The plastics industry

Understanding its material flows in the context of the ecological crisis

RESEARCH REPORT – March 2025

a report by BASIC

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Acronyms

ABS	Acrylonitrile Butadiene Styrene
ASA	Acrylonitrile Styrene Acrylate
BPA	Bisphenol A
BTX	Benzene, toluene, and xylene
CMRs	Carcinogens, mutagens, and/or reproductive toxicants
C2C / CTC	Crude to Chemical
COTC	Crude Oil to Chemical
DEHP	Di(2-ethylhexyl) phthalate
EU	European Union
HDPE	High-Density Polyethylene
HVC	High-Value Chemical
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
NGL	Natural Gas Liquids
OECD	Organisation for Economic Cooperation and Development
PA	Polyamide
PAHs	Aromatic hydrocarbons
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PFAS	Polyfluoroalkyl substances
PMBT	Persistent, bioaccumulative, mobile, and/or toxic
PMMA	Polymethyl methacrylate
POP	Persistent Organic Pollutant
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride
PYGAS	Pyrolysis Gasoline
SAN	Styrene Acrylonitrile
TC2C	Thermal Crude to Chemical
UV	ultraviolet

Introduction: plastics in the context of the ecological crisis

Plastics have become ubiquitous: they are embedded in nearly every aspect of our daily routines, from the packaging that preserves our food to the components of our vehicles, electronics, and medical devices. This material's versatility, durability, and cost-effectiveness have made it indispensable across most industries, allowing the advent of the consumer society. Yet, this ubiquity has also fostered a dependence that raises significant questions about associated ecological and health impacts.

One of the problematic aspects of plastics is their longevity. Designed for durability, many plastics resist degradation for decades or even centuries. While this durability makes plastics valuable for some applications, it poses a severe problem when plastic waste accumulates in the environment. From landfills to oceans, plastics contribute to pollution, harming ecosystems, wildlife, and human populations. As plastics degrade into micro and nano plastics, they infiltrate food, water supplies and living organisms. The additives they contain also leach into the environment, posing sanitary risks to animal and human populations. Additionally, the production and incineration of plastics are energy-consuming and release pollutants, contributing to greenhouse gas emissions and air quality issues. These various impacts are all the more significant as the use of plastics has increased more than sixfold since 1980 and shows no sign of slowing down[1].

In this context, a global treaty on plastic pollution is under discussion since 2022 in the framework of the United Nations. While the treaty was due to be finalised in December 2024 in Busan, this fifth negotiation session revealed the deeply conflicting nature of the issue. No ambitious objective was adopted and negotiations are meant to continue in 2025. Within the EU, the European regulation on packaging adopted in March 2024 provides, among other measures, for the end of single-use plastics by 2030, as well as a target of 100% recycling of packaging by 2035. But these measures, as welcome as they may be, are representative of a potentially limiting approach to the problem. While the pressing need is to reduce the *production* of plastics, these measures focus only on the downstream end of the plastics chain (the consumption and end-of-life stages). The dynamics at work upstream or in the middle of the chain (at the raw material extraction and transformation stages) are left untouched.

This type of approach finds its justification in the idea of circularity: if the lifespan of plastics is extended and if they become fully recyclable (and recycled), then the extraction of raw materials is actually reduced, as the main source becomes plastics that have already been produced and can be reused in a sort of quasi-closed loop. The following diagram, produced by the European lobby for plastics producers, is representative of this ideal vision: material flows appear to be mainly circular, while the supply of fossil raw materials and the associated extraction ("fossil feedstock" in the bottom right corner of the diagram) represents only a residual and minor flow.

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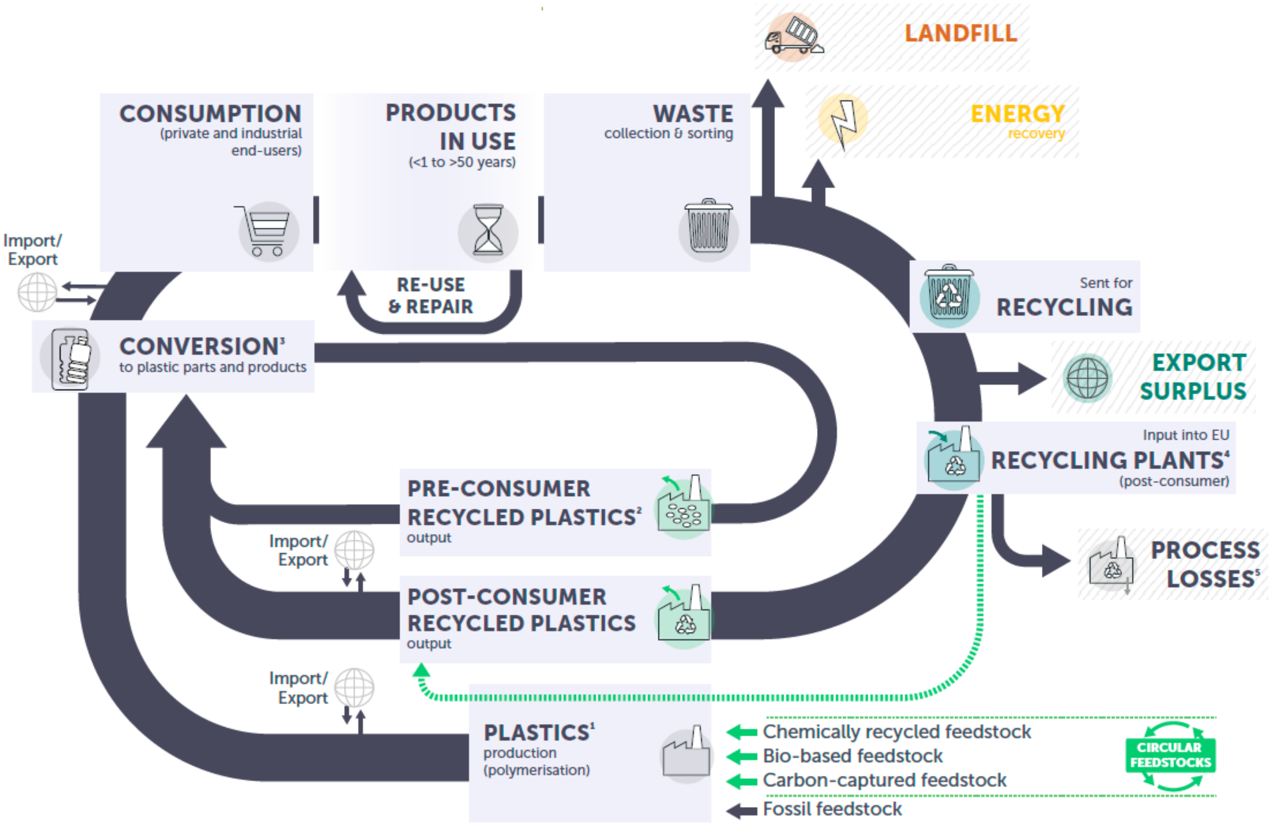
[1] OECD, "Global Plastics Outlook: Policy Scenarios to 2060," June 21, 2022, https://www.oecd.org/en/publications/global-plastics-outlook_aa1edf33-en.html.

Figure 1: The circularity of plastics, as seen by the European lobby for plastics producers



Source: Plastics Europe, 2022[2].

This representation corresponds to a theoretical vision of circularity. It reflects an ideal to be achieved, but it could also turn out to be an idealised vision, impossible to achieve because of limitations linked both to physical realities and to the economic logic of the players involved in the production chain.

Against this background, the objectives of this report are to:

- Provide objective data on the material flows of the plastics industry, from final consumption up to fossil raw materials.
- Identify the economic actors that structure the plastics value chain and understand the links between their characteristics and the material flows of the plastics industry.
- Build a systemic vision of the plastics industry that connects physical realities and economic rationales, allowing to identify potential lock-ins and levers.

By adopting a value chain perspective, we aim to provide the insight necessary to question the role of the plastics industry in the urgent phase-out of fossil fuels. Indeed, plastics production could increasingly become an economic lifeline for oil and gas companies. In Busan, it was a coalition of oil-producing countries that opposed any ambitious agreement to reduce plastic production, demonstrating the potential paradigm shift at play within this industry. But this shift carries significant risks, most notably missing climate targets. By doubling down on plastics, petrochemical companies may sustain their business model at the expense of people and the planet, delaying the

[2] Plastics Europe, "Plastics - the Facts 2022," October 2022.

necessary shift toward truly renewable and low-impact alternatives and hindering progress in the broader energy and ecological transition.

To shed light on the plastics industry and its implications, the first part of this report explores the complexities of the plastics life chain, from the extraction of fossil resources to the management of plastic wastes, delving into petrochemistry in order to understand the special characteristics of this type of material. The second part of the report then lays the foundations for a systemic vision of the plastics value chain. We quantitatively model the material flows generated by the plastics industry and identify its main economic actors. Further work is needed to answer the many questions raised by the plastics industry, as discussed at the end of this report.

1. The plastics life chain

The story of plastics begins with petrochemistry, a field that harnesses the complex chemistry of hydrocarbons to create a vast array of polymeric materials. Petrochemicals derived from fossil fuels are the foundation of most plastics, and the processes involved in their production are reflections of industrial development. These processes have enabled the creation of plastics with diverse properties, from rigid and durable materials (like polyethylene/PE and polypropylene/PP) to lightweight, flexible options (like polystyrene/PS and polyethylene terephthalate /PET).

The plastic “life chain”
While it is common in the literature to find the term “plastics life cycle,” we chose to use the term “life chain” to illustrate the fact that plastics are far from being cyclical: as we will see in the next sections, only a few plastics are easily recycled and all of them generate micro and nanoplastics with quasi infinite life span.

1.1. Plastics production

How are plastics made? This section of the report breaks down the steps needed to get from oil/gas extraction to final plastics products. The section is mainly based on course materials from Penn State’s College of Earth and Mineral Sciences,[3] Britannica,[4] the Petrochemistry Europe flowchart of plastic synthesis,[5] the British Plastics Federation primer on plastic production,[6] the INEOS glossary of petrochemistry,[7] and the websites and articles named as sources for figures below.

Fundamentally, the petrochemical industry – of which the plastics industry is an integral part – is comprised of four basic steps:

1. Taking things out of the ground (oil and gas) and cleaning them.
2. Using heat to fractionally distil oil and gas. This process separates out molecules of different sizes, the lightest of which will be used to make plastics. The products of this process are called *feedstocks.*
    a. Oil distillation yields naphtha.
    b. Gas distillation gives ethane, propane, and butane.
    c. Both processes yield pygas, which yields toluene, benzene, and xylene.

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[3] Penn State College of Earth and Mineral Sciences, “FSC 432: Petroleum Processing,” 2023, https://www.e-education.psu.edu/fsc432/.

[4] Britannica, “Petroleum Refining,” 2024, https://www.britannica.com/technology/petroleum-refining., but also a variety of standalone articles such as “polybutylene terephthalate (PBT),” “polyurethane,” “plastic,” “polyester,” “butane,” “ethylene,” “propylene,” etc.

[5] Petrochemicals Europe, “Flowchart- Petrochemicals Europe,” 2024, https://www.petrochemistry.eu/about-petrochemistry/flowchart/; Petro Chemicals Europe, “Petrochemistry Flowchart,” August 2023, https://www.petrochemistry.eu/wp-content/uploads/2023/08/Petrochemistry-FlowChart_V102023_HQ-withoutFolds-1.pdf.

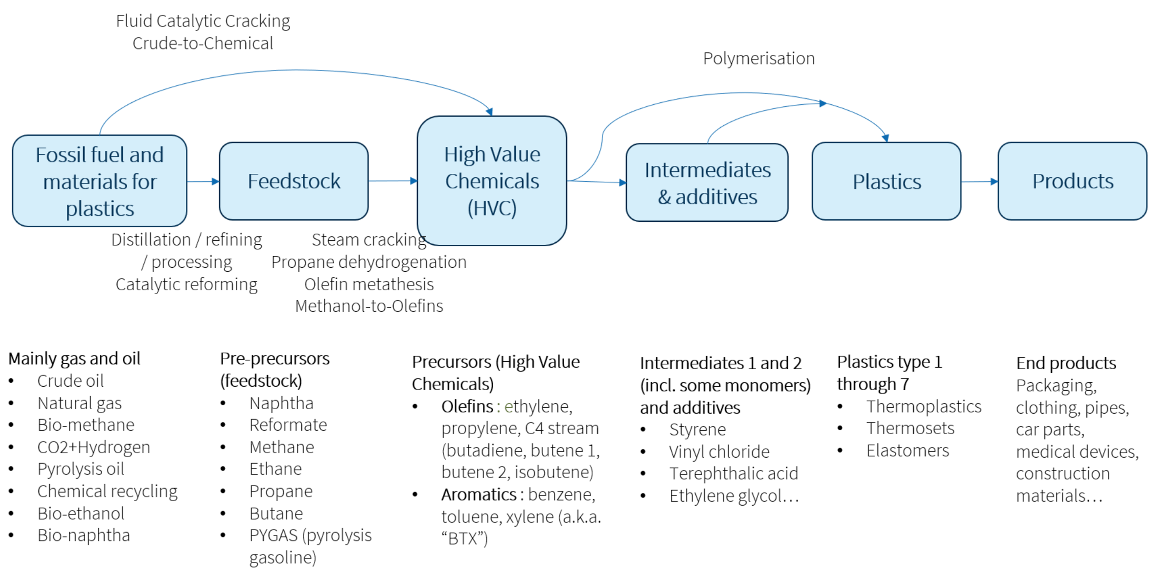
[6] British Plastics Federation, “How Is Plastic Made? A Simple Step-By-Step Explanation,” 2020, https://www.bpf.co.uk/plastipedia/how-is-plastic-made.aspx.

[7] INEOS, “INEOS Group Holdings 2023 Annual Report,” 2024, https://www.ineos.com/globalassets/investor-relations/public/annual-reports/annual-report-blocks/ineos-group-holdings-s.a._audit-report-conso_2023_signed.pdf., page 148.

3. Using heat and/or catalysts to transform these molecules into single-molecule plastic precursors (aka **monomers**). These are called *High-Value Chemicals* (HVCs) and include ethylene, propylene, the C4-stream, and benzene, toluene, and xylene
4. Using further processing (polymerisation) to tie the plastic precursors to one another, making **polymers** – the chemical name for plastics in this context.
5. Additionally, many types of plastics incorporate other, various chemical additives into the plastic structure both to push along the industrial process and to give it desired properties such as resistance, flexibility, transparency, resilience to bending, etc.

The below schematic of the value chain recapitulates the main steps in the plastics production process.

Figure 2: Main steps in the plastic production process



Source: BASIC

Step 1: Drilling and cleaning

Oil and gas do not come out of the ground ready for refining and processing (respectively). Rather, they have to be "cleaned." This entails, depending on the type, removing items such as water, salt, acid gasses, sulphur, and any dirt and grime.

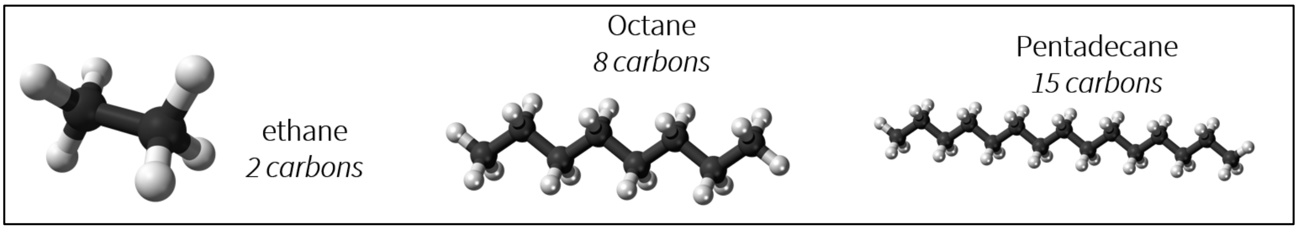
Step 2: Distillation

The next step toward plastic production is to isolate, out from oil and gas, the material that will serve as the first input in the plastics production chain. This material is called "feedstock" or "pre-precursors" because the material is one step removed from plastic precursors such as olefins and aromatics (more on these below); in this sense the downstream of the plastic life chain "feeds" on these pre-precursor chemicals. As will be detailed below, feedstock chemicals are obtained through distillation of oil and gas – that is, using heat to separate the oil or gas components by molecular weight. Petroleum refining and natural gas processing separates out the different molecules of which oil and gas are constituted in order to progressively isolate the molecules (or range thereof) whose weight and chemical composition is adapted to the end-use that is intended.

Petrochemistry 101

Gas and oil are a mix of hydrocarbons: molecules constituted of chains of carbon atoms linked to one another and linked to hydrogen atoms. Except for the first few of the lightest hydrocarbons, the name of the molecule usually reflects the number of carbon atoms. For instance:

Figure 3: Examples of hydrocarbons by chain length



Source: BASIC; images credit Wikipedia.

Petroleum (oil) generally contains molecules that are very large – some can go as high as 70+ carbons. Gas tends to contain smaller molecules – only up to about 15 carbons (pentadecane, see above).

The larger and heavier a molecule, the less it is likely to volatilise at any given temperature. As a result, petroleum, which contains those heavier molecules, is most often liquid at room temperature; gas, which is made up of lighter molecules, is – as its name suggests – usually gaseous at room temperature. The relevant word to describe this phenomenon is the notion of *boiling point.* To give two extreme examples based on the number of carbons in the chain (and thus the molecular weight):

A molecule containing **1 carbon atom** (methane) volatilises beginning at -161°C.[8]

A molecule containing **90 carbon atoms** will only volatilise above 720°C.[9]

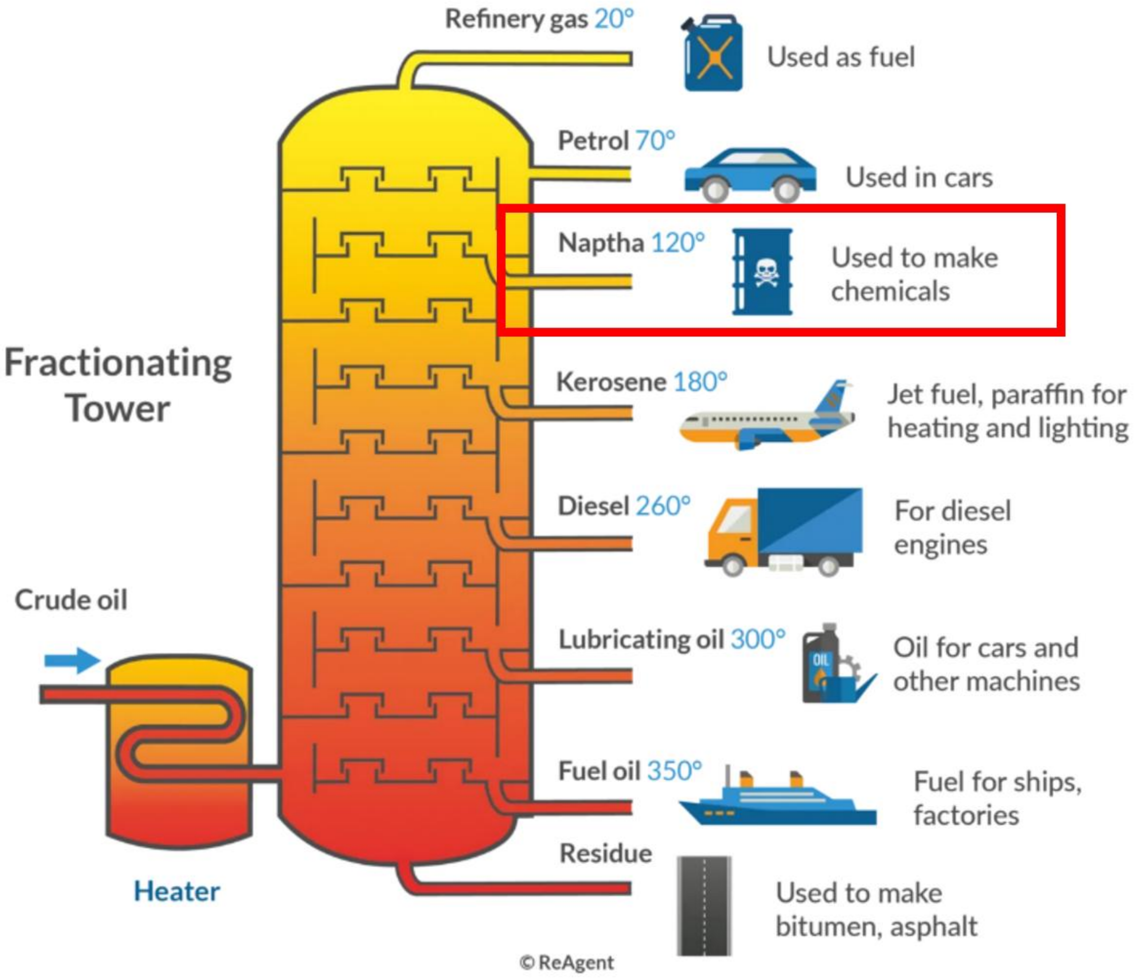
Crude oil refining and distillation

As concerns the distillation of crude oil, even the heaviest and the lightest of molecules are useful for some use or other. For instance, 70+ carbon chains are used in bitumen, while the lightest molecules are used to make refinery gas or petrol. Regarding plastics, the interesting category in the fractional distillation of crude oil is **naphtha,** which is composed of approximately 5 to 10 carbons. Naphtha is **used, among other uses,**[10] **as a source of plastic precursors**. A naphtha derivative called **reformate** is also used to create plastic precursors, in particular the aromatics (BTX; see below).

