Synthetic polymers: facing the inescapable environmental dilemma

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Are we in the “plastic age” ?

(Nature 2024, Sci. Adv. 2024, FEBS Open Bio. 2021)

“Plastics are a recent particulate material in Earth’s history. Because of plastics persistence and wide-range presence, it has a great potential of being a global age marker and correlation tool between sedimentary profiles.”

(Dimante-Deimantovica et al., 2024)

Plastics give and plastics take

(Richel et al, 2024)

Global production:

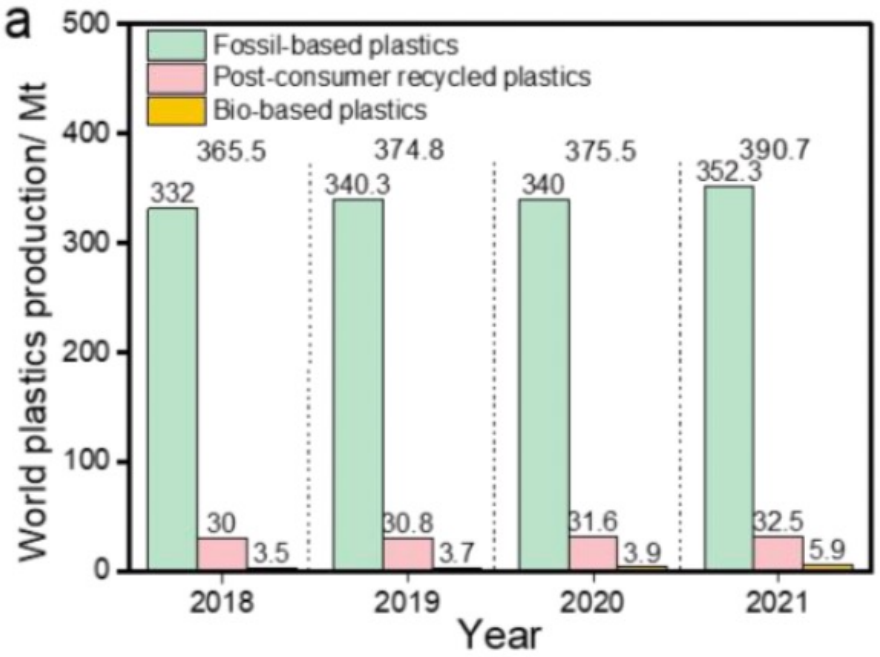
1950: 2 Mt
2021: 390 Mt
2050: 1,340 Mt

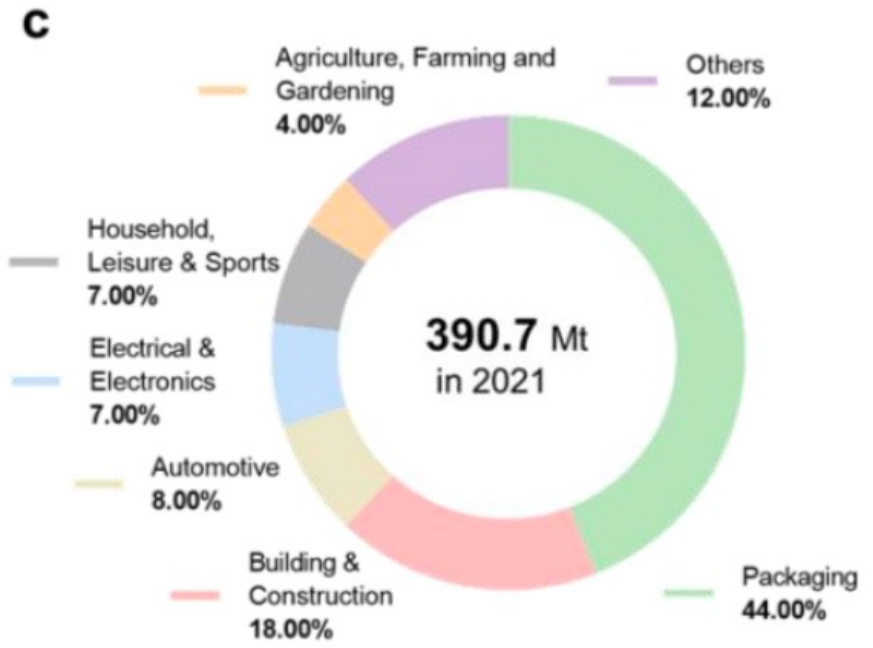
Multi-faceted and multi-beneficial

Inexpensive, lightweight, versatile, flexible, sterile, transparent, colorable, resistant, insulating, absorbable, etc.

