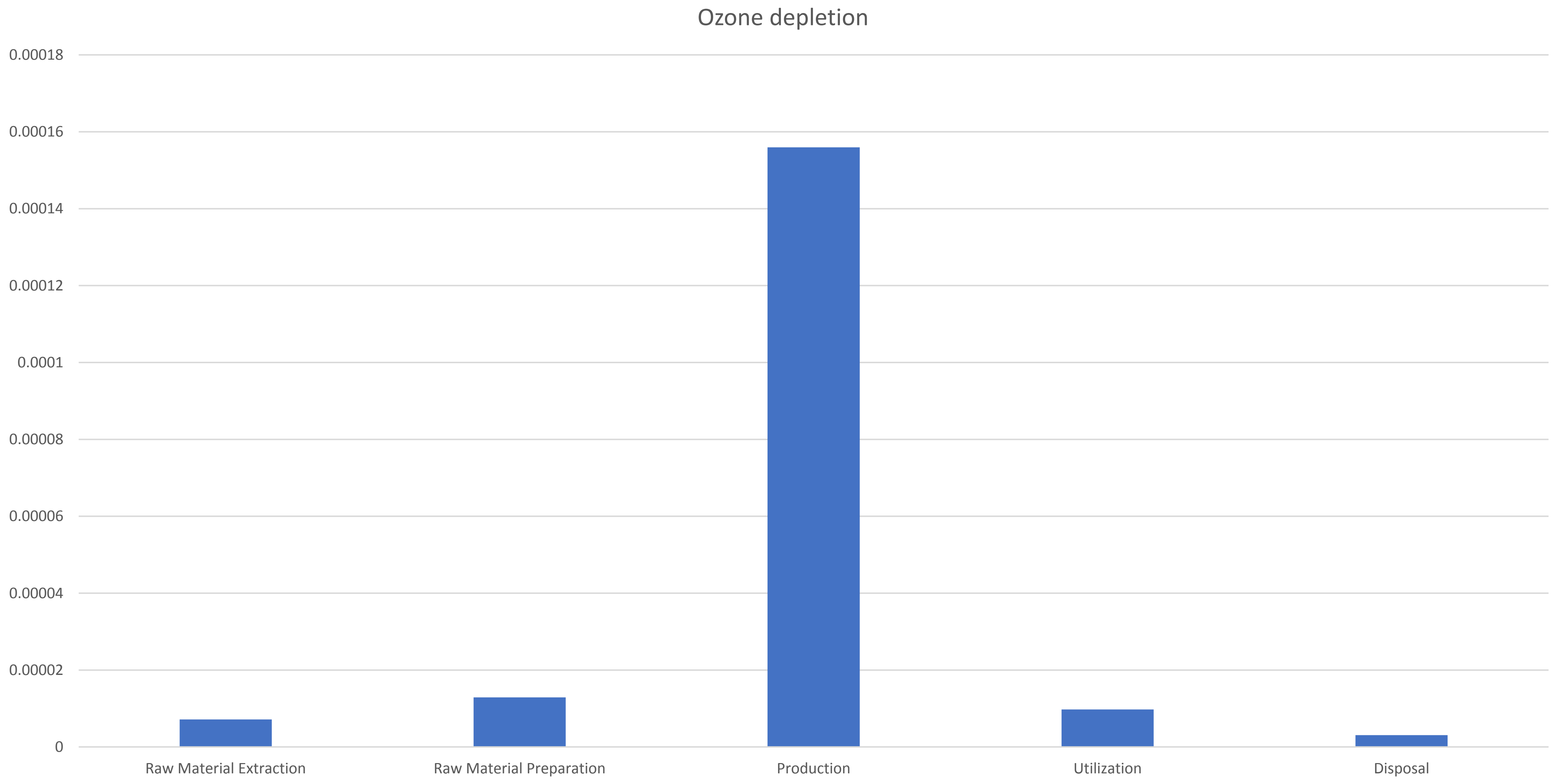
**Weighing and
Interpretation**

PERCENT OF LIFE CYCLE STAGES IN EACH IMPACT CATEGORY




Global warming 100a
6000
5000
4000
3000
2000
1000
0
Raw Material Extraction
Raw Material Preparation
Production
Utilization
Disposal