Below is a schematic of a typical fractional distillation column and the fractions taken out of the column, based on their molecular weight and each molecule's vapour pressure (boiling point), where the fraction useful to plastic precursor formation, **naphtha**, is visible.

[8] GuideChem, "8006-14-2 Natural Gas - Chemical Dictionary," 2024, https://www.guidechem.com/dictionary/en/8006-14-2.html.
[9] GuideChem, "6703-98-6 Decacontane - Chemical Dictionary," 2024, https://www.guidechem.com/dictionary/en/6703-98-6.html.
[10] Other uses include as a precursor to liquid fuels, solvents or diluants for paint, dry-cleaning solvents, solvents in the rubber industry, solvents for asphalt, etc. See James G. Speight and Nour Shafik El-Gendy, "Refinery Products and By-Products," in *Introduction to Petroleum Biotechnology* (Elsevier, 2018), 41–68, https://doi.org/10.1016/B978-0-12-805151-1.00002-3.

Figure 4: Crude oil fractional distillation tower



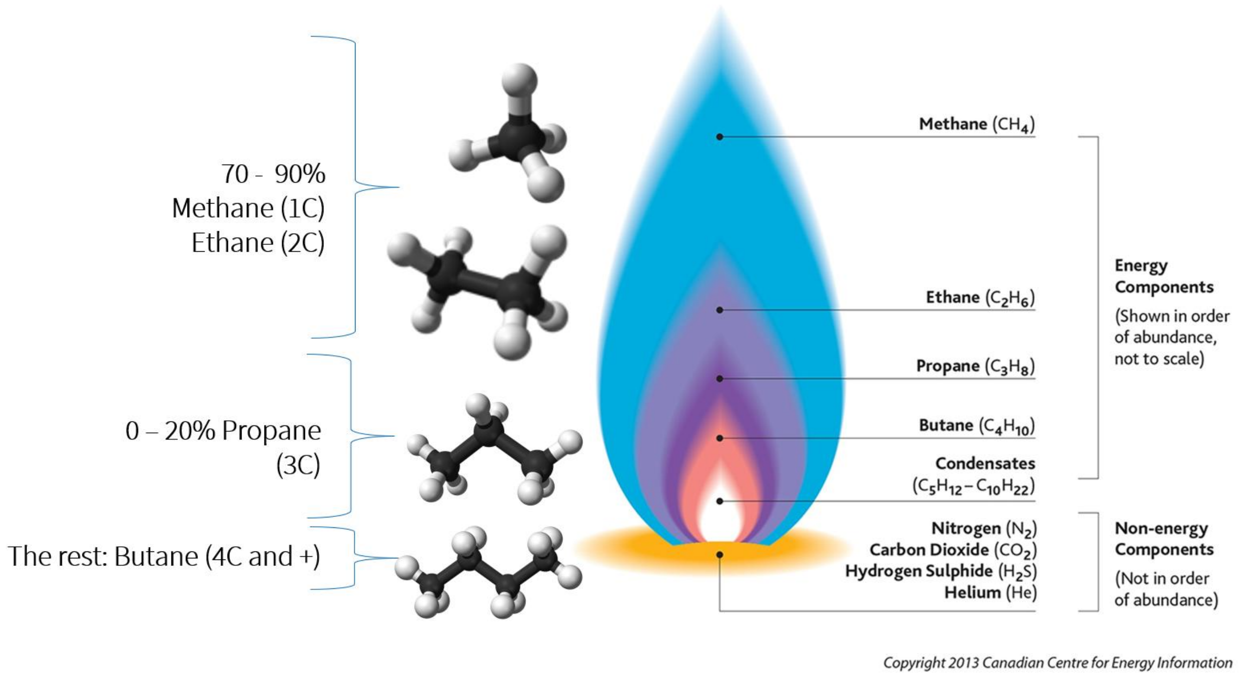
Source: BASIC, photo courtesy ReAgent Chemical Suppliers[11]

Natural gas processing

Natural gas is a substance that is in gaseous form at room temperature. It is largely comprised of 4 carbons molecules and under, as can be seen in the figure below:

[11] ReAgent, "What Is Fractional Distillation? - The Chemistry Blog," September 27, 2023, https://www.chemicals.co.uk/blog/what-is-fractional-distillation.

Figure 5: Composition of natural gas, broken down by principal molecules



Source: BASIC, adapted from Canadian Centre for Energy Information (2013)

Gas[12] recovered from drilling is overwhelmingly constituted of **methane** (1 carbon). It also contains what are called Natural Gas Liquids: these are the heavier subset of gasses obtained from gas, such as ethane (2C), propane (3C), butylenes (4C) and natural gasoline (5 carbons+). These are called *Natural Gas Liquids* because they become liquid under a certain temperature.

Table 1: Boiling point of key Natural Gas Liquids

Alkane	Formula	Boiling point
Methane	CH_4	-161 °C
Ethane	C_2H_6	-89 °C
Propane	C_3H_8	-42 °C
Butane	C_4H_{10}	-1 °C
Pentane	C_5H_{12}	36 °C
Hexane	C_6H_{14}	69 °C
Heptane	C_7H_{16}	98 °C
Octane	C_8H_{18}	126 °C

NGLs (Ethane – Pentane)

room temperature (between Butane and Pentane)

Source: adapted from OpraChem[13]

Natural gas refining involves processes similar to crude oil distillation, with iterative skimming off of the lighter molecules as they volatilise under the effect of progressively warmer temperatures.

[12] There is an ambiguity around the significance of the words "natural gas." In common parlance, they can refer either to (1) the molecule methane (CH_4) or (2) the mixture of light hydrocarbon molecules that is extracted from the ground. To avoid confusion, we have reserved the use of the words "natural gas" or simply "gas" to refer to the mix in number 2, while when we need to refer to number 1 we simply use the word "methane."

[13] OperaChem, "Alkanes," June 16, 2023, https://www.operachem.com/alkanes/.

Ultimately, the refining of oil and the processing of gas produces the following molecules which are called **feedstocks in the context of the plastics industry:**

Table 2: Main plastic feedstocks, their origins and number of carbon atoms

Main feedstocks	Source	Number of carbon atoms
Methane	Natural gas processing Co-product of oil refining	1
Ethane	Idem	2
Propane/Liquid Petroleum Gas (LPG)	Idem	3
Butane	Idem	4
Naphtha	Product of oil refining	5 to 10 (approximately) *Yields all of the above*
Reformate	Product of further naphtha processing	5 to 10 (approximately) *Yields in particular three High Value Chemicals: benzene (6 carbons), toluene (7 carbons) and xylene (8 carbons)*
Pygas (pyrolysis gasoline)	Product of naphtha steam cracking	5 to 12 (approximately) *Yields three High Value Chemicals: benzene (6 carbons), toluene (7 carbons) and xylene (8 carbons)*

Source: BASIC

Step 3: Transforming feedstocks into High Value Chemicals (HVCs)

The next step in plastics production is turning feedstocks into High Value Chemicals (HVCs). There are a few ways to do this. The overwhelming proportion of production takes place as **steam cracking.** Steam cracking consists of forcing a chemical reaction in the presence of water and oxygen at a high temperature. This leaves the molecules lighter than they were previously.

The below image illustrates the step where **steam cracking of naphtha (a product derived from oil, as seen above)** yields HVCs, such as ethylene, propylene, etc. As an example, here a 6-carbon molecule (hexane) is steam-cracked into ethylene, the HVC derived from ethane (2 carbons). Note that the equation given is an example, and that it does not represent the entirety of the possible outputs of steam cracking hexane. For instance, one paper describing the possible outputs from octane (8 carbon) steam cracking lists no less than seven possible chemical equations, yielding fractions of chemicals ranging from two to seven carbon molecules (although the majority of outputs are the lighter fraction, most notably ethylene, methane, and ethane).[14]

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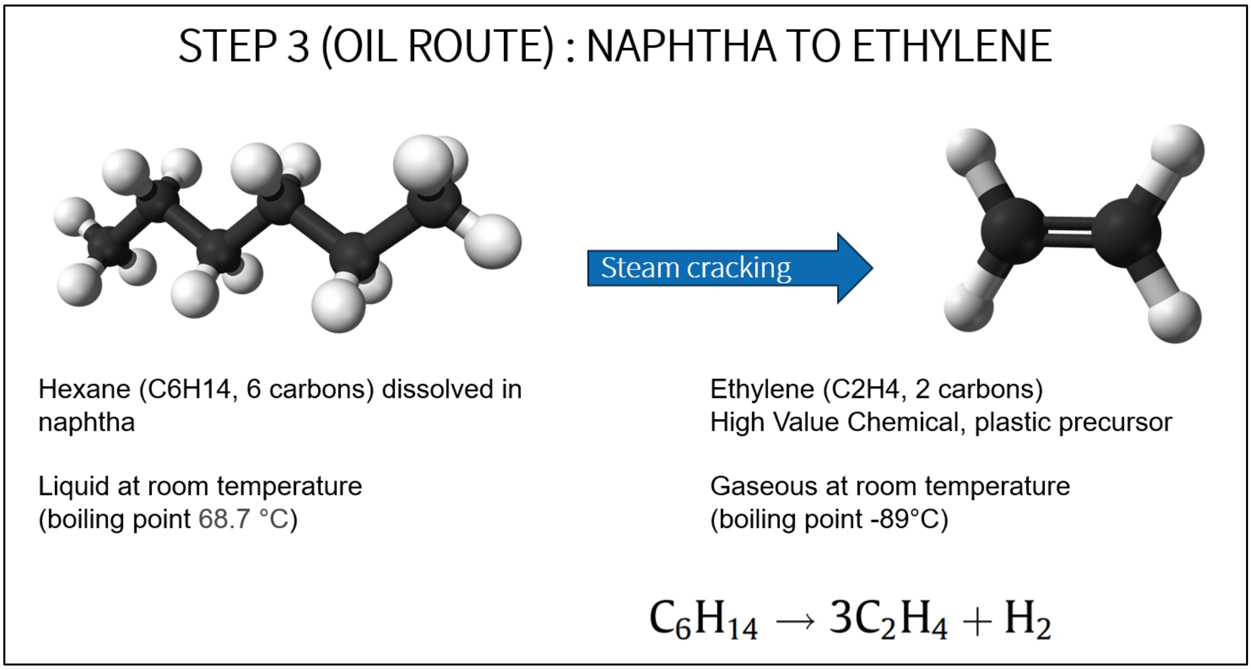
[14] N. Razafinarivo et al., "Pyrolysis of N- Octane at Very Low Concentration and Low Temperature," *Journal of Analytical and Applied Pyrolysis* 117 (January 2016): 282–89, https://doi.org/10.1016/j.jaap.2015.11.004.

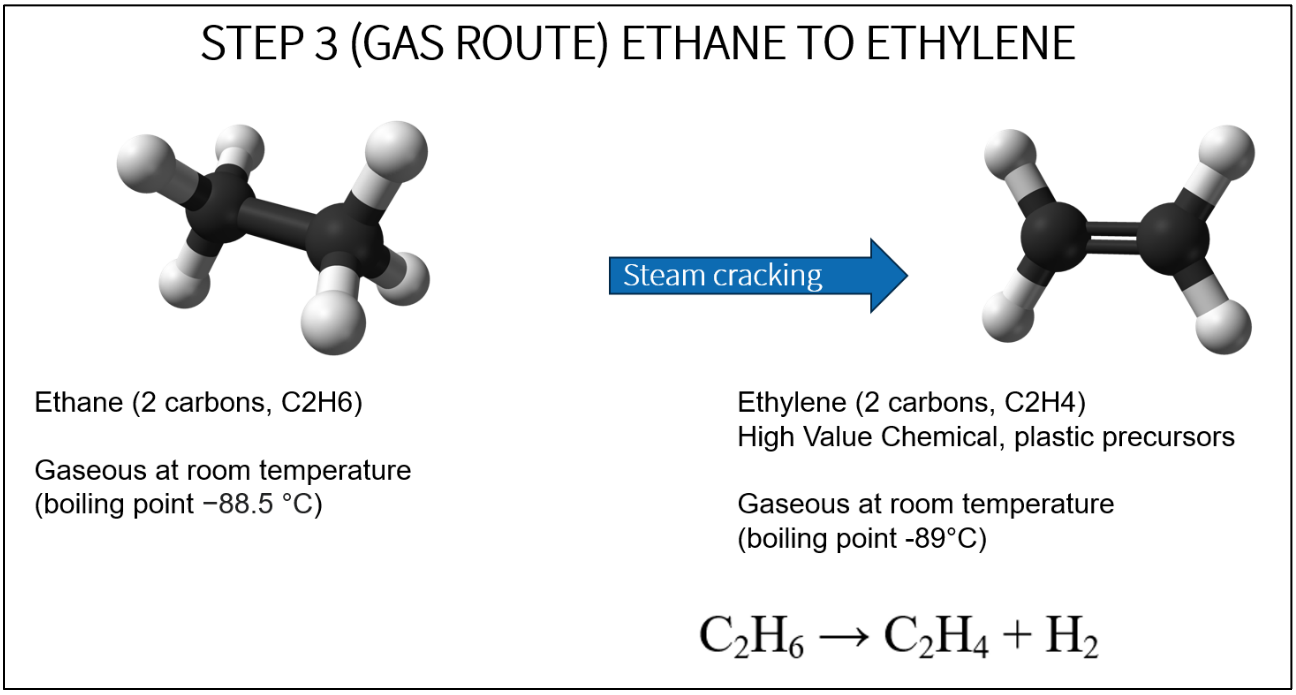
Figure 6: Naphtha steam cracking to ethylene



Source: BASIC (molecule images from Wikipedia)

Steam cracking also works on feedstocks that have the same number of C molecules as the targeted HVC, typically Natural Gas Liquids (see above). For instance, here a molecule of ethane recovered from natural gas processing is steam-cracked into the HVC ethylene. Note that the ethylene is lighter than ethane: there are only four hydrogen atoms in ethylene, as against six in ethane.

Figure 7: Ethane steam cracking into ethylene



Source: BASIC (molecule images from Wikipedia)

The below table recapitulates the main HVCs that are derived from petrochemical feedstocks. Ethylene (2 carbons), propylene (3 carbons), and different isomers of butane (4 carbon, a.k.a. the butylenes) are collectively called “olefins.” Pygas (pyrolysis gasoline) is a byproduct of ethylene and propylene production and yields molecules with 5 or more carbons, as does reformate. Three of these 5+ carbon molecules are of interest for plastic production: the “aromatics” benzene, toluene, and xylene, so named because they have a smell. Note that xylene is of three types: ortho-xylene (also known as o-xylene), meta-xylene (m-xylene), and para-xylene (p-xylene). The three molecules have slightly different uses (see Figure 11 below).

Table 3: Feedstocks and their use for different High Value Chemicals

Main feedstocks	Serves as a basis (mainly via steam cracking) for HVCs…	Chemical family name (where applicable)
Methane **not through steam cracking, rather through conversion at a methanol plant*	Methanol	
Ethane *and naphtha*	Ethylene	
Propane/Liquid Petroleum Gas (LPG) *and naphtha*	Propylene	OLEFINS
Butane *and naphtha*	C4 stream (butylenes)	
Reformate **not through steam cracking, rather through fractional distillation of natpththa*	Benzene	
	Toluene	
	Xylene	
Pyrolysis gasoline (Pygas)	Benzene	AROMATICS
	Toluene	
	Xylene	

Source: BASIC

Step 4: Polymerisation

The final step in creating plastics is to further process High Value Chemicals to turn them from *monomers* (isolated molecules) into *polymers* (molecules chained to one another). It is worth remembering the word **polymerisation**, as this describes the process that applies to the vast majority of plastics produced.

The polymerisation process yields products that typically take a name composed of the word “poly” followed by the name of the High Value Chemical from which the product is derived. For example, ethylene is polymerised into different kinds of *poly*ethylene; propylene is polymerised into *poly*propylene; and so on. These chemically based categories are used, in turn, as the basis for distinguishing different types from one another (see subchapter 2.3). Note that polyethylene terephthalate (PET), despite what its name suggests, is not a polymer of ethylene; rather, it is composed of ethylene glycol and terephthalic acid.

For some kinds of plastics, the polymerisation process is accompanied by the incorporation of so-called “intermediates,” many – but not all – of which are derived from oil and gas. While they are too numerous to be listed here, a selection of the most important first, second, and third-tier intermediates are available in pages 14 to 24 of the Supplementary Material to Levi and Cullen (2018).

Step 5: Other chemicals incorporated into plastics

Plastics are versatile materials, but their inherent properties often need enhancement or modification to suit specific applications. This is why polymerisation is often combined with the incorporation or use of additives, which allow plastics to meet the diverse requirements of industries such as packaging, automotive, and construction. Broadly, additives can improve durability, flexibility, colour, and resistance to environmental factors. By blending these chemicals during the manufacturing process, manufacturers tailor the final product's characteristics to specific uses.

One common group of additives includes plasticisers, which increase flexibility and elasticity in plastics like PVC.[15] Without plasticisers, materials like PVC would be rigid and brittle, unsuitable for applications like cables or medical tubing. Stabilisers are another vital category, ensuring that plastics maintain their structural integrity and resist degradation over time.[16] For example, heat stabilisers are essential in processes like injection moulding, where high temperatures could otherwise degrade the plastic.[17] Similarly, UV istabilisers protect outdoor applications, such as garden furniture or vehicle interiors, from damage caused by prolonged sun exposure.[18]

Specialty additives provide even more specific functionalities. Flame retardants, for instance, are incorporated into plastics to reduce flammability, a critical feature in electronics and construction materials – although older flame retardants have come under criticism due to health concerns.[19] Colorants, like pigments or dyes, are used to achieve aesthetic appeal and brand identity, while antimicrobial agents are added to prevent bacterial growth in medical and food packaging applications.[20] Fillers, such as glass fibres or calcium carbonate, can enhance mechanical strength and reduce production costs.[21] Lubricants play a critical role during the process of polymerisation.[22] Together, these additives transform basic polymers into advanced materials with a wide diversity of uses. The figure below presents the variety of uses to which additives are put, as well as their very high number (note that some additives have more than one function).

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[15] SpecialChem, "Plasticizers: Types, Uses, Classification, Selection & Regulation," 2025, https://polymer-additives.specialchem.com/selection-guide/plasticizers.

[16] ChemBroad, "Heat Stabilizer for Soft Plastic: Benefits and Applications," January 19, 2024, https://www.chembroad.com/heat-stabilizer-for-soft-plastic-benefits-and-applications/.

[17] ChemBroad.

[18] EuroPlas, "UV Stabilizers in Plastic: 4 Common Types and Applications," 2025, https://europlas.com.vn/en-US/blog-1/uv-stabilizers-in-plastic-4-common-types-and-applications.

[19] National Institute of Environmental Health Sciences, "Flame Retardants," January 30, 2025, https://www.niehs.nih.gov/health/topics/agents/flame_retardants.