Multi-applications

Packaging, construction, automotive, medical, electronics, agriculture, leisure, textiles, etc.





Plastics give and plastics take

(Nature Rev. Mat. 2022, New-York Times 1984, Marine Pollution Bulletin 2021)

"The world's seas and oceans, already polluted with spilled oil, toxic chemicals and radioactive waste, are now being fouled by a new and insidious form of pollution - plastic waste."

Plastics and climate change

(MIT Climate Portal 2022, Nature 2024)

Plastic pollution and climate change have many of the same root causes:

- over-consumption of natural resources and non-renewable energy
- insufficient recycling and reuse systems

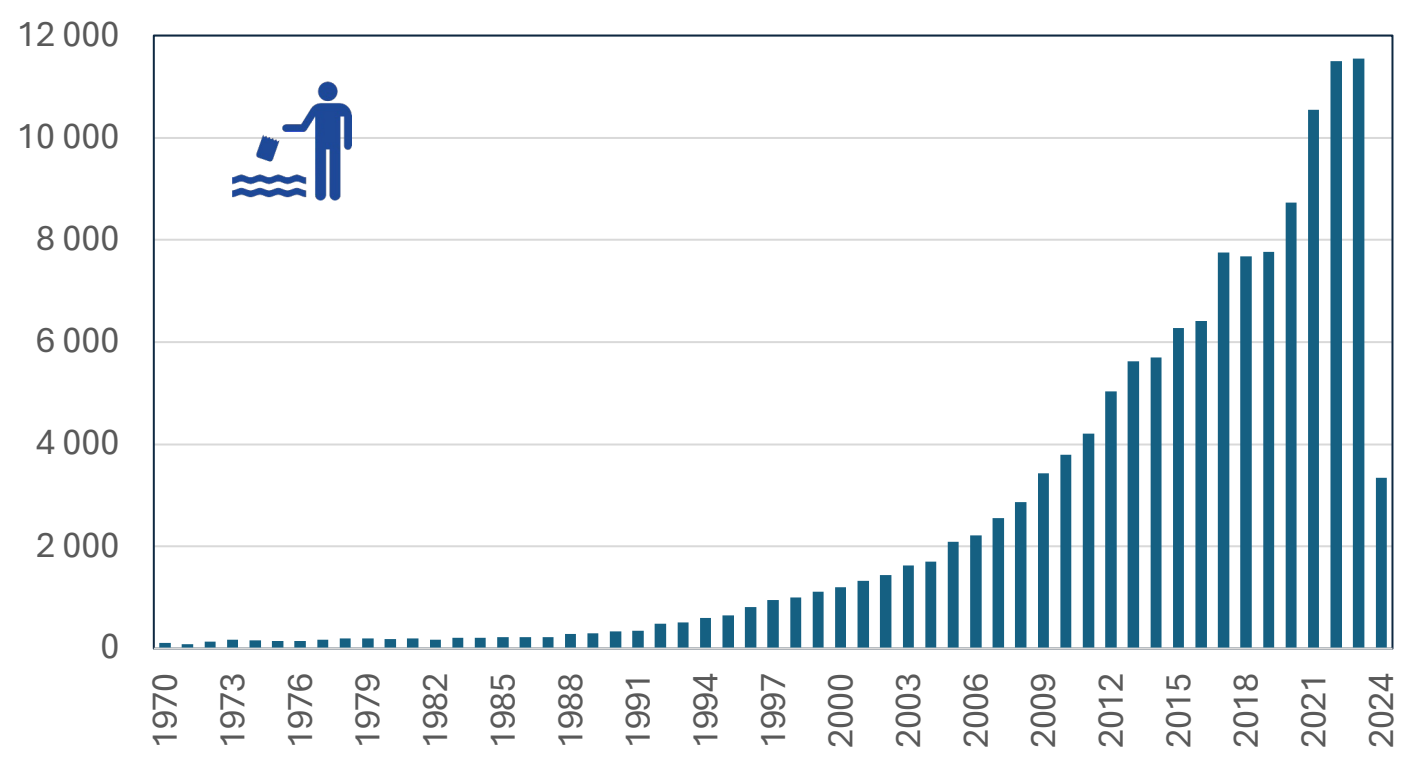
Plastic pollution and climate change contribute to many of the same environmental problems