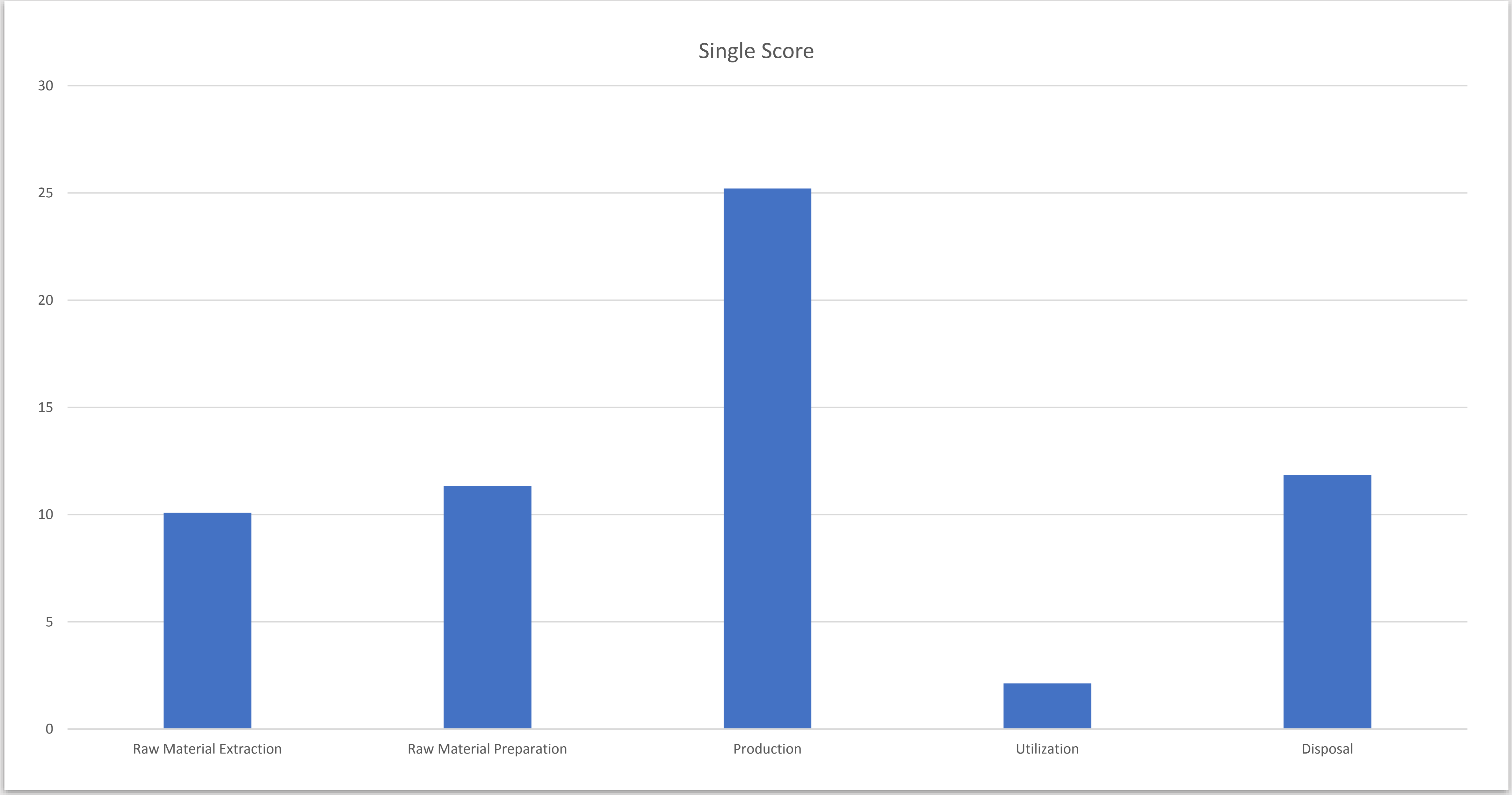

Acidification
500
450
400
350
300
250
200
150
100
50
0
Raw Material Extraction
Raw Material Preparation
Production
Utilization
Disposal


Ozone depletion
0.00018
0.00016
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
Raw Material Extraction
Raw Material Preparation
Production
Utilization
Disposal

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.