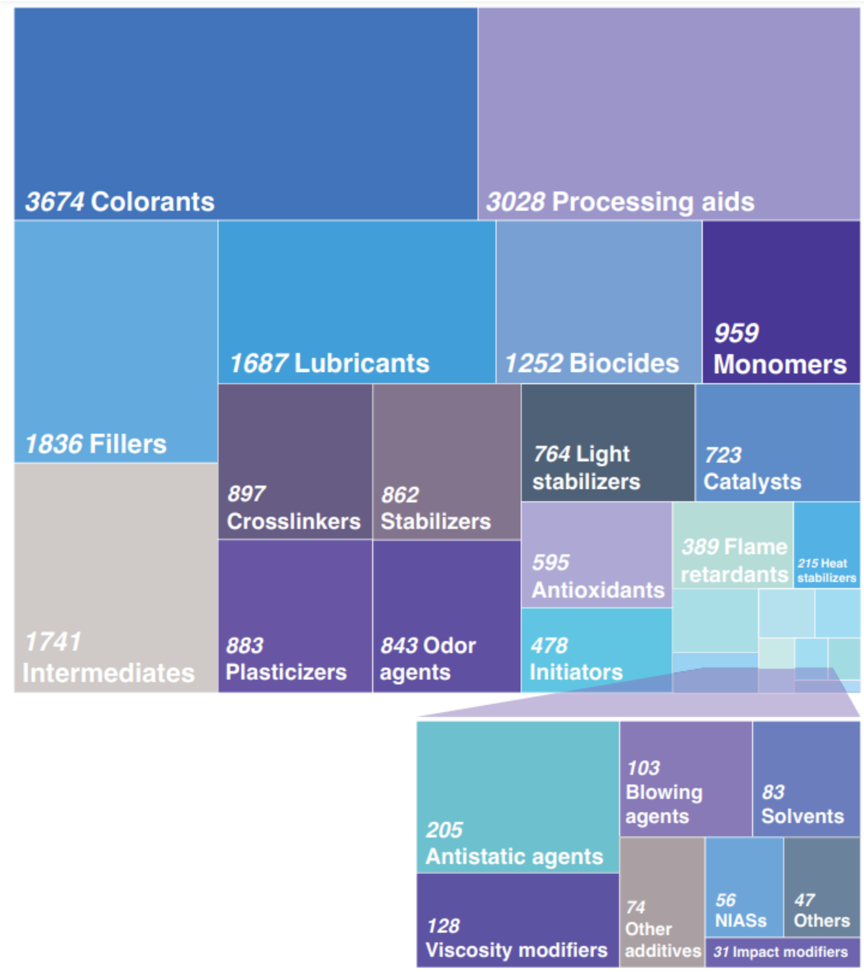
[20] FOW Mould, "Plastic Additives: Complete Guide," November 22, 2023, https://www.immould.com/plastic-additives/.

[21] FOW Mould.

[22] SpecialChem, "Lubricants Additives : Types, Properties, Uses & Processing Guide," 2025, https://polymer-additives.specialchem.com/selection-guide/lubricants.

Figure 8: Overview of the functions of chemicals in plastic, including monomers.

Note that many compounds have more than one function.



Source: PlastChem Project, 2024[23]

Nonetheless, additives in plastics, while crucial for enhancing properties like durability, flexibility, and colour, have raised concerns about potential health and environmental impacts. An estimated 16,000 chemicals are potentially used or present in plastic materials and products, of which at least 4,200 are of concern because they are persistent, bioaccumulative, mobile, and/or toxic (PMBT).[24] For instance:[25]

- More than 2,200 plastic chemicals investigated by the PlastChem project are classified as carcinogens, mutagens, and/or reproductive toxicant (CMRs).
- Some additives, such as phthalates used as plasticisers and bisphenol A (BPA) employed in polycarbonate plastics, have been linked to endocrine disruption, which can interfere with hormonal systems in humans, but also to cardiovascular diseases, diabetes, and obesity.

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[24] PlastChem Project, "State of the Science on Plastic Chemicals: Identifying and Addressing Chemicals and Polymers of Concern," March 14, 2024.
[25] PlastChem Project.

- Brominated and organophosphate flame retardants have been associated with neurodevelopmental effects and endocrine disruption, adversely affecting cognitive function and behaviour in children, as well as thyroid and reproductive health.
- Polyfluoroalkyl substances (PFAS), widely utilised for their non-stick and water-repellent properties, are strongly associated with an increased risk of cancer, thyroid disease, and immune system effects, including reduced vaccine efficacy in children.
- Yet other plastic chemicals are known to cause harm to human health, for example because they are mutagens (e.g., formaldehyde) or carcinogens with other modes of action, like melamine.

These chemicals can leach out of plastics during use or disposal, leading to human exposure through ingestion, inhalation, or skin contact. There is also evidence of toxicity of plastic chemicals to the aquatic environment and to a variety of organisms, including cells, microorganisms, plants, invertebrates, and vertebrates.[26] In addition, the biocide properties of certain plastic chemicals can promote antimicrobial resistance. The cumulative and long-term effects of exposure to problematic chemicals – in particular their environmental impacts – are still being studied, prompting increased regulatory scrutiny and a push for safer, non-toxic alternatives in plastic production.

Focus on two alternative production routes

In addition to the conventional plastics production route described above, there are two other routes. They are relatively minor at present, but the second one may have important implications for the future of the plastics industry.

a. “Coal to Olefins”: a technology allowing the valorization of abundant resources

Oil and gas are by far the most used fossil resources in plastic production. In much smaller quantities, coal can also be used as a petrochemical feedstock.[27] In particular, the “methanol to olefins” (MTO) technique, which consists of transforming coal first into methylalcohol (methanol) and then into olefins (ethylene and propylene), is to date the main technique for producing plastics from coal.

This technology is relatively new (the process is in use since 2013 according to Mackay[28]) and marginal today because it does not seem to offer any performance advantage compared to the traditional process.

On the other hand, for plastic-producing countries with significant coal resources (and less so oil and gas), this technique offers the advantage of valorising this resource and possibly increasing the autonomy (via self-supply) of the countries in question. The price of coal compared to a barrel of oil can also play in favour of coal.[29]

[26] PlastChem Project.

[27] "99% of plastics in circulation today are produced from oil (70% of the raw material used since 1970 according to the International Energy Agency - IEA), gas (25%) and coal (between 1 and 5%, figures which are probably underestimated, mainly used in China)." *Source:* https://www.zerowastefrance.org/face-cachee-industrie-plastique/#

[28] Source: https://www.ecst.college/coal-to-plastic-technology-could-help-china/

[29] In 2008, Les Échos stated that : “ At the current price of a barrel of oil, it would already be economically profitable to produce our polymers from coal or gas. Provided that it can be demonstrated technically" - Source: https://www.lesechos.fr/2008/10/total-va-au-charbon-pour-fabriquer-du-plastique-500094

The example of China is particularly illustrative of this phenomenon : according to Levi and Cullen (2018), "MTO is a relatively newly commercialised technology which […] is gaining increased penetration in China, where coal-based methanol capacity is plentiful."

In the future, MTO technology could experience strong development, particularly in India and China, due to the high local availability of coal resources and forecast strong global demand for ethylene and propylene.

b. "Crude to Chemical": new developments in oil refining

The past few years have seen major developments in oil refining processes, due to a new refining process known as "crude-to-chemical," or "Crude Oil to Chemical" (COTC), "Crude to Chemical" (C2C or CTC), but also "Thermal Crude to Chemical" (TC2C).

Essentially, C2C is a technology that enables going from 10% petrochemical production to anywhere from 40% to 70% or even 80% petrochemical production from a single barrel of crude oil. (The most advanced technology is deployed by Saudi Aramco and is reported to yield 80% olefins and aromatics from a single barrel of crude. At this rate, relatively speaking, it takes 1.25 unit of oil to produce 1 unit of petrochemicals, against 10 units of oil for a single unit of petrochemicals in the conventional route). C2C requires slightly less energy than the traditional route from crude oil to the targeted olefins (ethylene, propylene, C4 stream) and aromatics (benzene, toluene, xylene). There are a variety of routes to achieve these results, including using entirely new technologies or reconfiguring refinery design. As the consulting firm McKinsey notes:

> "Different oil-to-chemicals technologies have varying costs and degrees of conversion. The simplest modification, employing new technology in a single FCC unit, would result in up to 40 percent of refinery output as petrochemicals. Alternatively, using a mix of conventional technologies reconfigured for maximum chemical yield could bring chemicals' share closer to 50 to 60 percent of total output. Combining these—reconfiguring the mix of conventional-process units and employing new technologies—could push petrochemical yields to 80 percent of total output. Direct crude-to-chemicals production could yield output of nearly 100 percent chemicals. The price of these approaches rises with the level of yield shift. Individual unit modifications cost $50 million to $100 million. Full-refinery reconfigurations can cost multiple billions of dollars."[30]

The high petrochemical-per-barrel ratio is increasingly attractive in a world where fossil fuel demand is likely to diminish while plastics demand is set to explode (especially thanks to demand in developing economies) – see Figure below.

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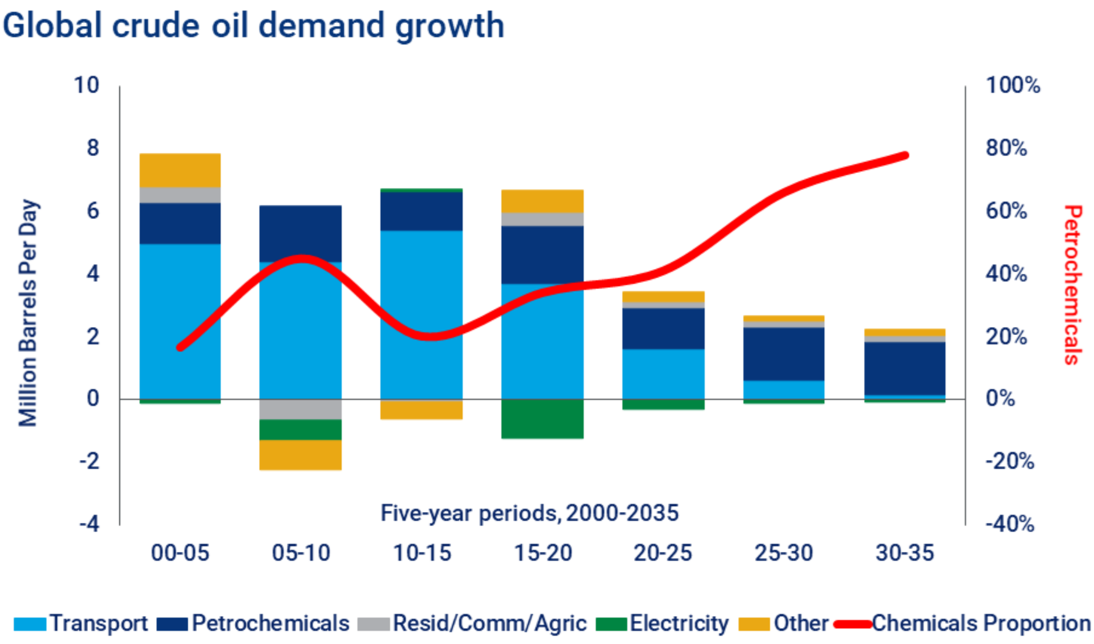
[30] McKinsey, "Crude Oil to Chemicals: How Refineries Can Adapt," June 30, 2022, https://www.mckinsey.com/industries/chemicals/our-insights/from-crude-oil-to-chemicals-how-refineries-can-adapt-to-shifting-demand.

Figure 9: Global crude oil demand growth and petrochemicals proportion, 2000 - 2035



Source: Wood Mackenzie[31]

According to industry sources cited in an article dating to June 2024, the average price for a ton of ethylene produced in the latest, highest-technology complexes in the near future will be around \$100, compared to \$300 in China and \$200 for less state-of-the-art complexes in the Middle East.[32] This suggests that the heavy investments in modernising and adapting equipment to implement C2C is rapidly recouped thanks to the increased efficiency of olefin and aromatics production. By 2027, there will be at least 47+ Mt per year production capacity for ethylene, olefins and/or para-xylene that is C2C.[33] (Para-xylene is the type of xylene that is used in polyester production).

1.2. Output of petrochemistry: types of plastics

This section delves into the output of the petrochemical process, namely, the production of plastics. It presents the different types plastics as per their standard typology (types 1 through 7), as well as the percentage of plastics that fall into each type. Subsequently, the main uses of each type of plastics are presented. Finally, other categorisations of plastics are addressed. The main sources for this

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[31] Wood Mackenzie, "Why Crude-to-Chemicals Is the Obvious Way Forward," April 27, 2020, https://www.woodmac.com/news/opinion/why-crude-to-chemicals-is-the-obvious-way-forward/.

[32] TankTerminals, "Saudi Aramco to Revolutionize Petrochemical Industry With World's Largest COTC Plant," June 13, 2024, https://tankterminals.com/news/saudi-aramco-to-revolutionize-petrochemical-industry-with-worlds-largest-cotc-plant/.

[33] BASIC, based on research into C2C plants that have recently come online or that are projected to come online by 2027.

section include the Plastic Atlas,[34] Britannica,[35] the Petrochemicals Europe petrochemistry flowchart,[36] and the sources listed as sources in "**Erreur ! Source du renvoi introuvable.**" in section 4.2.

1.2.1. Types 1 through 7

In general, plastics are classified into seven types. The first six types are constituted of distinct polymers – long molecules – which result from the polymerisation of High Value Chemicals derived from oil and/or gas, as explained above. The seventh type of plastics is a catch-all for substances that do not clearly fit this model, or which require more complex transformation or other precursors in order to be produced.

Below are the main links from the High Value Chemicals that were introduced above to the final plastic type and its number:

Table 4. Type 1 through 7 plastic by main monomer

Name of main monomer	Intermediates (where applicable)	Plastic name	Plastic type number
Ethylene & p-xylene	Ethylene glycol & terphthalic acid	Polyethylene terephthalate (PET)	1
Ethylene & p-xylene	Ethylene glycol & terphthalic acid	Polyester (fibre)	1
Ethylene	--	High Density Polyethylene (HDPE)	2
Ethylene & o-xylene	Vinyl chloride	Polyvinyl Chloride (PVC)	3
Ethylene	--	Low Density Polyethylene (LDPE)	4
Propylene	--	Polypropylene (PP)	5
Benzene/ethylene, and methanol/toluene[37]	Styrene	Polystyrene	6
Methanol; ethylene, propylene, C4 stream (butylenes); benzene, toluene, xylene	*Various intermediates*	*Various plastics*	7

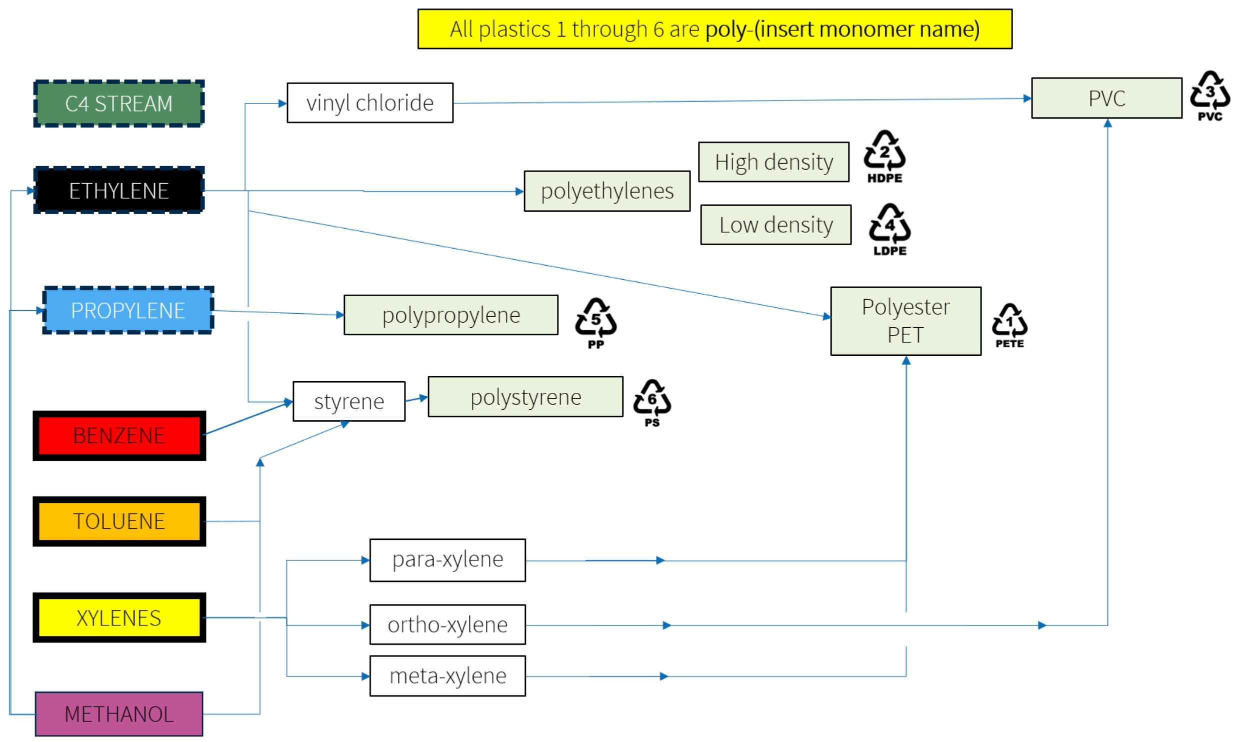
Source: BASIC

The below image presents a simplified view of the plastics production chain, featuring HVCs and their downstream components. As can be seen, ethylene is involved in all but one (PP, type 5) of the type

[34] Heinrich-Böll-Stiftung, La Fabrique Écologique, and Break Free From Plastic, "Plastic Atlas: Facts and Figures about the World of Synthetic Polymers," 2019, https://www.boell.de/sites/default/files/2020-01/Plastic%20Atlas%202019%202nd%20Edition.pdf.
[35] Articles such as "plastic" (Britannica, "Plastic | Composition, History, Uses, Types, & Facts," 2025, https://www.britannica.com/science/plastic.) as well as the individual pages for the main types of plastics listed below (PET, polyester, polyethylene, PVC, polypropylene, polystyrene), and other pages on oil and gas processing.
[36] Petrochemicals Europe, "Flowchart- Petrochemicals Europe."
[37] The use of toluene and methanol to manufacture styrene is an innovation dating to the mid-2000s. The traditional route using benzene and ethylene required additional steps, more energy, and more expensive inputs, in addition to being more toxic. Chemical & Engineering News, "Styrene Breakthrough," March 19, 2007, https://cen.acs.org/articles/85/i12/Styrene-Breakthrough.html.

1 through 6 plastics: ethylene contributes to PET (type 1), both polyethylenes (types 2 and 4), PVC (type 3), and polystyrene (type 6). The C4 stream, toluene, and methanol, while they appear in the chart, are not connected to any other item for the simple reason that they are precursors to type 7 plastics only – rubbers, polyurethane, and a variety of plastics respectively.

Figure 10: Simplified flowchart of plastics derived from HVCs (types 1 through 6 only)



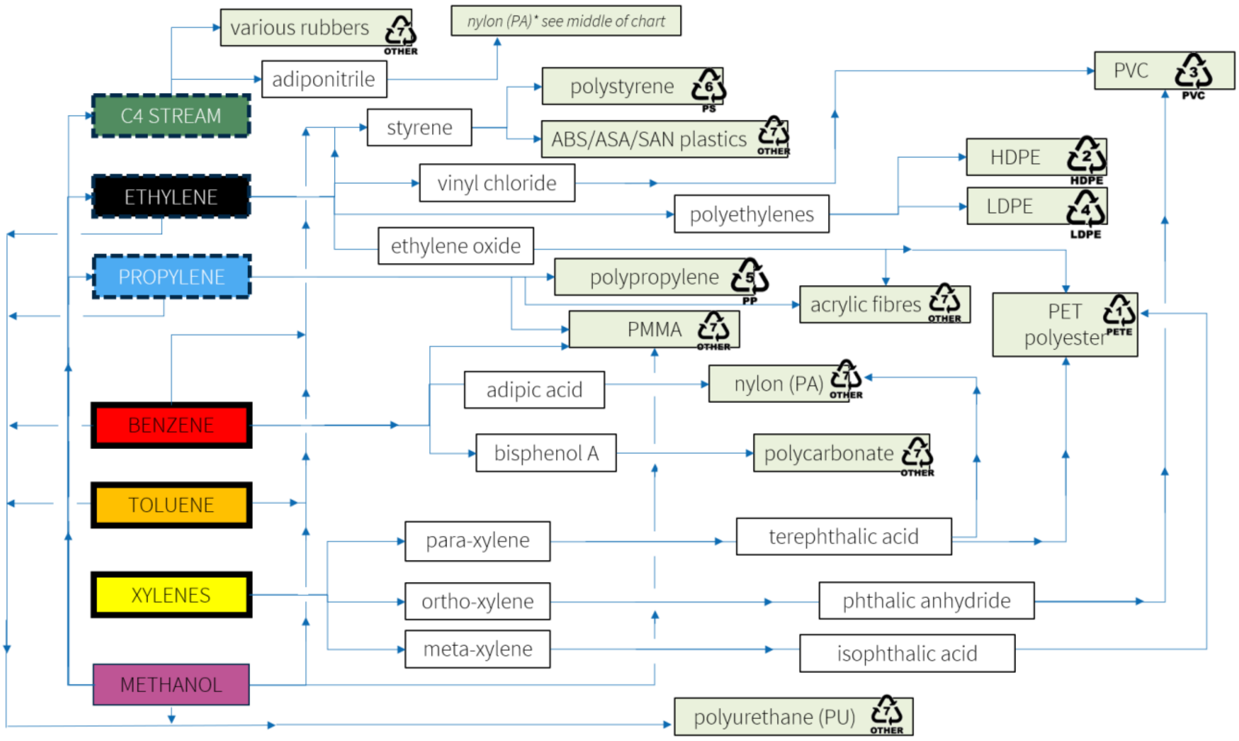
Source: BASIC

The image below shows a more detailed flowchart of the plastics production that goes not just to plastics type 1 through 6, but also to all of the major type 7 plastics, which are as follows (due to lack of data, listed in no particular order):[38]

- PC: polycarbonate
- PA: polyamide (=nylon)
- PMMA: poly(methyl methacrylate) = plexiglass
- PUR: polyurethane
- ABS/SAN/ASA plastics (Acrylonitrile Butadiene Styrene, Styrene Acrylonitrile, Acrylonitrile Styrene Acrylate)
- Other relevant plastics

[38] The list of the major type 7 plastics is taken from the Plastics Atlas pie chart reproduced below.