Climate change also worsens plastic pollution's effects

Analysis of scientific publications

(1865-2023, SciFinder – Research on April 8th, 2024
"(plastic or polymer) and (environment or pollution)"

137,660 results (38% recorded since 2019)



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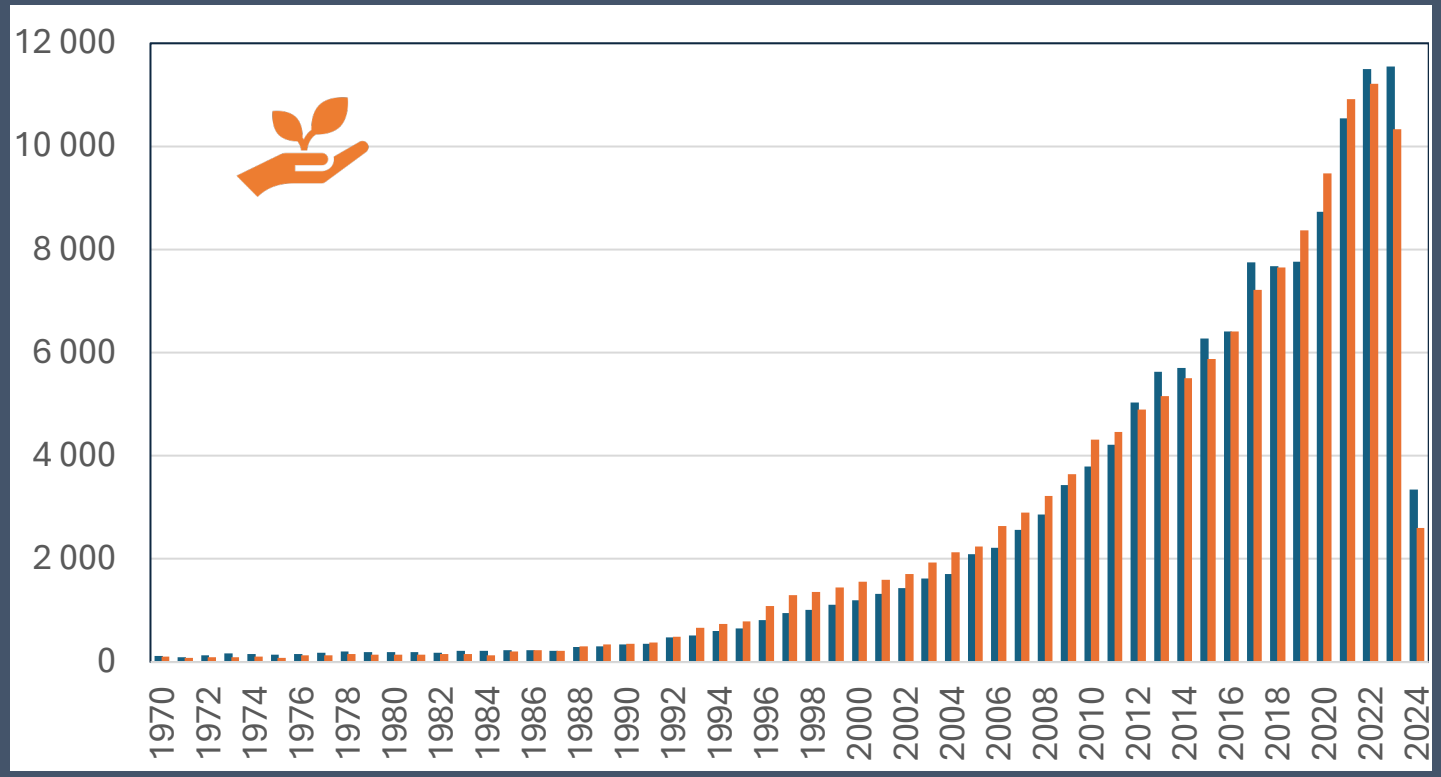
Analysis of scientific publications