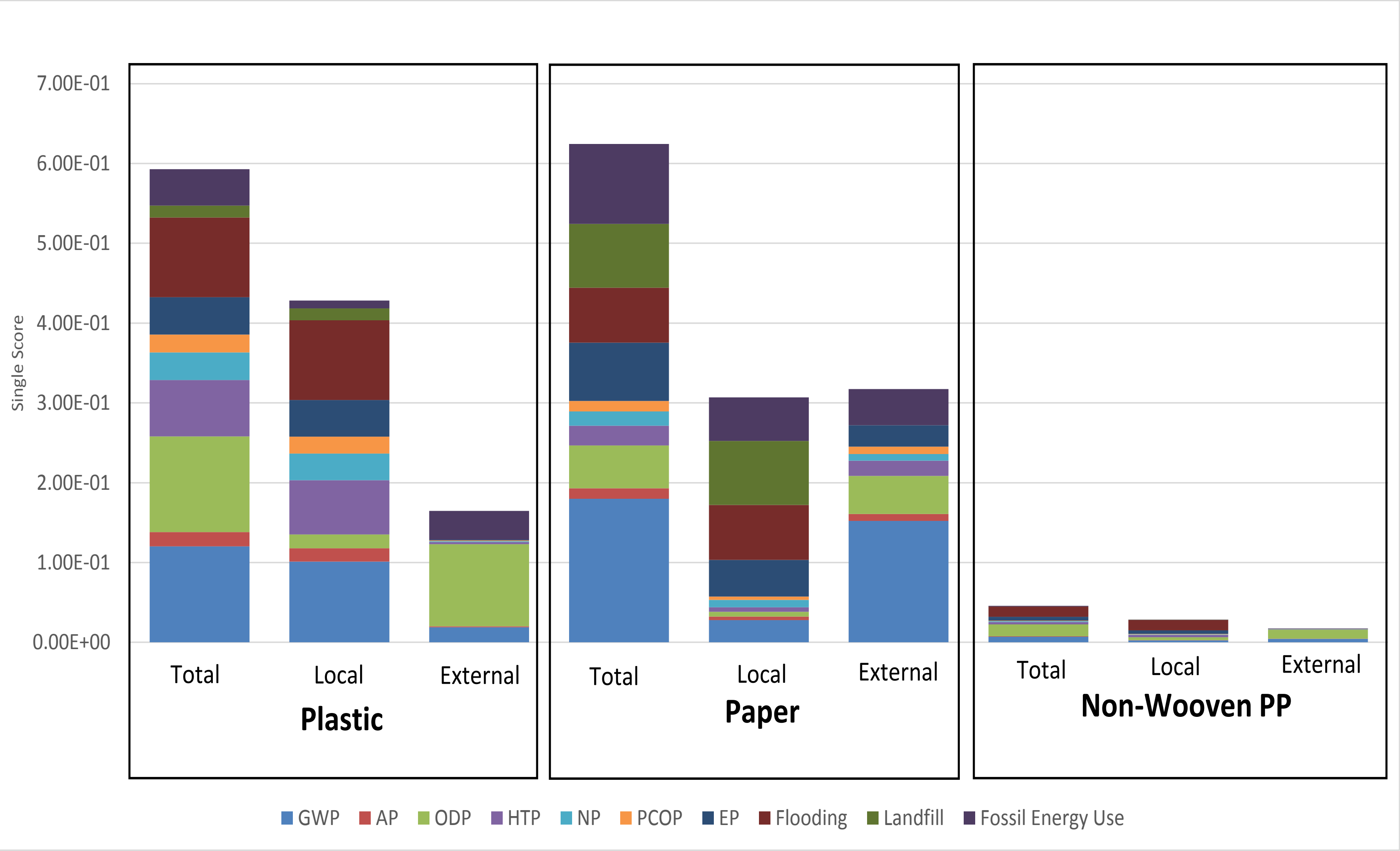
All environmental impact scores are converted with a single unit and then added to determine a single score amount.


Single Score
30
25
20
15
10
5
0
Raw Material Extraction
Raw Material Preparation
Production
Utilization
Disposal

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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