Figure 11: Simplified flowchart of plastics derived from HVCs (type 1 through 6 and main type 7s)



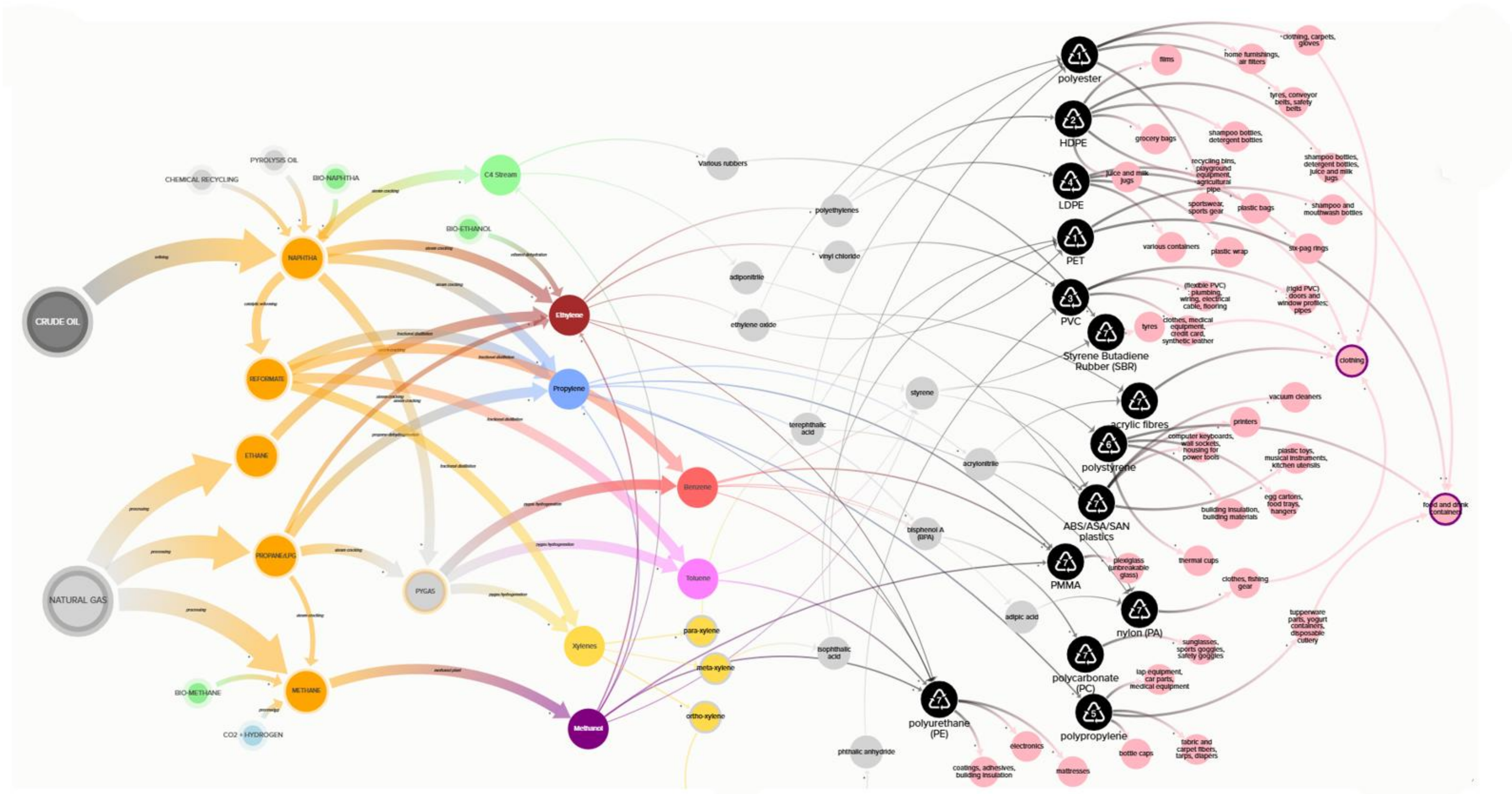
Source: BASIC, based on bibliographical research

An interactive map of the above flowchart is available at the address: https://kumu.io/BASIC/plastics-value-chain-2025. The online flowchart differs in two ways from the static chart given above:

(1) The online chart is dynamic, and one can retrace the flow of matter by hovering one's mouse on any given element
(2) The online chart goes beyond the plastic types (1 to 7) and presents the final plastic uses.

The below image is a static screenshot of the flowchart.

Figure 12: Overview of the plastics production flowchart as constructed in the online tool Kumu



Source: BASIC.

The flowchart above is a qualitative one: it presents the different inputs, from oil/gas, all the way to final products. Below is a figure showing the quantitative breakdown of production by plastic type, from types 1 through 7.

1.2.2. Main uses by plastic type

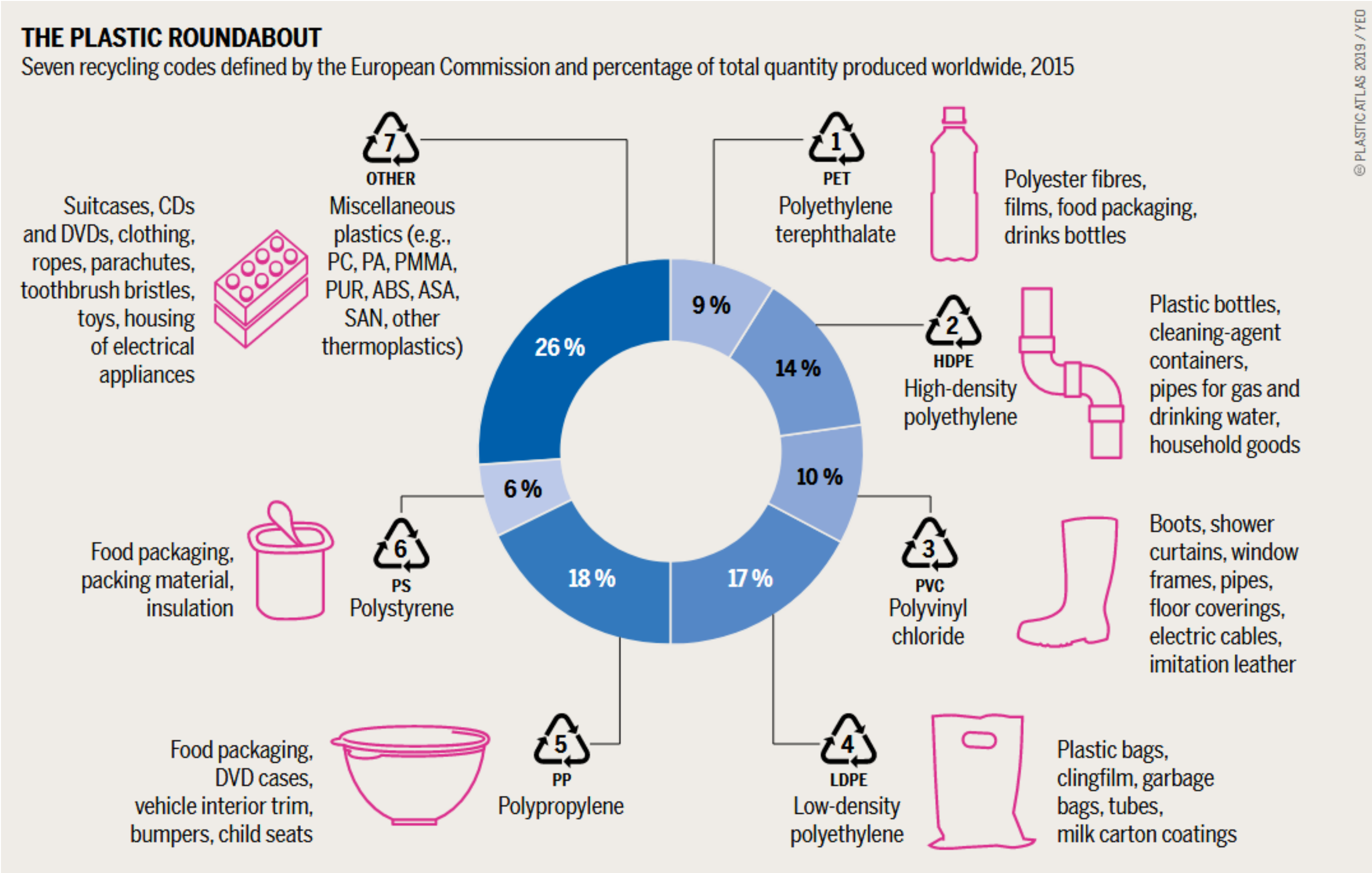
Plastics from types 1 through 7 have the following main properties and uses, as detailed in the figure and table below:

Table 5: Main characteristics and uses of type 1 through 7 plastics

Type no.	Acronym	Full name	Characteristics	Main uses
1	PET	Polyethylene terephthalate	Strong, transparent, lightweight, barrier to gas (such as oxygen which could contaminate food)	Used in beverage bottles, food containers, and packaging due to its strength and barrier properties
1		Polyester (fibre)	Strong, durable, low moisture absorption, and resistant to light, weather, chemicals, and shrinking and stretching	Used in clothing and carpets, sportswear and sports gear, nets, ropes and safety belts, among others due to its strength and resistance
2	HDPE	High Density Polyethylene	Stiff, strong, resistant to chemicals, low moisture absorption	Used for milk jugs, shampoo bottles, cutting boards, piping, and playground equipment due to its strength and chemical resistance
3	PVC	Polyvinyl Chloride	Rigid, strong, good chemical resistance	Commonly used in construction materials, pipes, and medical devices due to its durability and chemical resistance
4	LDPE	Low Density Polyethylene	Flexible, tough, low-temperature resistance	Suitable for grocery bags, food wraps, squeezable bottles, and plastic wrap due to its flexibility and toughness
5	PP	Polypropylene	Strong, heat-resistant, chemical resistant	Used in car parts, food containers, disposable cutlery, and bottle caps due to its strength and heat resistance
6	PS	Polystyrene	Clear, hard, brittle, low moisture absorption	Used in protective packaging, containers, and disposable cutlery due to its clarity and rigidity
7		*Various*	Depending on the plastic in question, type 7 plastics typically possess one or more of the following qualities: strong and durable, optically clear, heat resistant, chemical resistant, versatile, highly resilient and deformable	Depending on the plastic: electronics (due to heat resistance and durability), automotive (strength and chemical resistance), medical devices (durability and ability to withstand sterilisation), optical products (optical clarity), consumer goods, 3D printing (versatility and moldability), rubbers (resilience and deformability)

Source: BASIC, 2025, based on literature review

Figure 13: The seven plastics types, their principal uses and proportion of plastics produced, as of 2015

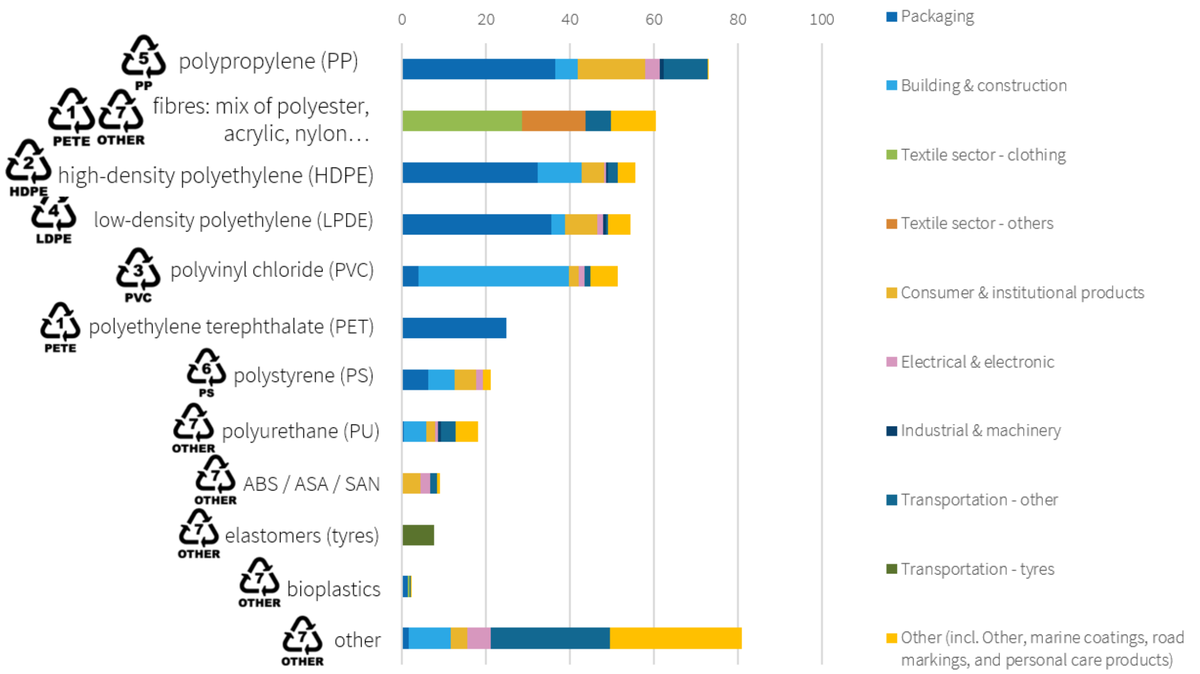


Source: Plastics Atlas 2019[39]

[39] Heinrich-Böll-Stiftung, La Fabrique Écologique, and Break Free From Plastic, "Plastic Atlas: Facts and Figures about the World of Synthetic Polymers."

The following figure illustrates the breakdown of uses by plastic type, in slightly broader categories as defined by the OECD. There are several takeaways from this chart. First, it is clear that packaging represents a significant part of plastic use overall and especially so for PP, HDLE, LDPE, and PET. Another takeaway concerns the category at the bottom of the chart, which groups all plastics not named above it: in this category, transportation and “other” uses dominate (see chart for what “other” entails). Finally, it is worth noting that some types of plastics are strongly associated with certain sectors, such as PET with packaging; PVC with building and construction; and fibres with the textile sector.

Figure 14: Plastic use by type, in Mt in 2019, absolute terms

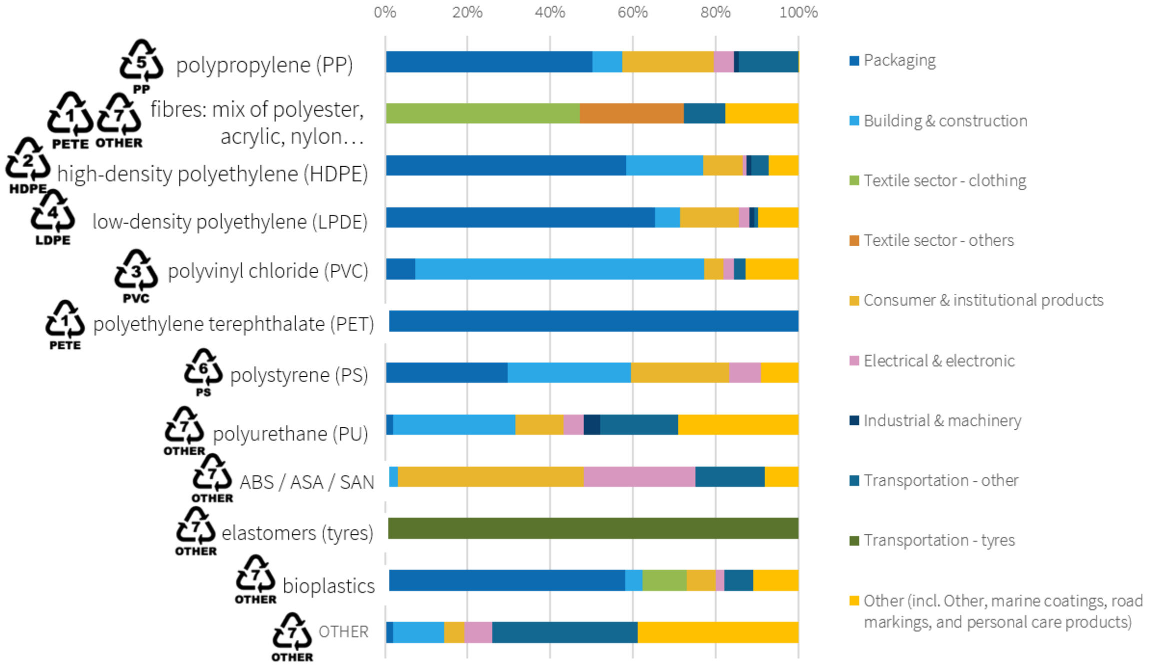


Source: BASIC, based on OECD[40]

[40] OECD, “OECD Data Explorer - Archive • Plastics Use by Polymer,” 2019.

In relative terms, the same graph looks as follows:

Figure 15: Plastic use by type, in Mt in 2019, relative terms



Source: BASIC, based on OECD[41]

1.2.3. Other categorisations

Beyond the standard typology of plastics 1 through 7, some sources – such as the OECD, whose data are used for Figure 14 and Figure 15 – isolate some of the plastics from group 7 to spotlight them in diagrams relating to plastic production breakdowns. For instance:

- It is common for **polyurethane** (PU/PUR) to be separated out from group 7 and made into a standalone plastic alongside the first six types.
- Often, **fibres** are isolated too. This can lead to confusion: first, because several type 1 through 6 plastics can be spun into fibres – PET,[42] but also polypropylene,[43] and to a

[41] OECD.
[42] "The stiffness of PET fibres makes them highly resistant to deformation, so they impart excellent resistance to wrinkling in fabrics. They are often used in durable-press blends with other fibres such as rayon, wool, and cotton, reinforcing the inherent properties of those fibres while contributing to the ability of the fabric to recover from wrinkling. PET is also made into fibre filling for insulated clothing and for furniture and pillows. When made in very fine filaments, it is used in artificial silk, and in large-diameter filaments it is used in carpets. Among the industrial applications of PET are automobile tire yarns, conveyor belts and drive belts, reinforcement for fire hoses and garden hoses, seat belts (an application in which it has largely replaced nylon), nonwoven fabrics for stabilising drainage ditches, culverts, and railroad beds, and nonwovens for use as diaper topsheets and disposable medical garments." Britannica, "Polyethylene Terephthalate (PET or PETE) | Structure, Properties, & Uses," December 20, 2024, https://www.britannica.com/science/polyethylene-terephthalate.
[43] "A large proportion of polypropylene production is melt-spun into fibres. Polypropylene fibre is a major factor in upholstery and indoor-outdoor carpets. Numerous industrial end uses exist as well, including rope and cordage, disposable nonwoven fabrics for diapers and medical applications, and nonwoven fabrics for ground stabilisation

lesser extent polyethylene.[44] There are at least an additional three other types of fibres within the type 7 plastics: polyamide (nylon) fibre, acrylic fibre, and spandex (a thermoplastic version of polyurethane). When looking at statistics on plastics production that have a "fibre" category, it is difficult to ascertain which of these six fibre types are retained within the perimeter of "fibre."