(1865-2023, SciFinder – Research on April 8th, 2024
"(plastic or polymer or bioplastic or biopolymer) and (eco-conception or eco-design or recycling)"

139,700 results (39% recorded since 2019)



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A complex riddle to solve

(World Economic Forum 2023, Science 2021)

Two critical challenges for the plastic value chain: curbing plastic waste * AND reducing GHG emissions **

A more responsible and sustainable demand, and a promotion of innovation

Raise public awareness of the beneficial and essential roles of plastics

* e.g. Low-Carbon Emitting Technologies Initiative (LCET)
** e.g. Alliance to End Plastic Waste

Public perception

(Plastics, Cambridge University Press, 2023)

Numerous studies on the awareness of plastic pollution (ocean pollution, microplastics, single-use plastics), **recycling and bio-based plastics**

No consolidated data: variation linked to country, gender, age, level of education, salary, etc.

For more than 70% of respondents: knowledges come from social networks, internet, and TV/radio

The plastics dilemma

(Science 2021)

Despite proven and manifest, significant and major risks, synthetic polymers offer undeniable advantages compared to other materials (natural or synthetic) in logistics, health, and even the environment.

The most obvious advantages

(Polymers 2024, Biomaterials Res. 2023, Adv. Mat. 2023)

Particularly apparent (and accepted) in medical applications and public health.

Sterility, enhanced safety, cost-effectiveness, biocompatibility, comfort, innovative applications

Gloves, disposable syringes, blood bags, prosthesis, surgical suture, protective masks, coatings, tissues adhesives, new heart valves, « dummy » organs » for practice procedures, 3D-printed devices, etc.

The benefits that everyone forgets

(Philos Trans R Soc Lond B Biol Sci. 2009)

Supply and storage of clean drinking water

Flexible, versatile, resistant to corrosion, long lifetime, recyclable, lightweight, easy to manufacture, etc.

Membranes, filters, pipes, storage containers, etc. could be installed in a range of different water control and distribution systems (e.g. seawater, sewerage, storm water, land drainage, irrigation)

The benefits that everyone forgets

(MIT Technology Review 2022)

Supply, storage and/or transportation of (renewable) energy

Electric conductor or insulator, lightweight, resistant, high thermal capacity, rigidity, etc.

Electrical cables, electrodes, solid membranes, electrical insulators, dissipative elements, components of long-distance energy transmission cables, wind turbine blade components, battery components, photovoltaic panels, etc.

The hidden advantages

(Applied Plastics Engineering Handbook 2017, Frost & Sullivan 2022)

"A reduction of 10% in vehicle weight can result in the improvement of fuel economy by 6–8%"*

"Automotive Plastics Market Growth Fueled by CO_2 Emission Reduction Requirements"

* Current synthetic polymers (PP, ABS, PC, PA, etc.)