- Occasionally, a distinction is made between thermoplastics, thermosets, and elastomers:
    - Thermoplastics are polymers that can be repeatedly softened by heating and hardened by cooling. They do not undergo a chemical change during processing, meaning they can be re-melted and reshaped multiple times. All plastics type 1 through 6 and some type 7 plastics are thermoplastics.
    - Thermosetting polymers (or "thermosets") are materials that undergo a chemical change when they are heated and moulded, resulting in a rigid, permanently hardened structure. Once set, they cannot be re-melted or reshaped by heating. Many type 7 plastics are thermosets. Note that polyurethane can be both a thermoset and a thermoplastic.
    - Elastomers are polymers that have the ability to return to their original shape after being stretched or deformed. They are highly elastic and can withstand significant strain without permanent deformation. A variety of rubbers (type 7) are elastomers. Note that tyres and shoes, for instance, are partially composed of these synthetic rubbers as well as synthetic fibres.[45]
- Occasionally, a focus is made on Styrene Acrylonitrile (SAN), Acrylonitrile Butadiene Styrene (ABS), and Acrylonitrile Styrene Acrylate (ASA) plastics. These plastics have in common that they all have styrene as a primary component in their chemical structure (and SAN provides the matrix of ABS and ASA polymers). The inclusion of styrene gives these materials their base structure, and other chemicals modify the properties.

1.3. End of life

The end of use of plastic objects does not mean the end of the life of plastic itself. Indeed, plastic use ultimately entails the generation of plastic waste. Management of this waste is a critical component of the global plastic life chain, encompassing methods such as incineration, landfilling, recycling, and the emerging challenges posed by microplastics and nanoplastics. Each of these pathways presents unique advantages and limitations. Incineration offers energy recovery and diverts matter from landfills, but contributes to greenhouse gas emissions and air pollution. Landfills serve as containment sites, but raise concerns about long-term environmental persistence. Recycling, often touted as a sustainable alternative, is constrained by technological, economic, and contamination barriers. Meanwhile, discarding of plastic in the open environment puts direct pressure on ecosystems, on biodiversity, and on human

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and reinforcement in construction and road paving." Britannica, "Polypropylene | Properties, Definition, & Uses," February 7, 2025, https://www.britannica.com/science/polypropylene.

[44] Britannica, "Polyethylene (PE) | Properties, Structures, Uses, & Facts," January 10, 2025, https://www.britannica.com/science/polyethylene.

[45] Britannica, "Elastomer | Synthetic Rubber, Polymer & Properties," February 7, 2025, https://www.britannica.com/science/elastomer.

health. The tendency of plastics to break down into micro- and nanoplastics makes them infiltrate ecosystems and pose risks to biodiversity and human health. This section explores these waste pathways and their advantages and disadvantages as concern plastic pollution.

1.3.1. Landfilling, incineration, and discarding into the environment

Worldwide, the two most dominant ways of disposing of plastic waste are landfilling and incineration, followed by discarding into the environment. Globally, most plastic waste ends up in landfills. According to the OECD, approximately 50% of plastic waste is disposed of in sanitary landfills, making it the most common method of plastic waste management;[46] McKinsey estimates that the figure is 40%.[47]

Incineration is another significant method for managing plastic waste but is less prevalent than landfilling. Globally, around 19% of plastic waste is incinerated, according to the OECD.[48] Incineration is sometimes used for energy recovery: burning plastic and other waste produces heat, which is used to heat water and generate steam, which can in turn power turbines to generate electricity. However, incineration comes with severe environmental consequences, including high greenhouse gas emissions and toxic byproducts like dioxins and ash. For the EU 27 countries, approximately 35% of plastic waste is handled through energy recovery.[49]

Finally, a significant fraction of plastics ends up in unmanaged dumps – 19% of the flow according to McKinsey (see below), and 22% of the flow according to the OECD.[50] (*Diagrams from both sources are given below).*

1.3.2. Recycling

Recycling is a term used to describe several processes used to handle plastic waste. These processes have in common that processing occurs without significant alteration to the chemical structure of the material. These processes also have in common that they attempt, in some form or other, to recover either plastic, energy, or energy feedstocks (such as gas and oil derivatives) from plastic waste.

Because the plastic is not, strictly speaking, discarded or incinerated, these processes take the name "recycling." The word "recycling" is meant to evoke the notion that plastic waste can

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[46] OECD, "Plastic Pollution Is Growing Relentlessly as Waste Management and Recycling Fall Short, Says OECD," February 22, 2022, https://www.oecd.org/en/about/news/press-releases/2022/02/plastic-pollution-is-growing-relentlessly-as-waste-management-and-recycling-fall-short.html.
[47] McKinsey, "How the Chemical Industry Could Expand Its Activities in Plastics Waste Recycling," 2018, https://www.mckinsey.com/industries/chemicals/our-insights/no-time-to-waste-what-plastics-recycling-could-offer.
[48] OECD, "Plastic Pollution Is Growing Relentlessly as Waste Management and Recycling Fall Short, Says OECD."
[49] Eurostat, "Packaging Waste by Waste Management Operations," October 23, 2024, https://ec.europa.eu/eurostat/databrowser/view/env_waspac__custom_15371312/default/table?lang=en.
[50] OECD, "Plastic Pollution Is Growing Relentlessly as Waste Management and Recycling Fall Short, Says OECD."

somehow be recovered through an infinite number of self-feeding, cyclical processes. Reality is much more complex than this perception, for two reasons:

- First, the volume of plastics that emerges from recycling cycles is not equal to the original/parent volume. According to 2022 data from the OCED, for example, in 2019, of the worldwide 55 Mt of plastics collected for recycling, only 29 Mt (55%) re-entered the plastics life chain; the remainder was lost as process losses or recycling residues.[51]
- Second, in traditional mechanical recycling (except for PET – see below), the recycled material is of lower quality and functionality than the original material. This means that a plastic parent can only go through the recycling cycle so many times; ultimately, it will end up as waste, in addition to leaching micro- and nano-plastics during its lifetime.

For these reasons, most "recycling" ought more accurately to be called "downcycling," that is, it results in production of plastics of lower quality than the parent polymer that was initially fed into the process. Recycling techniques that reproduce the same kind of plastic as the parent material are in the minority, and those technologies that do have come under criticism for their environmental impacts – see "Chemical recycling" below.

There are two ways to dispose of plastic other than discarding or incineration:

- Mechanical recycling. Here, plastic waste is sorted, cleaned, shredded, and melted into plastic pellets that can be used to make other plastics. The process does not involve degrading the polymer back into its polymer – rather, the output of the process is a polymer. However, most often during this process the plastic's quality is degraded, which limits the purposes to which it can be put. For instance, a used bottle of PET will be transformed into fibres, which are used to make a fleece jacket, which is downcycled into plastic pellets that will be melted into garden furniture, which ultimately ends up being incinerated or left in a dump. In this case, so-called recycling does not allow for circularity; it merely extends the material's useful life.[52]
  Of all the plastics discussed above, only one type – PET bottles – are truly mechanically recyclable, where "recycling" means producing a given polymer from used specimens of the same polymer of the same quality and purity. In other words, PET bottles can be called "recycled" in the sense that PET bottles can be made from other PET bottles. However, this process is not strictly 1-to-1 recycling: in fact, multiple PET bottles are required to produce a single new bottle. Further, decontamination requirements mean that the PET-to-PET recycling route is closed when something other than water or sugared beverages (e.g., drinkable yogurt) was in the container. For the remainder of plastics, therefore "re"-cycling is not possible: a more appropriate term would be "downcycling."[53]
- Chemical recycling. Chemical recycling breaks down plastic waste at the molecular level, converting polymers back into their original building blocks or into new raw

[51] OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options," February 2022, https://www.oecd-ilibrary.org/environment/global-plastics-outlook_de747aef-en.
[52] BASIC Interview with plastic sector experts, May 30, 2024, June 25, 2024, and October 6, 2024.
[53] Sophie Aubin et al., "Plastics in a Circular Economy: Mitigating the Ambiguity of Widely-Used Terms from Stakeholders Consultation," *Environmental Science & Policy* 134 (August 1, 2022): 119–26, https://doi.org/10.1016/j.envsci.2022.04.011.

materials. This method is promoted as offering a solution for recycling complex, mixed, or contaminated plastics that are challenging to recycle mechanically. There are at least two broad families of chemical recycling:[54]

- Solvent-based purification, which uses solvents to decompose plastics back to the polymer stage.
- Chemical depolymerisation, which turns the plastics back into their monomers via a chemical reaction.
- In addition, several sources argue that thermal depolymerisation (pyrolysis and gasification) should be considered as chemical recycling as it cracks polymers back into monomers and further down into hydrocarbons, in fact, in some reports chemical recycling is synonymous with thermal depolymerisation.[55]

What these chemical recycling processes have in common is that the plastic returns to its original, monomer form or in its original polymer form; further, collectively they can be used to process plastics 1 through 6 in addition to PMMA (=plexiglass) and polyurethane (PU).[56] Thermal depolymerisation technology, which is only scheduled for rollout on the 2025-2030 timeframe, theoretically promises a way out for plastics that are hard to recycle mechanically. However, it has come under fire for being more expensive, more polluting, and more energy-intensive than mechanical recycling.[57] In particular, thermal depolymerisation has been criticised for advertising itself as a "advanced recycling" technology, whereas its principal output (around 85%) is diesel fuel, hydrogen, methane and other chemicals, and only 15% plastic monomers like ethylene and propylene.[58] (In California, ExxonMobil has come under legal action for disinformation of the public as to the recyclability of its plastic production, including claims about "advanced recycling").[59] The illustration below from IPEN and Beyond Plastics summarises the "merry-go-round" of waste and pollution involved in chemical recycling.

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[54] Zero Waste Europe, "El Dorado of Chemical Recycling: State of Play and Policy Challenges," August 28, 2019.
[55] Zero Waste Europe, "Chemical Recycling and Recovery: Position Paper December 2021," December 2021, https://zerowasteeurope.eu/wp-content/uploads/2021/12/December2021_ZWE_Chemical_Recycling_position_paper.pdf. ProPublica, "The Delusion of 'Advanced' Plastic Recycling," June 20, 2024, https://www.propublica.org/article/delusion-advanced-chemical-plastic-recycling-pyrolysis. IPEN and Beyond Plastics, "Chemical Recycling: A Dangerous Deception," October 2023, https://tinyurl.com/27cr47or.
[56] Eunomia, "Chemical Recycling: State of Play," December 8, 2020.
[57] IPEN and Beyond Plastics, "Chemical Recycling: A Dangerous Deception."
[58] ProPublica, "The Delusion of 'Advanced' Plastic Recycling."
[59] State of California - Department of Justice - Office of the Attorney General, "Attorney General Bonta Sues ExxonMobil for Deceiving the Public on Recyclability of Plastic Products," September 22, 2024, https://oag.ca.gov/news/press-releases/attorney-general-bonta-sues-exxonmobil-deceiving-public-recyclability-plastic.

Figure 16: The chemical recycling "merry-go-round"

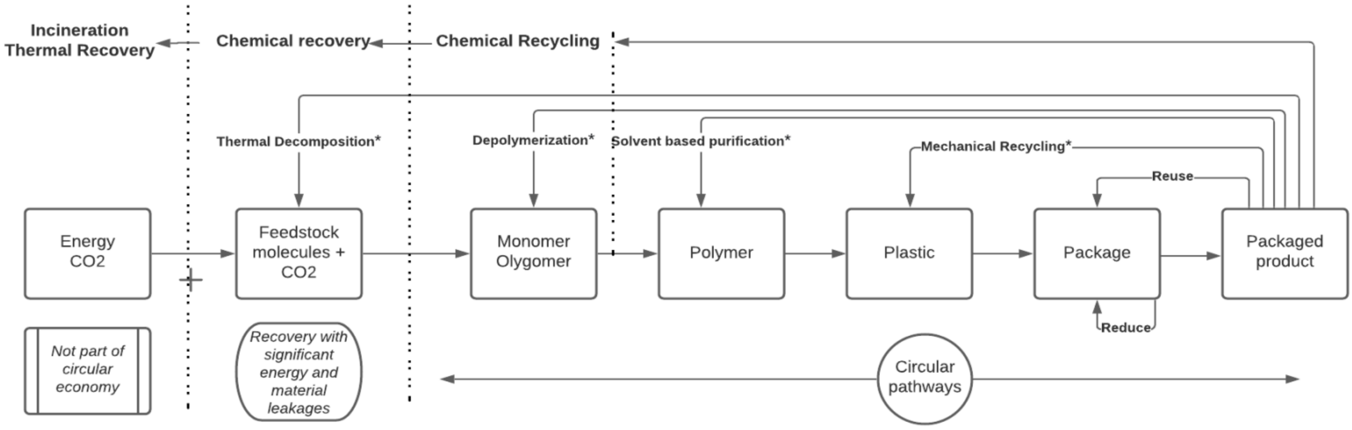
Source: IPEN and Beyond Plastics[60]

According to multiple sources,[61] the easiest-to-downcycle plastics are type 1 (PET/polyethylene terephthalate) and type 2 (HDPE/high-density polyethylene). The remaining types of plastic are either more difficult to downcycle, not accepted by recycling programs, too often mixed with other substances for them to be separated from the plastic, and/or can only be recycled effectively through chemical recycling.

The following figure illustrates the options for recycling, from mechanical recycling all the way to incineration, using plastic packaging as an example:

[60] IPEN and Beyond Plastics, "Chemical Recycling: A Dangerous Deception."
[61] one5c, "Plastic Recycling Numbers and Symbols, Explained," December 13, 2023, https://one5c.com/plastic-recycling-numbers-136931526/. U.S. Department of Energy, "Consumer Guide to Recycling Codes," December 2012, https://www.energy.gov/sites/default/files/2021-12/ES_ConsumerGuide_RecyclingCodes.pdf.

Figure 17: Circular pathways available to plastic packaging



Source: Zero Waste Europe[62]

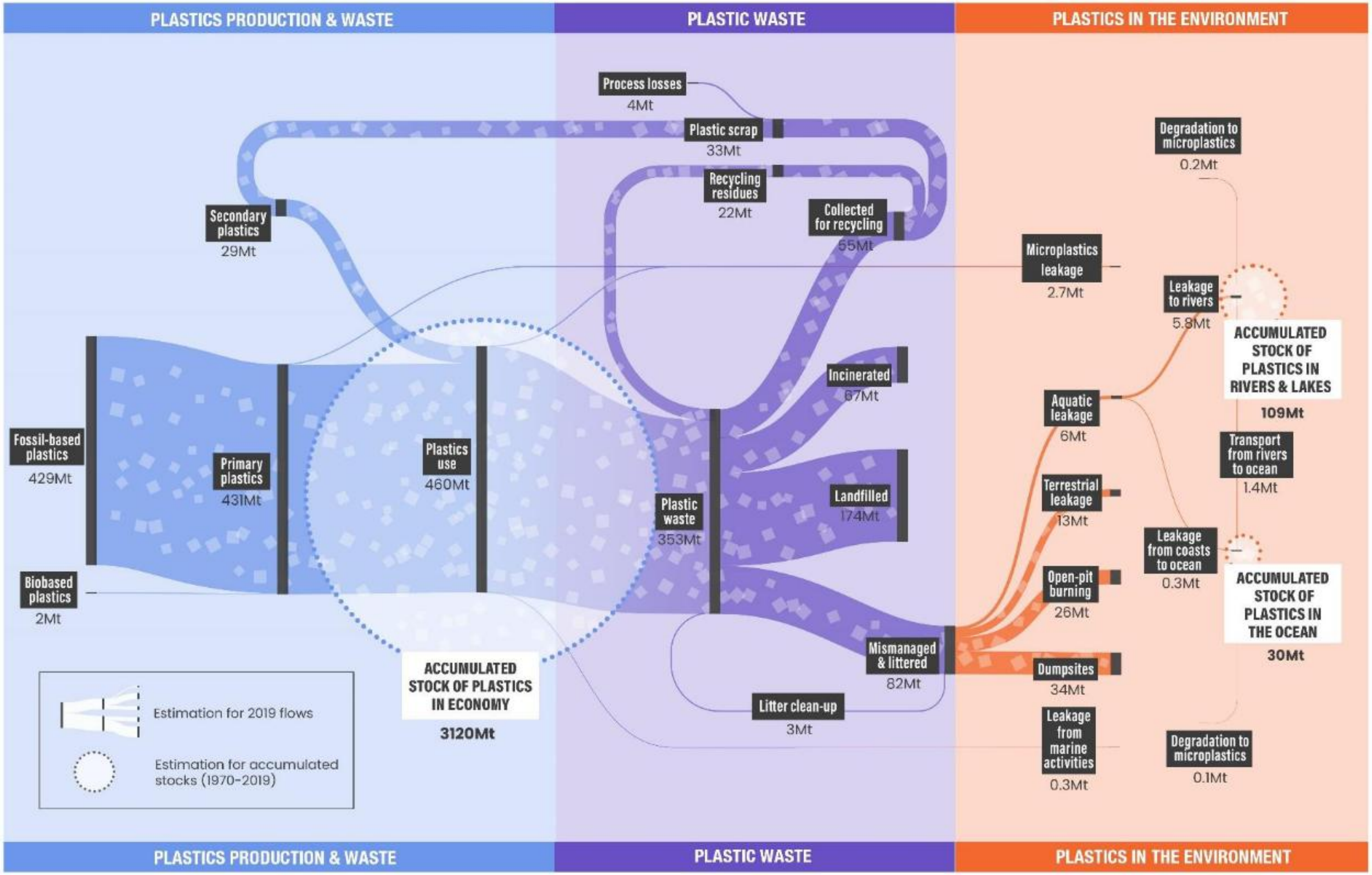
According to two different sources, in 2016[63] and 2019[64] approximately 16% of world waste was directed to recycling facilities. According to the 2016 data, four percentage points of this material was lost in the process, while 12% of this flow was directed to mechanical recycling, and less than 1% was fed into chemical recycling to be turned back into monomers.[65] According to the 2019 data, process losses mean that only 9% of the 353 Mt of plastic waste was fed back into the life chain as secondary plastics.[66] In Europe, up to 64% of packaging waste is collected for recycling. According to the European Environment Agency:[67]

> "The **overall recycling rate**, i.e. the ratio between total waste generated excluding major mineral wastes and the quantities that were managed through recycling, stood at 46% in 2020. The highest recycling rate in 2021 was registered for packaging (64%)."

A figure from the OCED illustrates the plastic life chain as of 2019:

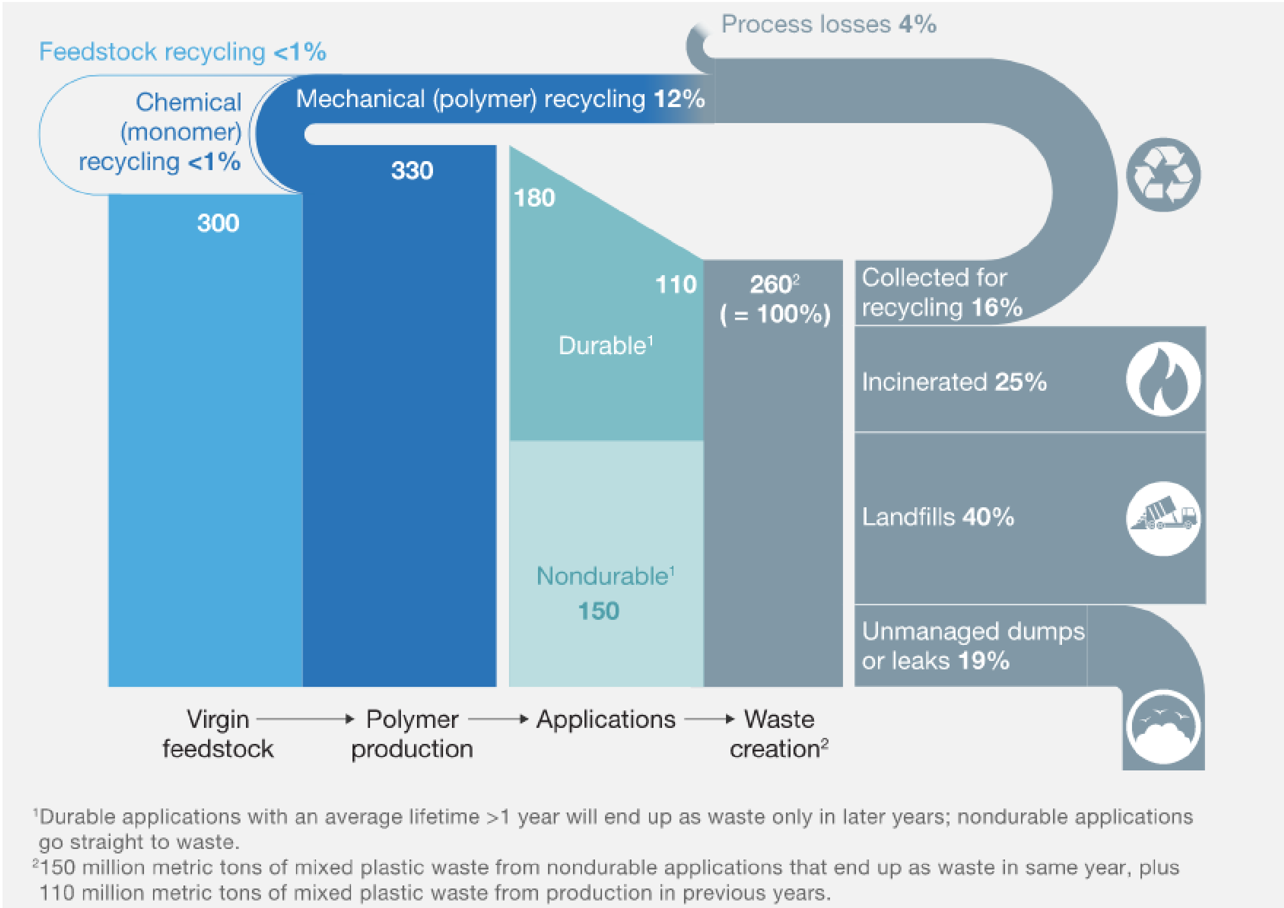
[62] Zero Waste Europe, "Chemical Recycling and Recovery: Position Paper December 2021."
[63] McKinsey, "How the Chemical Industry Could Expand Its Activities in Plastics Waste Recycling.".
[64] OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options."
[65] McKinsey, "How the Chemical Industry Could Expand Its Activities in Plastics Waste Recycling.".
[66] OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options."
[67] EEA, "Waste Recycling in Europe," December 19, 2023, https://www.eea.europa.eu/en/analysis/indicators/waste-recycling-in-europe.

Figure 18: Flow of plastics through its life chain, from fossil-based plastics through to release in the environment



Source: OECD[68]

Figure 19: Global polymer flows, millions of metric tonnes per annum, 2016



Source: McKinsey[69]

[68] OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options."

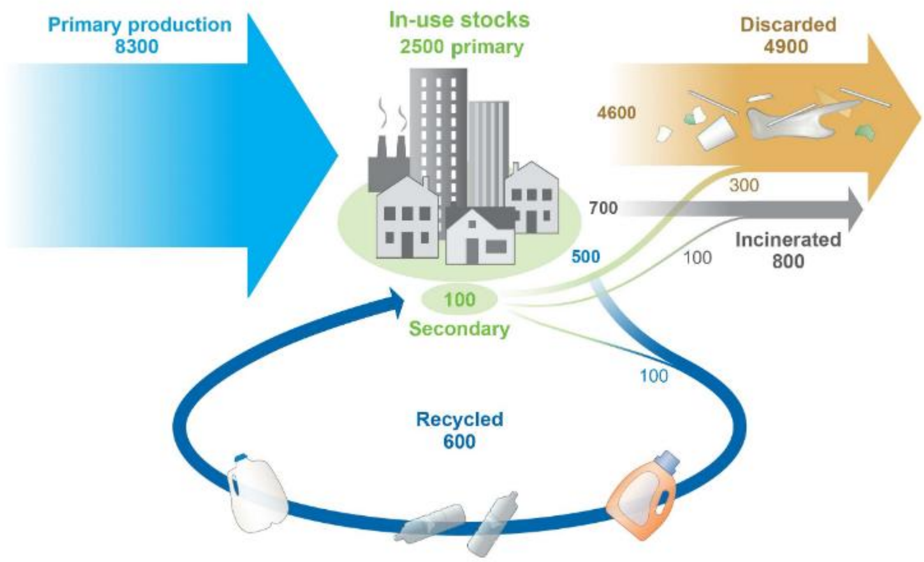
[69] McKinsey, "How the Chemical Industry Could Expand Its Activities in Plastics Waste Recycling." Remark: the drop in the "durable" category from 180 Mt to 110 Mt reflects the notion that in any given year, 70 Mt of plastics – because it is "durable," i.e. designed to last more than a year in use – will outlive a single year's waste cycle.

1.3.3. Fate of plastics produced

As to the fate of these plastics since 1950, as can be seen in the following figure:

- 31% is in use, including about 7% which is "recycled"
- 10% has been incinerated
- 59% has been discarded

Figure 20: Global production, use, and fate of polymer resins, synthetic fibres, and additives (1950 to 2015, in million metric tonnes)



Source: Geyer[70]

1.3.4. A dispersive life chain: micro- and nanoplastics

Plastics are known for their persistence in the environment, but also their potential for breakdown into smaller particles – microplastics and nanoplastics. These tiny fragments of plastic have become pervasive, infiltrating ecosystems, food chains, and human bodies. This section explores the process by which plastics degrade, the factors that influence this degradation, and the environmental and health consequences of microplastic and nanoplastic pollution.

Plastic degradation refers to the process by which large plastic items break down into smaller pieces over time. This process occurs through various mechanisms, including photodegradation (caused by sunlight), mechanical abrasion, and chemical oxidation. Conversely, conditions such as low temperatures, limited sunlight, or anaerobic environments slow degradation. The chemical composition of the plastic also plays a critical role:

[70] Roland Geyer, "Production, Use, and Fate of Synthetic Polymers," in *Plastic Waste and Recycling* (Elsevier, 2020), 13–32, https://doi.org/10.1016/B978-0-12-817880-5.00002-5.

biodegradable plastics break down more readily under the right conditions, while traditional plastics like polyethylene and polypropylene are more resistant. Additives such as stabilisers or flame retardants can also influence the degradation process.[71]

Unlike organic materials, plastics do not biodegrade completely; instead, they fragment into smaller and smaller pieces, eventually becoming microplastics and nanoplastics. The latter are defined as follows:

- Microplastics are generally defined as plastic particles less than 5 millimeters in diameter.
- Nanoplastics are even smaller, typically less than 100 nanometers.

Nanoplastics often arise as a further degradation product of microplastics and are of particular concern due to their potential to penetrate biological barriers and interact with cells.[72] In addition, "Decreasing particle size results in increasing surface-area-to-volume ratio, providing greater opportunity for diffusion of additives from the plastic, or adsorption and subsequent release of chemicals from the environment."[73]

The origin of microplastics and nanoplastics in the environment are diverse. Microplastics frequently leach into waterways through urban runoff, wastewater treatment plants, and littered debris. For example, synthetic fibres shed from clothing during washing enter sewage systems and pass through treatment facilities, many of which are not equipped to capture such small particles. Similarly, tire wear particles generated by road traffic accumulate in soil and water. Nanoplastics, being even smaller, can spread widely through atmospheric transport, settling in oceans, rivers, and soils far from their point of origin. Agricultural practices that use sewage sludge as fertiliser further introduce microplastics into soils, where they can persist for decades.[74]

Once leached into the environment, microplastics and nanoplastics accumulate in various reservoirs. Oceans are among the largest sinks, where these particles can float on the surface, sink to the seafloor, or be ingested by marine organisms. In terrestrial environments, microplastics persist in soils, altering microbial communities and potentially affecting plant growth. They also infiltrate freshwater systems, including rivers and lakes, where they interact with sediments and aquatic life. Even pollinators are exposed to and can ingest micro/nanoplastics, with detrimental impacts on their health.[75] For other wildlife (fish in particular), microplastics and nanoplastics have pervasive and detrimental effects, such as

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[71] Yan-Duan Lin et al., "Sources, Degradation, Ingestion and Effects of Microplastics on Humans: A Review," *Toxics* 11, no. 9 (September 1, 2023): 747, https://doi.org/10.3390/toxics11090747.

[72] Christos Symeonides et al., "Buy-Now-Pay-Later: Hazards to Human and Planetary Health from Plastics Production, Use and Waste," *Journal of Paediatrics and Child Health* 57, no. 11 (2021): 1795–1804, https://doi.org/10.1111/jpc.15777.

[73] Symeonides et al.

[74] Lin et al., "Sources, Degradation, Ingestion and Effects of Microplastics on Humans."

[75] Dong Sheng et al., "Plastic Pollution in Agricultural Landscapes: An Overlooked Threat to Pollination, Biocontrol and Food Security," *Nature Communications* 15, no. 1 (September 28, 2024): 8413, https://doi.org/10.1038/s41467-024-52734-3.

physical blockages in digestive systems, reduced feeding behaviour, and impaired growth and reproduction.[76] Atmospheric microplastics, transported through winds and deposited during rainfall, expand the scale of contamination.[77]

In humans, exposure to microplastics and nanoplastics are the result of eating, drinking, inhalation, and skin contact. Statistics on nano- and micro-plastic exposure diverge, but some findings are arguably alarming, such as the finding by Hernandez et al. that "steeping a single plastic teabag at brewing temperature (95 °C) releases approximately 11.6 billion microplastics and 3.1 billion nanoplastics into a single cup of the beverage."[78]

The health impacts of microplastics and nanoplastics are an area of active investigation, but the evidence so far underscores significant risks. Because it is not always possible to study humans, studies on plastic toxicity sometimes reflect either work on other animals in the wild, on laboratory rodents, or on human-derived cells and cell lines.[79] Collectively, such studies have found that:[80]

- Microplastics are commonly ingested via contaminated food and water. They have been detected in seafood, salt, drinking water, and even packaged foods. When consumed, these particles can accumulate in the gastrointestinal tract, potentially disrupting the gut microbiome and causing inflammation. Studies suggest that ingested microplastics can release toxic additives and adsorbed pollutants, such as pesticides or heavy metals, into the body. These substances may lead to oxidative stress, hormonal imbalances, and chronic diseases such as cancer or cardiovascular disorders.[81]
- Airborne microplastics and nanoplastics, originating from tire wear, synthetic textiles, and urban dust, can be inhaled into the respiratory system. Once inhaled, they may accumulate in the lungs, causing inflammation and respiratory distress. Nanoplastics, due to their size, can penetrate deeper into lung tissues and even enter the bloodstream. Prolonged exposure to airborne plastics has been linked to respiratory conditions, including asthma and chronic obstructive pulmonary disease (COPD).[82]
- Nanoplastics are of particular concern due to their ability to interact with cells at a molecular level. These particles can cross cellular membranes and accumulate in organs such as the lungs, liver, kidneys, brain, and placenta, among others. Research indicates that nanoplastics can induce oxidative stress, a condition that damages cells

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[76] Natalia Zolotova et al., "Harmful Effects of the Microplastic Pollution on Animal Health: A Literature Review," *PeerJ* 10 (June 14, 2022): e13503, https://doi.org/10.7717/peerj.13503.
[77] Zolotova et al.
[78] Laura M. Hernandez et al., "Plastic Teabags Release Billions of Microparticles and Nanoparticles into Tea," *Environmental Science & Technology* 53, no. 21 (November 5, 2019): 12300–310, https://doi.org/10.1021/acs.est.9b02540.
[79] Sridhar Jayavel et al., "Impacts of Micro and Nanoplastics on Human Health," *Bulletin of the National Research Centre* 48, no. 1 (October 22, 2024): 110, https://doi.org/10.1186/s42269-024-01268-1.
[80] Jayavel et al.
[81] Jayavel et al.
[82] Jayavel et al.

and DNA, potentially leading to chronic inflammation and increased risk of diseases such as neurodegeneration and cancer. Laboratory studies suggest that nanoplastics might disrupt normal cellular functions, including metabolism and immune responses. Cutting-edge research suggests that nanoplastics may interfere in cell nuclei with DNA proliferation, synthesis, and repair.[83]

- Micro- and nanoplastics may induce metabolic changes that lead to metabolic disorders, such as metabolic syndrome,[84] and plastic additives like Di(2-ethylhexyl) phthalate (DEHP) and bisphenol A (BPA) are significant risk factors for obesity.[85]
- Plastics often contain chemical additives such as bisphenol A (BPA), phthalates, and flame retardants, which are known endocrine disruptors or endocrine-disrupting chemicals (EDCs). These chemicals can leach from microplastics and nanoplastics into the body during exposure. Endocrine-disrupting chemicals are associated with "hormonal cancers, reproductive problems, metabolic disorders, asthma, and neurodevelopmental issues."[86] Furthermore, the adsorption of environmental toxins like polycyclic aromatic hydrocarbons (PAHs) and persistent organic pollutants (POPs) onto plastic particles can amplify their toxic effects.[87]
- Humans *in utero* and infants are particularly vulnerable to plastic and plastic additive exposure, a fact that raises questions about the potential intergenerational influence of plastics, i.e., the potential for a baby to be born with a predisposition to illnesses associated with plastic exposure, or to be exposed to plastics through breastmilk.[88]

In conclusion, the breakdown of plastics into microplastics and nanoplastics is a complex process influenced by environmental conditions such as UV exposure, mechanical forces, and chemical composition. These fragments, which persist in the environment for decades or longer, have become widespread in ecosystems, entering oceans, soils, and the atmosphere. Once present, they interact with living organisms at various levels, accumulating in marine life, terrestrial environments, and even human systems, where they can cause physical, chemical, and biological disruptions. While much remains to be understood about micro- and nanoplastics' long-term effects, current findings highlight their capacity to influence ecosystems and biological systems in significant ways.

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[83] Jayavel et al.
[84] "Metabolic syndrome is a cluster of conditions that occur together, increasing your risk of heart disease, stroke and type 2 diabetes. These conditions include increased blood pressure, high blood sugar, excess body fat around the waist, and abnormal cholesterol or triglyceride levels." Mayo Clinic, "Metabolic Syndrome: Increased Risk of Cardiovascular Disease, Diabetes-Metabolic Syndrome - Symptoms & Causes," 2025, https://www.mayoclinic.org/diseases-conditions/metabolic-syndrome/symptoms-causes/syc-20351916.
[85] Jayavel et al., "Impacts of Micro and Nanoplastics on Human Health."
[86] Jayavel et al.
[87] Jayavel et al.
[88] Yue Li et al., "Potential Health Impact of Microplastics: A Review of Environmental Distribution, Human Exposure, and Toxic Effects," *Environment & Health* 1, no. 4 (October 20, 2023): 249–57, https://doi.org/10.1021/envhealth.3c00052.

1.4. Discussion

Everyone uses and interacts with plastics every day and in countless ways. Plastics are used in everything, so much so that it is now hard to do without them. But compared to this ubiquity, the actual fossil nature of plastics tends to be overshadowed, in particular by discourses on recycling and circularity. The study of the plastics life chain carried out here is an invitation to recall that the plastics industry is an integral part of the petrochemical sector, inextricably linked to the extraction of fossil resources. Consequently, this industry should also be subject to policies aimed at transitioning away from fossil fuels, whereas the industry is – for now – almost exclusively concerned by waste-related policies.

From raw materials to discarded objects and their decomposing elements, the plastics life chain is of increasing complexity. It begins with fossil resource extraction and concludes with a dispersive and persistent environmental footprint. The initial stages – drilling, distillation, and the transformation of feedstocks into high-value chemicals – lay the foundation for plastic production by converting raw hydrocarbons into usable compounds. Subsequent polymerisation and the incorporation of additives allow for the creation of diverse plastic materials with tailored properties.

These processes are highly transformative. While plastics are commonly classified into seven types (which indicate their chemical makeup), the addition of additives and the wide diversity of end uses result in an almost infinite number of concrete manifestations of plastics. Combined with the chemical complexities of some plastic types, this greatly limit the effectiveness of any end-of-life management strategy, greatly challenging the ideal vision of circularity as exposed in the introduction of this report. The fact that many plastics can only be *downcycled* rather that recycled is a stark illustration of these limitations.

If we take into account the fact that plastics have a dispersive life chain, due to their degradation as micro- and nanoplastics, and their long-term persistence as such, it even seems inappropriate to speak of an "end of life" for plastics. Independently of the circularity issue, this persistence of plastics in the environment raises significant ecological and health concerns, as they are now found in virtually every ecosystem on Earth – as well as in every type of human tissues. Once produced (and unless incinerated), plastics have a virtually infinite life span, which is a sufficient reason to question the upstream part of the plastics value chain and the overall volume of plastics produced.

But ultimately it is the economic factors that are key to understanding the dynamics at play – and to come – in the value chain. Even in a situation where full circularity could be achieved from a physical point of view, this would not happen if the associated business case was unclear. In comparison, the business case for the production of virgin plastics seems to gain traction, in a context where commitments are beginning to be made about "Transitioning away from fossil fuels *in energy systems*" (as per the COP28 Dubai Declaration, emphasis added). Faced with a potentially shrinking fuel market, oil and gas majors may be betting on an expanding plastics market. The ongoing revamping of refining plants based on the C2C technology discussed above would fit this logic, making plastics a central element of economic rationales, rather than the byproduct it used to be.

In order to further explore these open questions, let's now turn to the analysis of the plastics value chain, in terms of material flows and of economic actors.

2. The plastics value chain

In this part of the report, leaving petrochemistry, we adopt a value chain perspective that allows to uncover the economic aspects associated with plastics production. Here, we lay the first foundations for such an analysis: we model the material flows of plastics and map the main economic actors behind these flows.

2.1. Plastics material flows

In this section, we analyse the material flows of the plastics industry: how many tonnes of materials are extracted, transformed and produced, from fossil feedstocks to final objects? These orders of magnitude can be used to balance the weight of the plastics industry with the actions needed to meet fossil fuel phase-out commitments.

2.1.1. The challenge of data scarcity

The plastics industry is characterised by a complex structure, as explained in the previous sections. The representation of the plastics life chain in the form of material flows, whether in volume (t) or in value (€), can contribute to obtaining an overall vision of the chain. However, there are few resources, articles, or databases that present or reconstruct the complete flows of the petrochemical industry, at either global or regional levels.

Some studies focus on production, such as OECD (2022) and Heinrich-Böll-Stiftung et al. (2020). There are also databases or large quantitative tables which describe the oil and gas industry as well as plastics production, such as the following: Eurostat's "EU Energy Balance Data,"[89] the US Energy Information Agency's "Energy Outlook" data,[90] Minderoo's "Waste Makers Index,"[91] the OECD's "Global Plastics Outlook,"[92] and the International Energy Agency's "Energy Statistics Data Browser."[93] Some interprofessional organisations publish flowcharts of the petrochemical process from oil and gas down to plastics,[94] while other resources publish general information on the building blocks of petrochemistry (e.g. Britannica). This study relies on such sources, as well as on the wealth of publications put out by NGOs and think tanks such as Greenpeace,

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[89] https://ec.europa.eu/eurostat/web/energy/database/additional-data#Energy%20balances
[90] US Energy Information Administration (EIA), "International Energy Outlook - Data Tables," October 2023, https://www.eia.gov/outlooks/ieo/data.php.
[91] Minderoo, "Plastic Waste Makers Index 2021," 2021, https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf. Minderoo, "Plastic Waste Makers Index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf.
[92] For instance: OECD, "OECD Data Explorer - Archive • Plastic Use in 2019," March 26, 2024, https://data-explorer.oecd.org/vis?tenant=archive&df[ds]=DisseminateArchiveDMZ&df[id]=DF_PLASTIC_USE_6&df[ag]=OECD&dq=..&to[TIME]=false. OECD, "OECD Data Explorer - Archive • Plastics Use by Polymer - Projections," March 21, 2024, https://data-explorer.oecd.org/vis?tenant=archive&df[ds]=DisseminateArchiveDMZ&df[id]=DF_PLASTIC_USE_V2_2&df[ag]=OECD&pd=2019%2C2019&to[TIME_PERIOD]=false.
[93] International Energy Agency, "Energy Statistics Data Browser – Data Tools," December 21, 2023, https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser.
[94] Petrochemicals Europe, "Flowchart- Petrochemicals Europe." Petrochemicals Europe.

WWF, Break Free From Plastic, Zero Waste Europe, Beyond Plastic, the Centre for International Environmental Law, Minderoo, and Wood Mackenzie, among others. It also relies on a selection of academic articles and industry reports that are cited in-line.

These resources all provide valuable information, including some statistics, about plastic production, but the flow of petrochemicals from cradle to grave is not addressed in detail, especially quantitatively. This may be due to the lack of publicly available data, itself linked to the lack of transparency in the sector.

To our knowledge, only the work of Levi and Cullen (2018) presents the global flows of the petrochemical sector, from detailed public data dating from 2013 but also from modelling when the precise data was not available. In this article, the authors carry out a significant amount of data collection and modelling by equations to map the different stages of transformation. The authors arrive at a Sankey flow diagram of the petrochemical sector, including the production of plastic but also fertilisers.

Downstream, the authors represent the major types of plastics (thermoplastics, thermosets, fibres and elastomers), but not the individual polymers that constitute the penultimate stage in the chain. As a result, a polymer-by-polymer or product-by-product breakdown of how these thermoplastics, thermosets, and elastomers are used is absent.