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The hidden advantages

(Polymers 2022, Richel et al. ongoing)

Design of new functional composites to align with a paradigm shift (electric vehicles), including composites (bio-composites * or incorporating recycled materials) enabling better end-of-life management ** (legislations)

* natural-fiber-reinforced polymer composites
** including the selection and design of new highly biodegradable materials

The hidden advantages

(Nature 2023)

Mulch films: agronomic benefits (weed and pest control, soil moisture conservation control soil and air temperatures, enhancement of nutrient uptake) leading to improved yields, improved water and nutrient use efficiency, and reduced pesticide use.*

* In China: without the use of mulch film, an additional 3.9 million hectares of arable land would be required to produce the same amount of food

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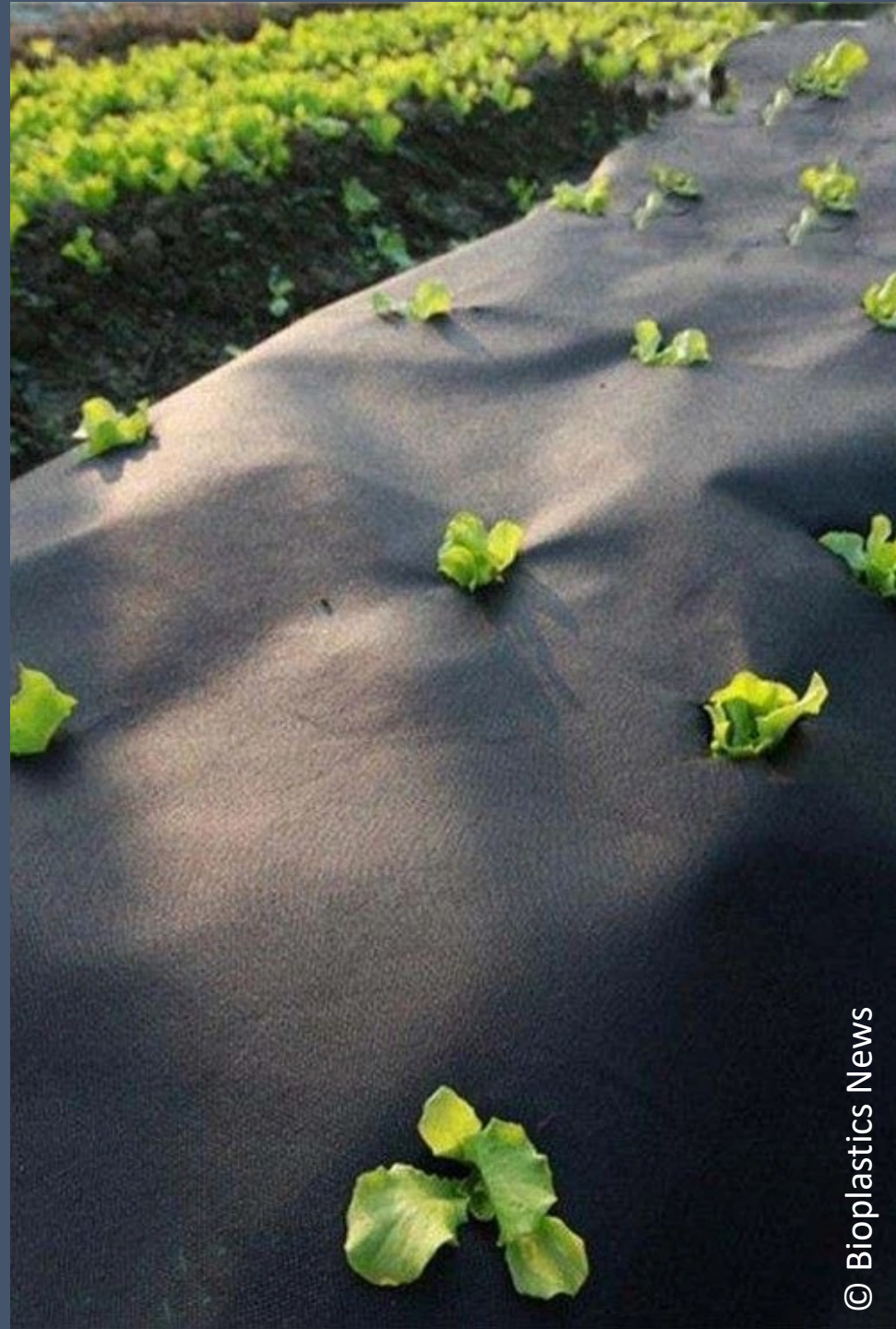
The hidden advantages

(FNRS-NSFC 2023)

Several adverse effects (MP, additional stressors for soils, effects on biota, leaching of additives, etc.). Need to a sustainable use (collection after use and recycling), design of fully biodegradable polymers, mandatory use of environmentally benign additives, etc.

Materials adapted to climate change.



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The hidden advantages

(Trends in Food Science & Technology 2021, US 2022)

Protect food from pathogens, oxidation, moisture, light, shocks, contamination, odors, etc.*

Food waste emits 8% of human greenhouse gases, far exceeding plastic's carbon footprint.

* Current synthetic polymers (HDPE, LDPE, PET, PVDC, EVOH, etc.), mono-material or composite (including mixes with paper, etc.). Major drawback = single-use and non-degradable.

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The hidden advantages

(Sustainability 2023)

Need to develop new, more durable materials (bio-sourced, biodegradable, compostable), including recycled content, reducing unnecessary packaging, offering new functions to packaging (e.g., smart or active packaging).

Circular economy, involvement of agri-food by-products

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The hidden advantages

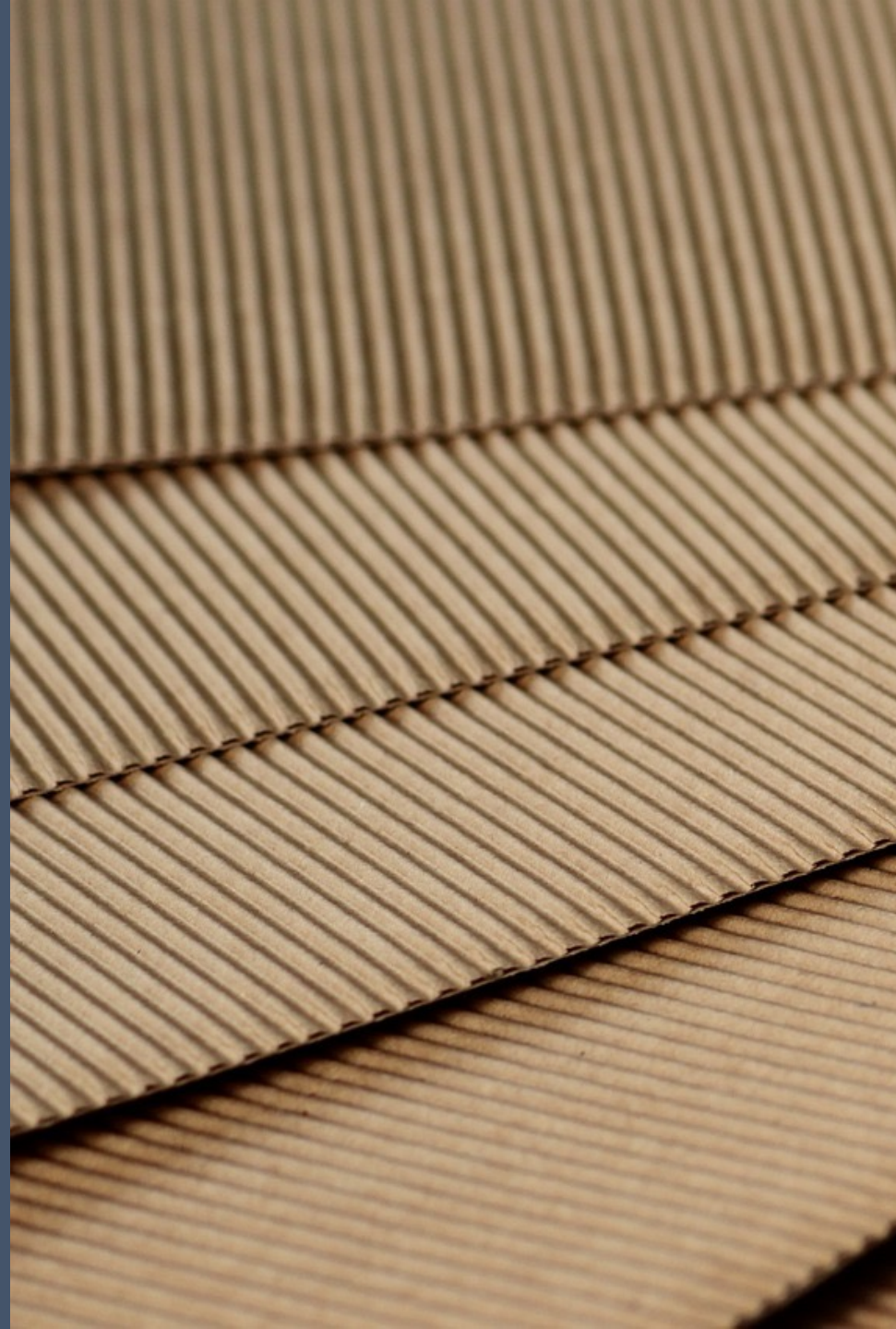
(Environ. Sci. Technol. 2024, McKinsey 2022)