2.1.2. A material flow analysis of plastics

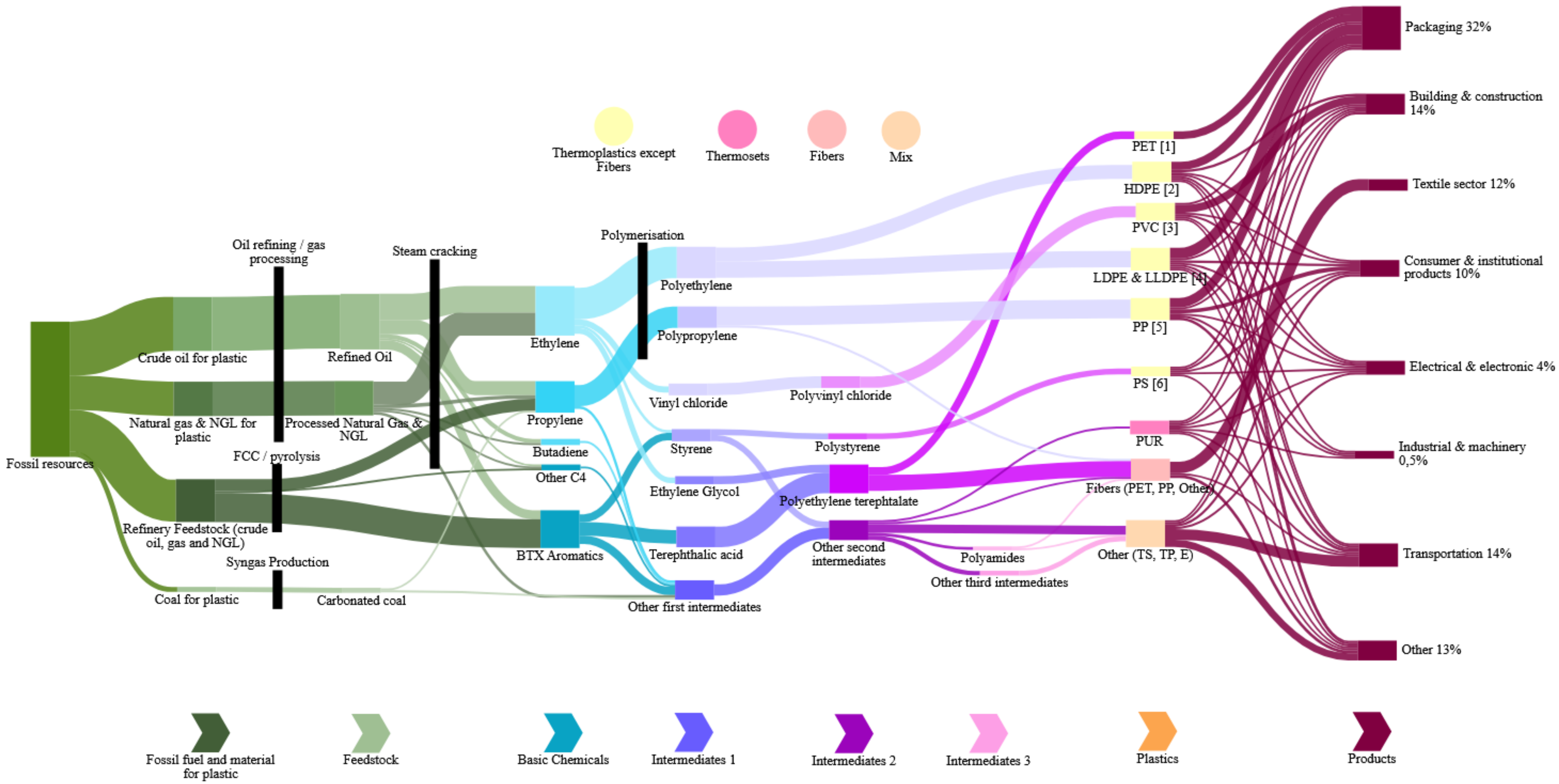
To model plastics material flows, we therefore started from the only public and complete data from the plastics sector, i.e. the data for 2013 collected and modelled by Levi and Cullen (2018). We completed these data downstream and aggregated them upstream, to arrive at a representation of material flows, in tonnes, in the plastics sector (see figure below), from raw resources to final uses, including the production of the various intermediaries.

Unlike Levi and Cullen (2018), we focus exclusively on plastic production, while their study covers the production not only of plastic but also of fertilisers, from fossil resources. We also further detail the downstream part of these flows, detailed into plastics types and final uses.

Our methodological approach, as well as its limits, are detailed in the methodological appendix (see Annex 0).

Once the data has been collected and aggregated, and the modelling has been carried out to fill in the missing information, we produced a visualisation in the form of a Sankey diagram, visible below. This visualisation follows the main categories mentioned above and explained in Figure 2, with a colour for each category: fossil fuel and material for plastics, feedstock, basic chemicals , intermediates (1, 2 and 3), plastics, and products.

Figure 21: Global flows of plastics: from production to end uses for the year 2013



Source: BASIC, based on 2013 data from Levi and Cullen (2018) . Visualization tool: Open Sankey[95].

[95] https://open-sankey.fr/

From this modelling, several lines of analysis can be followed.

A significant proportion of fossil resources is used for plastic production

Our model allows us to put into perspective the quantities of plastics produced and the quantities of fossil fuels necessary for this production.

When summing the quantities of oil, gas, coal and refinery feedstock (visible in the left of the Sankey diagram upstream of the chain), we obtain, for the year 2013, approximately 361 Mt of fossil resources for the production of plastics.[96] With the total annual production of fossil resources estimated at around 8,326 Mt,[97] this means that **in 2013 the plastic sector captured 4% of the fossil resources extracted**. According to a 2016 McKinsey study**, the figure could be higher** – 6% for oil alone (statistics on gas were unavailable).[98]

Note that in 2013, oil and gas account for the majority of fossil fuels used for plastic production (68%), while refinery-sourced olefins and aromatics represent 24%,[99] and coal barely 8%.

As explained in the previous sections, it is likely that these quantities will change in the years or decades to come, in particular due to the development of the "coal to olefins" and "crude to chemicals" technologies. In addition, one change is already underway: in the last decade, there has been a shift towards gas as a source of ethylene as the U.S. shale gas revolution makes for low-cost gas and ethane production.[100] As a result, worldwide (with the sole exception of the

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[96] This figure is obtained by adding the inputs from coal, oil, gas, and refinery-sourced feedstock into plastic precursors/HVCs (420.1 Mt), and subtracting that portion of precursors/HVCs (59.1 Mt) which does not end up being used for plastic production and instead are directed to the production of materials such as fertilisers and explosives.

[97] As of 2022 and 2023, oil production hovers around 100,000 barrels per day (bpd), which amounts to approximately 4.8 billion tonnes per year. As of 2023, gas production hovers around 4.195 trillion cubic meters (bcm), which translates to 3.526 billion tonnes oil equivalent per year. *Clarification: the equivalence between gas and oil is based on the notion of the energy contained therein: thus, to say that a quantity of gas in billion cubic meters corresponds to X quantity of oil equivalent means that the energy content of that volume of natural gas is equivalent to the energy content of X amount of oil.* Sources for production data: U.S. Energy Information Administration (EIA), "Natural Gas," accessed February 13, 2025, https://tinyurl.com/2ar5wzam; Energy Institute, "Statistical Review of World Energy," June 2024, https://www.energyinst.org/statistical-review/home; IEA, "Oil 2024," 2024, https://iea.blob.core.windows.net/assets/493a4f1b-c0a8-4bfc-be7b-b9c0761a3e5e/Oil2024.pdf; IEA, "Energy Statistics Data Browser," 2024, https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser; Enerdata, "Global Natural Gas Production | World Gas Natural Statistics," 2024, https://yearbook.enerdata.net/natural-gas/world-natural-gas-production-statistics.html.

[98] According to this source, "roughly half of this is used as material feedstock and half as fuel for the production process." Ellen McArthur Foundation, "The New Plastics Economy Rethinking the Future of Plastics," 2016, https://emf.thirdlight.com/file/24/_A-BkCs_skP18I_Am1g_JWxFrX/The%20New%20Plastics%20Economy%3A%20Rethinking%20the%20future%20of%20plastics.pdf.

[99] Refinery-sourced olefins/aromatics are those produced as by-products from fluid catalytic cracking, those extracted from Pygas streams and those produced from toluene hydrodealkylation (TDH) and disproportionation (TDP) (both converting toluene to benzene and mixed xylenes. BASIC correspondence with Dr. Peter Levi, 24 February 2025.

[100] Boston Consulting Group, "Opportunities in Global Ethylene Economics," May 2023, https://media-publications.bcg.com/opportunities-in-global-ethylene-economics.pdf.

Middle East), the price difference between the two ethylene feedstocks, naphtha and ethane, has reached up to $400 per metric ton, with naphtha being less profitable than ethane. This development has resulted in new investments in gas processing capacities.[101] The fact that this development concerns *ethane and ethylene* specifically is significant, as ethylene plays a significant role in the plastics life chain as a precursor to plastics types HDPE, LDPE, PVC and PET, which collectively represent between 40% and 50% of plastics manufactured annually in the last few years.[102]

New uses and outlets that drive plastics production upwards

On the downstream side, total plastic production in 2013, according to Levi and Cullen (2018) , amounted to 321 Mt.

According to OECD data on plastic use,[103] the main sector of use of plastic is packaging, up to 32%. We can assume that these are mainly single uses plastics (especially for food packaging). Note that except for the fraction that ends up as polyester (which is grouped under "fibres" by the OECD), PET/type 1 plastic, which belongs to the easiest-to-downcycle plastics,[104] is entirely used in packaging.

The textile sector is also largely represented (12%, including 8% for clothing and 4% for "others"). In addition to being a major supplier of nano and microplastics (the issues of which are discussed in section 1.3.4.), plastics in the textile sector is a typical case of the development of new uses for this material : indeed, textiles were historically mainly made of natural fibres. These resources are not becoming scarce, and yet plastics, in the form of synthetic fibres such as polyester (a type of PET), nylon (polyamide), acrylic and elastane, have gradually taken an important role in the textile industry.[105] Yet, plastics do not completely replace natural fibres such as cotton, wool or linen. In reality, the two types of fibres coexist and are combined in the production of clothing.

But as can be seen in the figure below, the quantity of natural fibres (cotton and wool) has stagnated and then decreased slightly since the 1980s, while synthetic fibres have exploded, particularly polyester.

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[101] "The last time the price difference had been this high was between 2012 and 2014." Boston Consulting Group., p. 2.

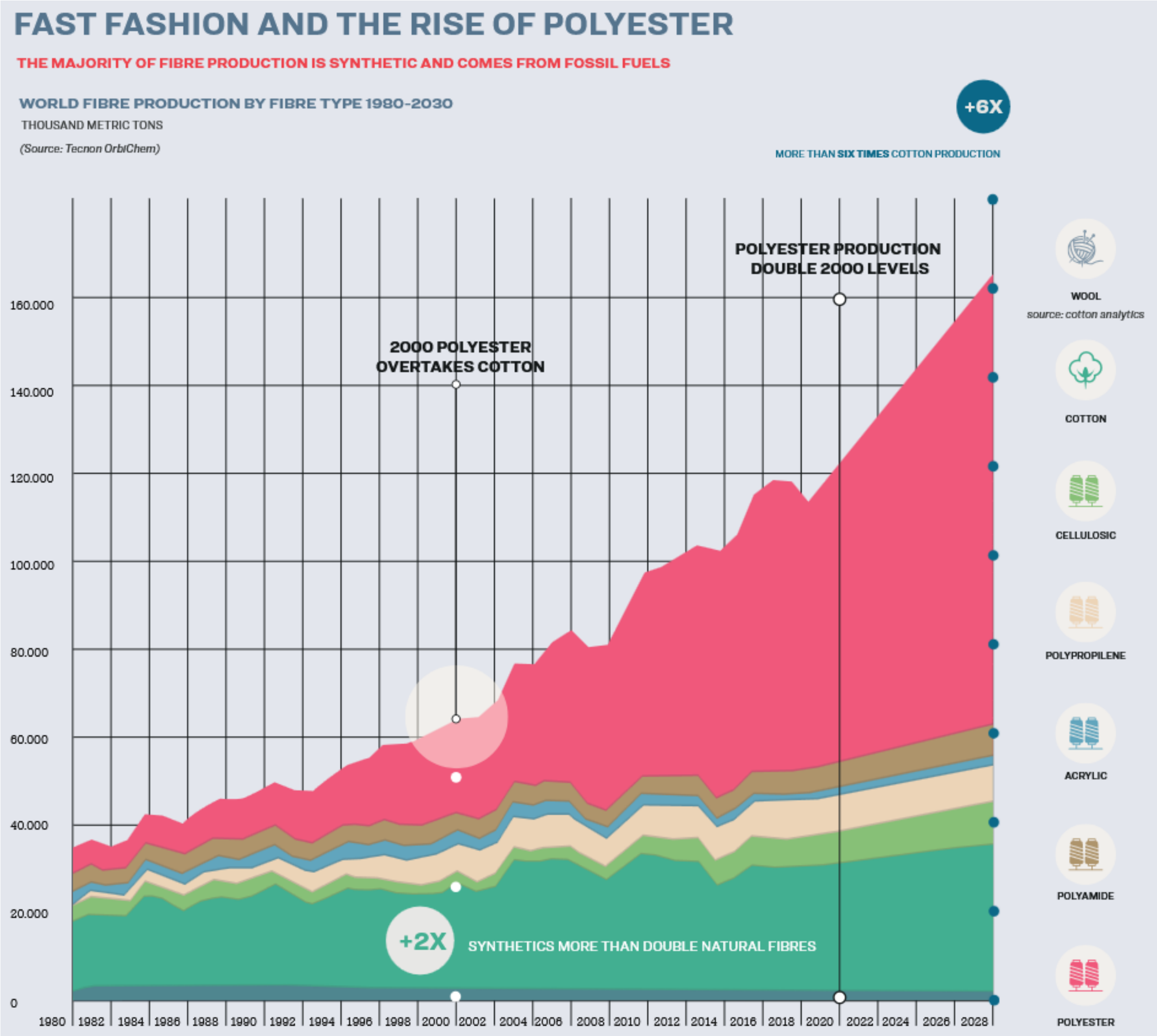
[102] Geyer, "Production, Use, and Fate of Synthetic Polymers." Plastics Europe, "Plastics - the Facts 2022." OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options." Peter G. Levi and Jonathan M. Cullen, "Mapping Global Flows of Chemicals: From Fossil Fuel Feedstocks to Chemical Products," *Environmental Science & Technology* 52, no. 4 (February 20, 2018): 1725–34, https://doi.org/10.1021/acs.est.7b04573.

[103] See Annex for details and calculation.

[104] one5c, "Plastic Recycling Numbers and Symbols, Explained." US Department of Energy, "Consumer Guide to Recycling Codes." See also section 1.3.2.

[105] Synthetic fibres are popular because of their lower production cost, durability over time, and specific properties such as water and stain resistance.

Figure 22: World fibre production by fibre type 1980-2030



Source: Changing Markets Foundation[106]

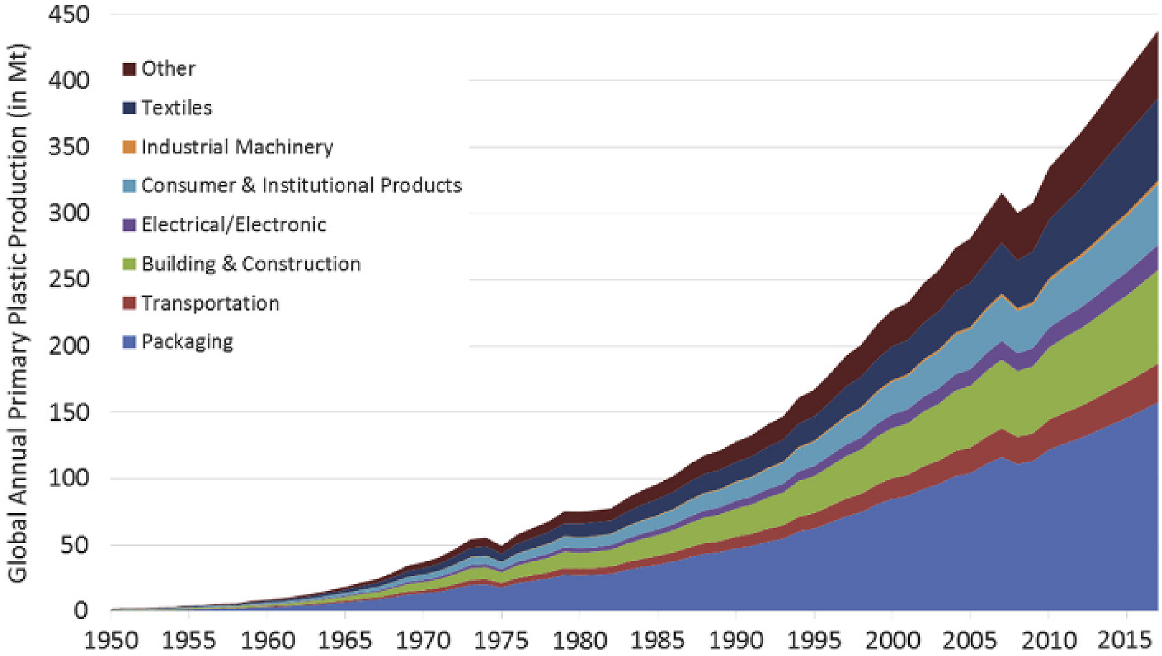
These **new uses thus stimulate the need for plastics and boost production**. This growth is not limited to the textile sector alone. Indeed, plastics production has been evolving in a context of exponential growth for several decades.

We have data on the growth in plastics production in the past, and scenarios for the near to mid-range future. In terms of past production, consumption of plastics has grown to next to nothing in the early 1950s to over 400 Mt annually. More precisely, different sources provide estimates for the production of plastics in the last few years: 348 Mt in 2017 according to Geyer

[106] Changing Markets Foundation, “Fashion's Plastic Paralysis: How Brands Resist Change and Fuel Microplastic Pollution,” September 2024, https://changingmarkets.org/report/fashions-plastic-paralysis/.

(2020) ,[107] 390.7 Mt in 2021 according to PlasticsEurope , [108] and 460 Mt in 2019 according to the OECD.[109] The use category that captures the greatest growth has been packaging.

Figure 23: Global annual primary plastics production (in Mt) by consuming sector from 1950 to 2017



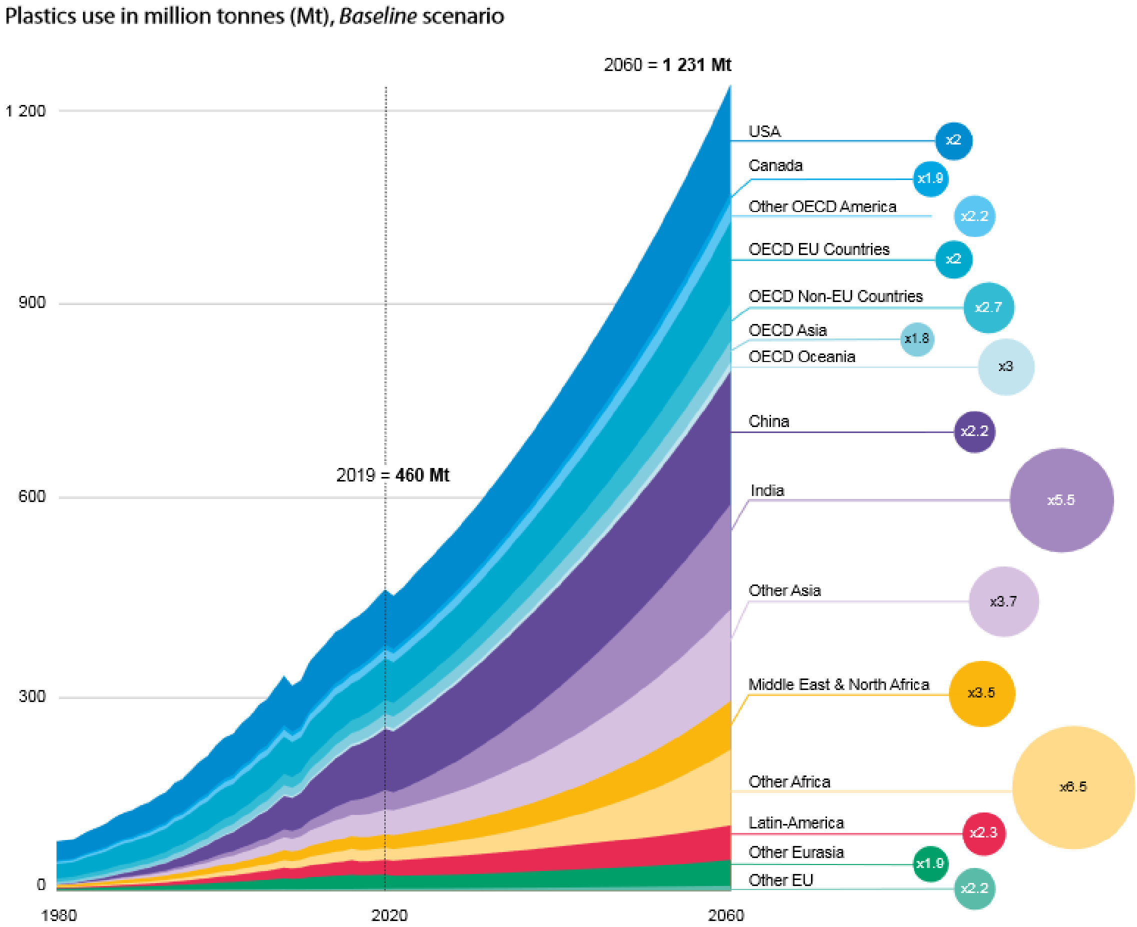
Source: Geyer (2020)

Growth that will continue until 2060, driving fossil resources extraction

As to the future, the OECD has published estimates of plastic consumption from 1980 to 2060. The estimates provided suggest that plastic consumption will grow by a factor of 2.67 in the next 40 years. In relative terms, the key emerging markets are India (x 5.5), Africa (x6.5), MENA (x3.5), and other Asia (x3.7), while the remainder of world regions will remain at about x2 (including China, at x2.2).