In traditional uses, substituting polymers with 'classic' materials results in higher GHG emissions.

Table 1. Climate Impact of 16 Plastic and Nonplastic Alternative Applications[a]

Sector	Application	Plastic	Next-best alternative	% GHG emission difference	Main drivers	Plastic favorable?	
						w/ indirect	w/o indirect
Packaging	Grocery bag	HDPE	Paper	80		Yes	Yes
	Wet pet food packaging	PET/PP	Aluminum/steel	70		Yes	Yes
	Soft drink container	PET	Aluminum	50		Yes	Yes
	Fresh meat packaging	EPS/PVC	Paper	35		Yes	No
	Industrial drums	HDPE	Steel	−30		No	No
	Soap container	HDPE	Glass	15		Yes	Yes
	Milk container	HDPE	Paper*	20		Yes	Yes
	Water cup	PS	Paper*	0		Yes	Yes
Building and construction	Municipal sewer pipe	PVC	Concrete/ductile iron	35–45		Yes	Yes
	Residential water pipe	PEX	Copper	25		Yes	Yes
	Insulation	PU	Fiberglass	80		Yes	No
Consumer goods	Furniture	PP	Wood	50		Yes	Yes
Automotive	Hybrid fuel tank	HDPE	Steel	90		Yes	Yes
	BEV battery top enclosure	PP/glass fiber	Steel	10		Yes	No
Textile	Carpet	PET/nylon	Wool	80		Yes	Yes
	T-shirt	PET	Cotton	15		Yes	Yes

[a]EPS (expanded polystyrene), HDPE (high-density polyethylene), PET (polyethylene terephthalate), PEX (cross-linked polyethylene), PP (polypropylene), PU (polyurethane), and PVC (polyvinyl chloride). * denotes plastic-enabled mixed materials.



A paradoxal position

(One Earth 2022)

Synthetic polymers currently play a significant role in contributing to climate change and altering ecosystems

BUT...

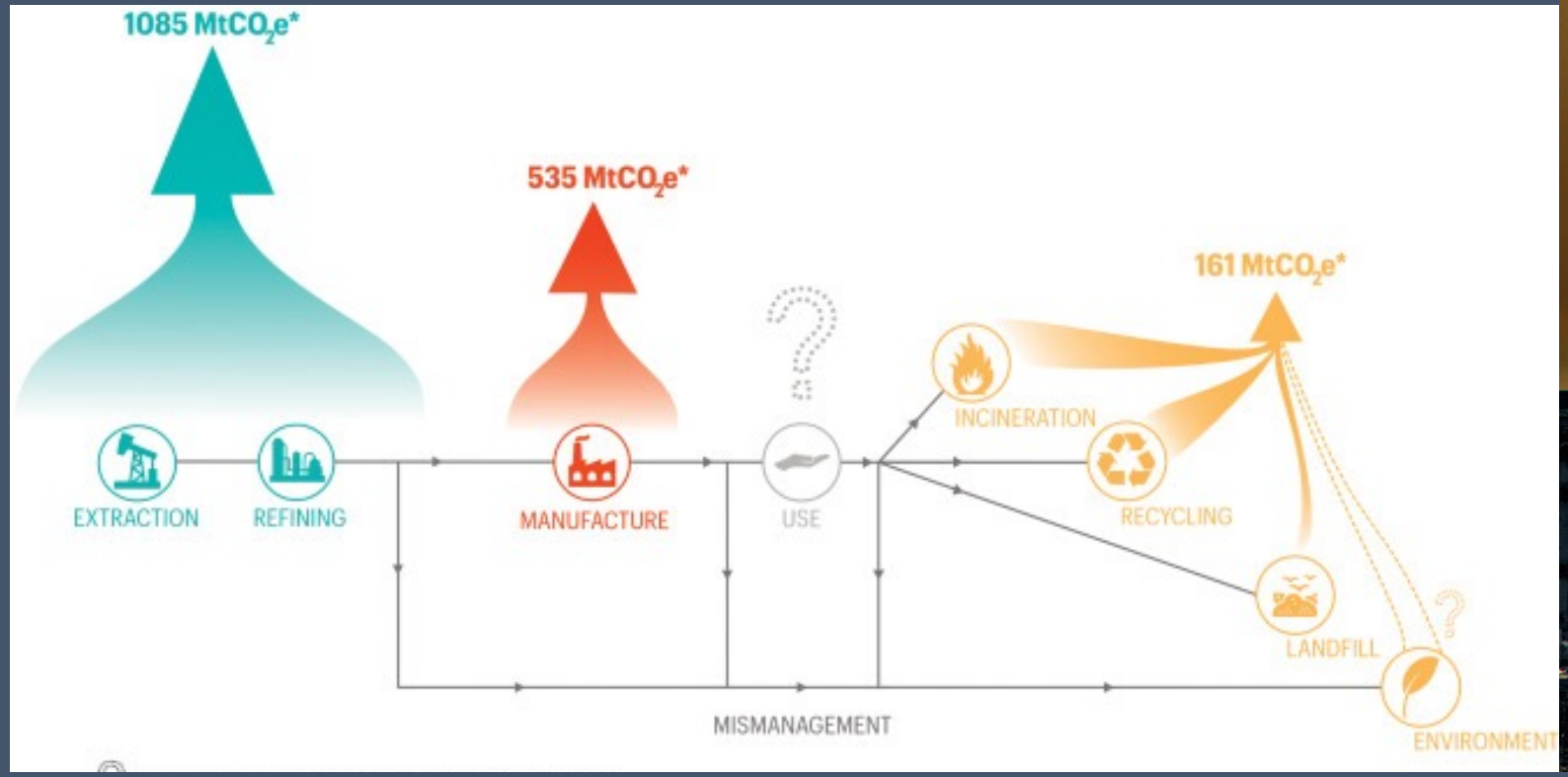
Unique benefits in health and sustainable development goals (food security, access to water, and renewable energy)

Plastics provide security

A new plastics economy is needed to protect the climate

(UNFCCC 2023, Plastic Pollution Treaty UNEA end-2024)

Under a business-as-usual scenario: plastics lifecycle could be responsible for as much as 19% of global GHG emissions by 2040.



The position of the academic world

(UNFCCC 2023)

- Challenging the acquired model of production dependent on fossil-based inflows
- Driving a paradigm shift by integrating renewable resources, promoting eco-design to produce fully-degradable and inoffensive polymers
- Drawing inspiration from living organisms and the possibilities offered by carbon in nature
- Promote plastic benefits, urge innovation, fund research, inform decision-makers

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