[107] Geyer, "Production, Use, and Fate of Synthetic Polymers."
[108] Plastics Europe, "Plastics - the Facts 2022."
[109] OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options."

Figure 24: Plastics use from 1980 to 2060, by country (estimates)



Source: OECD[110]

In order to know what quantity of fossil resources this projected quantity of plastic in 2060 could correspond to, we rely on the data of Levi and Cullen (2018) : according to our calculations, there is a ratio of 1.13 between the mass of plastics produced and the mass of fossil resources necessary for this production.

Thus, as a first approximation, we propose to apply this coefficient to the projections on plastic. In other words, with a quantity of plastic produced in 2060 of 1,231 Mt (see figure above), the quantity of fossil resources necessary for the production of plastics is estimated at 1,391 Mt.[111] Assuming that global fossil fuel production is the same in 2060 as it is today (which is undesirable), plastics production would mobilise more than 16% of extracted fossil resources

[110] OECD, "Global Plastics Outlook: Policy Scenarios to 2060."

[111] Be careful, this figure is probably underestimated, because it is the coefficient between the mass of plastics produced and the mass of refined/processed fossil resources required for this production, and therefore does not take into account the quantity of raw fossil resources to be mobilised. Furthermore, since "circular" plastics are outside the scope of Levi and Cullen (2018) , this calculation ignores their contribution.

in 2060. In this scenario, **the contribution of plastics to fossil fuel consumption would then be multiplied by more than 4 compared to today**.

These calculations provide orders of magnitude, but more detailed estimation possibilities for the future evolution of flows in the plastics industry exist and are discussed in the following section.

2.1.3. Potentials of updating and developing the model

A two steps approach could be followed to extend the Levi-Cullen study to the present day. First, updating the flows, since the data dates from 2013. Second, developing the model to make it fit to build scenarios of the future evolution of flows, and to predict quantities of plastics produced and of fossil resources necessary for this production, depending on other factors such as the extent of circular plastics.

The appendix 3 discusses the technical possibilities for updating and developing the modelling of plastics flows. Beyond technical aspects, we identify three key elements to take into account in the reflection:

- Technological leaps: for example the “Crude to Chemical” technology mentioned above.
- Variations in the proportions of different resources: for example the possible increase in coal, to the detriment of crude oil and gas.
- The increase in so-called “circular” plastics: notably recycled plastics, “carbon plastic capture” and “bio-based” plastics to the detriment of virgin plastics.
- The role of public regulations regarding particular plastics types or particular uses of plastics (notably single-use plastics).

Following, several scenarios of increased complexity can be considered, including or not these key elements:

- Scenario 1: the conservative updating scenario consists of multiplying all our flows by a global coefficient reflecting the growth in consumption, keeping constant the ratio between the quantity of plastics produced and the quantity of fossil resources needed for it. In this scenario, the underlying hypothesis is the conservation of the equations, hence the name “conservative” scenario.
- Scenario 2: hypothesis of technological leaps. For example, hypothesis of wide adoption of the “Crude-to-chemicals” technology, described above. This adoption would lead to a change in the proportions of the different resources upstream of the chain, all other things being equal. If this development could translate into efficiency gains (less fossil resources needed for the same quantity of plastics produced), a rebound effect could compensate them.
- Scenario 3: hypothesis of growth of the recycling sector. This growth would lead to a decrease in the use of virgin resources, upstream of the chain, all other things being equal. This decrease would be limited by the low recyclability of plastics already discussed. (A rebound effect could also take place in this scenario.)

The coefficients and proportions thus obtained could constitute variables, which could be integrated into a simulation tool.[112] To date, however, the Levi and Cullen data has not been transformed from its 2013 iteration; more work is needed to bring the data up to date, as described in Annex 2.

In order to incarnate these flows, we now turn to the economic actors behind them.

2.2. Who controls the chain: the economic actors behind the material flows

This section reviews publicly available information on some of the world's top producers of plastic, plastic intermediates, and plastic precursors. For the sake of brevity, in this section the word "precursors" is used in a broad sense, meaning any chemical – whether olefin, aromatic, or first- and second-tier intermediate – that is an output of gas or oil processing/refining and which is used in the manufacture of plastics of any kind. As shorthand, we use the moniker "plastics/precursors" to refer to all products within this scope.

The first step before engaging in an analysis of these companies was to make a short-list of the top plastic/precursor producers. To achieve this, we triangulated data from different sources, in particular Minderoo's Plastic Waste Makers Index of 2021 and 2023[113], data from Tilsted and Bauer on chemicals sales[114], data from a Greenpeace/Unearthed report on the Alliance to End Plastic Waste[115], and publicly available or disclosed information on or from the petrochemical companies themselves.

The top eight plastic/precursor manufacturers identified are:

Dow

Sinopec

[112] In the manner of the PARCEL tool developed by BASIC, see https://parcel-app.org/.
[113] Minderoo, "Plastic Waste Makers Index 2023"; Minderoo, "Plastic Waste Makers Index 2021."
[114] Joachim Peter Tilsted and Fredric Bauer, "Connected We Stand: Lead Firm Ownership Ties in the Global Petrochemical Industry," *Ecological Economics* 224 (October 2024): 108261, https://doi.org/10.1016/j.ecolecon.2024.108261.
[115] Unearthed, "Companies behind Campaign to 'End Plastic Waste' Produced 1,000 Times More Plastic than It Cleaned Up," November 20, 2024, https://unearthed.greenpeace.org/2024/11/20/alliance-to-end-plastic-waste-oil-chemical-exxon-shell-total/.

ExxonMobil

LyondellBasell

INEOS

PetroChina

SaudiAramco + SABIC[116]

Chevron Phillips Chemistry (CPChem)[117]

This listing is not a strict "Top 8" ranked from largest to smallest. Rather, it is a best attempt to map the companies that frequently fall within the "Top 5" of the listings cited above, and/or have remarkably high volumes of known plastic/precursor production. In addition, total figures on plastic/precursor production should be taken as indicative figures only. They are often incomplete, too high, or too low.[118] Finally, we were unable to account for material flows in-between companies: for instance, who sells pre-precursors or precursors to whom. The figure on single-use plastics is therefore given as a second barometer by which to gauge the relative importance of the different companies in terms of plastic production.

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[116] SABIC is a fossil fuels company owned at 70% by Saudi Aramco.
[117] Chevron Phillips Chemistry (CPChem) is a joint venture owned 50%-50% by Chevron and Phillips 66 respectively.
[118] Some figures are too high (such as PetroChina's information which is only "chemicals" of all kinds), some are too low (such as ExxonMobil, LyondellBasell, and Saudi Aramco, where not all businesses or processing facilities were able to be identified); others are missing (as with Dow, although we know it is a major player in plastics production). Only for INEOS, Sinopec, and CPChem are we relatively confident that the numbers cover all plastic/precursor production – for these three companies the source is the company itself <u>and</u> there are no major confusions as to product categories.

2.2.1. Vertical integration of the petrochemical sector

The plastic industry is dominated by several major players that are highly vertically integrated, meaning they control the production process from raw material extraction to polymer production (and possibly to the final plastic products). These companies manage everything from oil and natural gas extraction (the primary feedstocks for plastics) to refining, polymerisation, and even plastic product manufacturing.

ExxonMobil, one of the largest petrochemical companies in the world, is a prime example of vertical integration in the plastics sector. The company extracts crude oil and natural gas, refines these raw materials into key petrochemical components like ethylene and propylene, and then converts them into polyethylene (PE) and polypropylene (PP), two of the most widely used plastics. ExxonMobil also operates in other plastic resin production and has a strong presence in packaging and industrial applications.[119]

Other companies identified as being leaders in the sector and vertically integrated from extraction to plastics include, but are not limited to, Sinopec, INEOS, PetroChina, Saudi Aramco (including its 70% share in SABIC), and Chevron Phillips Chem (CPChem). Note that INEOS not only extracts oil and gas but also purchases plastic precursors such as ethylene, which is why a small white diagonal line appears in the Figure below. (We were unable to determine whether other vertically integrated petrochemical companies do the same.) These companies' vertical integration helps them mitigate risks related to raw material price fluctuations, secure supply chains, and maintain competitive pricing in the market. However, it also consolidates power within a few key players, raising concerns about competition and sustainability in the industry.

Vertical integration can, to some extent, also concern companies that do not extract oil and gas, such as LyondellBasell, Chevron Phillips Chemistry, and BASF. These companies are integrated in the sense that while they do not drill for oil and gas, they are only one step removed from the oil and gas extraction process, since they process pre-precursors into ethylene, propylene, butylenes (the three olefins), and toluene, benzene, and xylene (the three aromatics), along with other chemicals useful to the petrochemical process. The remainder of the value chain remains integrated in their hands.

It should be noted that all companies listed here also have business selling High Value Chemicals and/or intermediates. That is, they not only sell precursors such as olefins and aromatics, but in addition they may sell on the market intermediate products, such as styrene or vinyl chloride (precursors of polystyrene and polyvinyl chloride), or other chemicals used in polymer production such as vinyl acetate, ethylene glycol, ethylene oxide, and terephthalic acid.

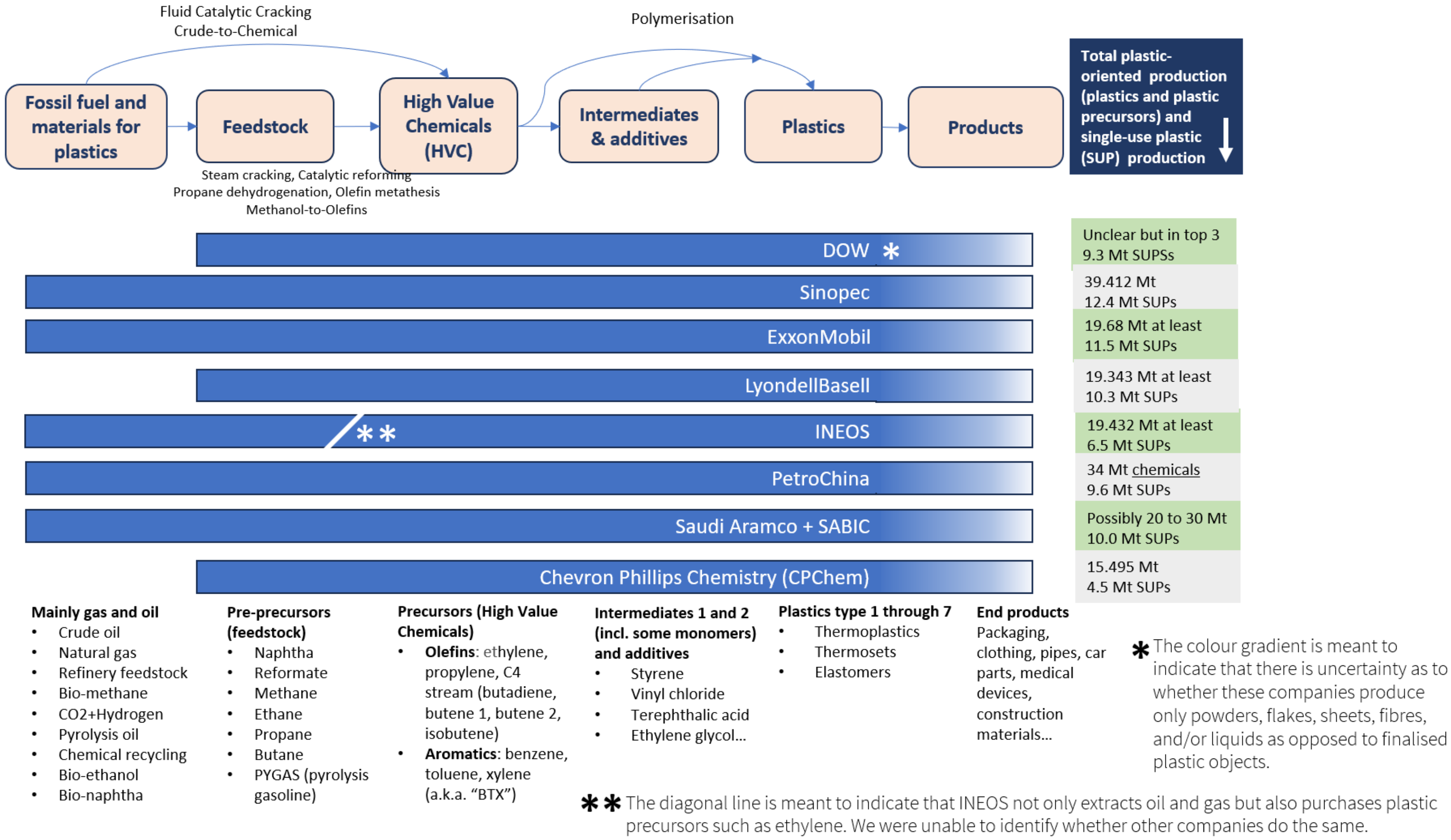
The **Annex** on vertical integration of the sector includes a detailed breakdown of available information on petrochemical production by each of the eight identified leading producers of

[119] For details on each of the companies listed in this section, please refer to the relevant Annex where their production of plastics/precursors is given in great detail.

plastics. It is important to note that within the scope of production, as noted above, we retained not just finished polymers but also other intermediate precursors as well as additives.[120]

[120] For the full list, see Annex.

Figure 25: Top eight producers of plastic and plastic precursors



Source: BASIC

2.2.2. Horizontal concentration of petrochemical production

Another way to interpret data on petrochemical production consist of asking what quantity of each product is in the hands of a small number of actors.

Regrettably, it is difficult to quantify the total proportion of plastics and plastic precursors that is attributed to any single actor in our review. Many of our statistics on plastic/precursor production are already aggregated, meaning it is not possible to isolate, for instance, the quantity of ethylene or polyethylene, or polypropylene or xylene (to name a few popular products) within the total production data from any given company.

What can be said with confidence is that, for the top eight plastics producers identified here, total plastics/precursor tends to hover around 20 Mt for each of the companies identified, with the exception of Sinopec, which reported 39.412 Mt of plastics/precursor production.[121]

Statistics from other sources shed light on the phenomenon of a small group of actors being responsible for plastic production and waste. For instance, as of 2019, ExxonMobil, Dow, and Sinopec represent 16% of global single-use plastic waste.[122] Further, of the world's 300 polymer producers, the top 20 account for 55% of single-use plastic waste.[123]

2.2.3. Concentration of capital in the petrochemical sector

The concentration of capital and shareholders in petrochemical companies is a defining feature of the industry, driven by the high capital requirements and long payback periods associated with petrochemical production. Establishing a petrochemical complex involves significant investment in advanced technologies, industrial-scale utilities, and infrastructure, making it a domain largely dominated by major corporations and institutional investors. Companies with substantial financial resources are better positioned to invest in innovation, sustainability initiatives, and operational efficiencies. Further, the industry's reliance on economies of scale further consolidates power among a few large players who can afford to weather periods of low margins or oversupply.

In this sub-chapter, we examine publicly available information on the leading institutional shareholders in each of the top eight companies identified above. What stands out is that a small number of institutional asset managers frequently occur as shareholders in each of the corporations. The most prominent of these are:

- Vanguard, which owns 6% of Dow, 10% of ExxonMobil, 10% of LyondellBasell, 9% of Chevron, and 10% of Phillips 66;[124]
- State Street Corp., which owns 4% of Dow, 5% of ExxonMobil, 4% of LyondellBasell, 9% of Chevron, and 7% of Phillips 66;

[121] Included within these 39 Mt are ethylene; synthetic resin; synthetic fibre; synthetic fibre monomer and polymer; and synthetic rubber. We make the assumption that synthetic resin is destined to become a kind of plastic – see Polyexcel, "Thermoplastic Resins: What Are the Applications," June 14, 2021, https://polyexcel.com.br/en/product-news/thermoplastic-resins-what-are-they-for-and-what-are-the-applications/. And Paul Murphy Plastics, "Thermoplastic vs. Thermoset Resins," March 18, 2020, https://paulmurphyplastics.com/industry-news-blog/thermoplastic-vs-thermoset-resins-2/.

[122] Minderoo, "Plastic Waste Makers Index 2021.", page 12.

[123] Minderoo., page 31.

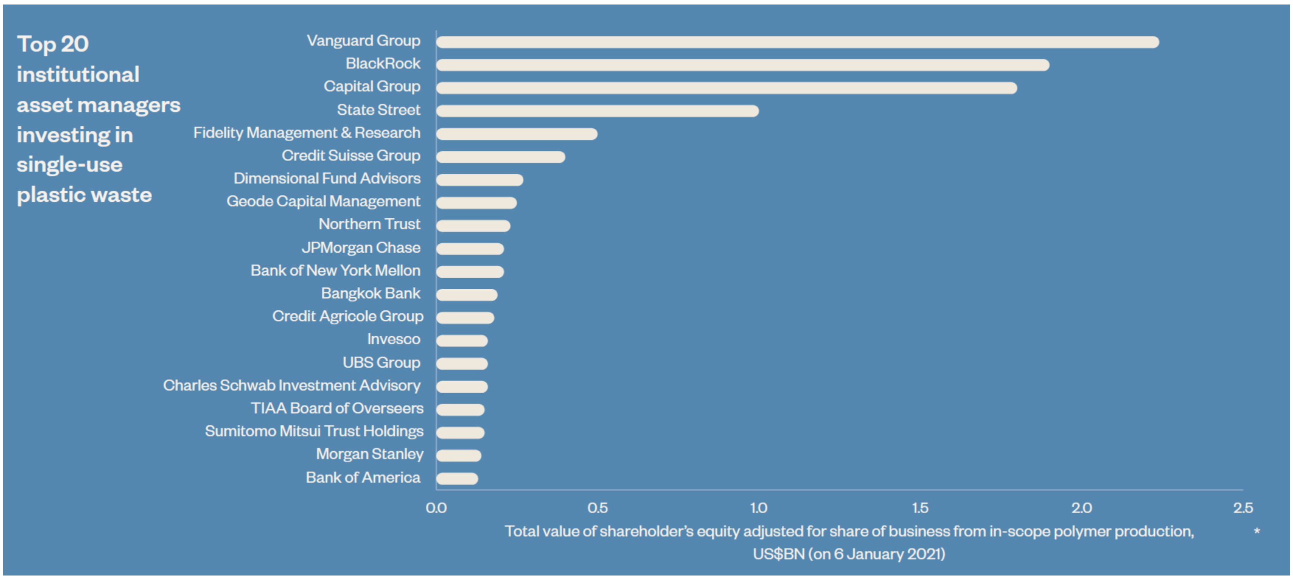
[124] CPChem is a joint venture between Chevron and Phillips 66, and shareholding numbers are available for the two parent companies only.

- **BlackRock,** which owns 3% of Dow, 6% of ExxonMobil, 6% of LyondellBasell, 6% of Chevron, and 6% of Phillips 66.

Meanwhile, three corporations are state-owned (China for Sinopec and PetroChina, and Saudi Arabia for Saudi Aramco[125]). As for the remaining company, INEOS's shareholders are three individuals, with founder James Ratcliffe holding 61%.

For the whole sector, a handful of institutional asset managers control the lion's share of value in companies responsible for plastic waste, according to data compiled by Minderoo (see figure below).

Figure 26: Top 20 institutional asset managers investing in single-use plastic waste



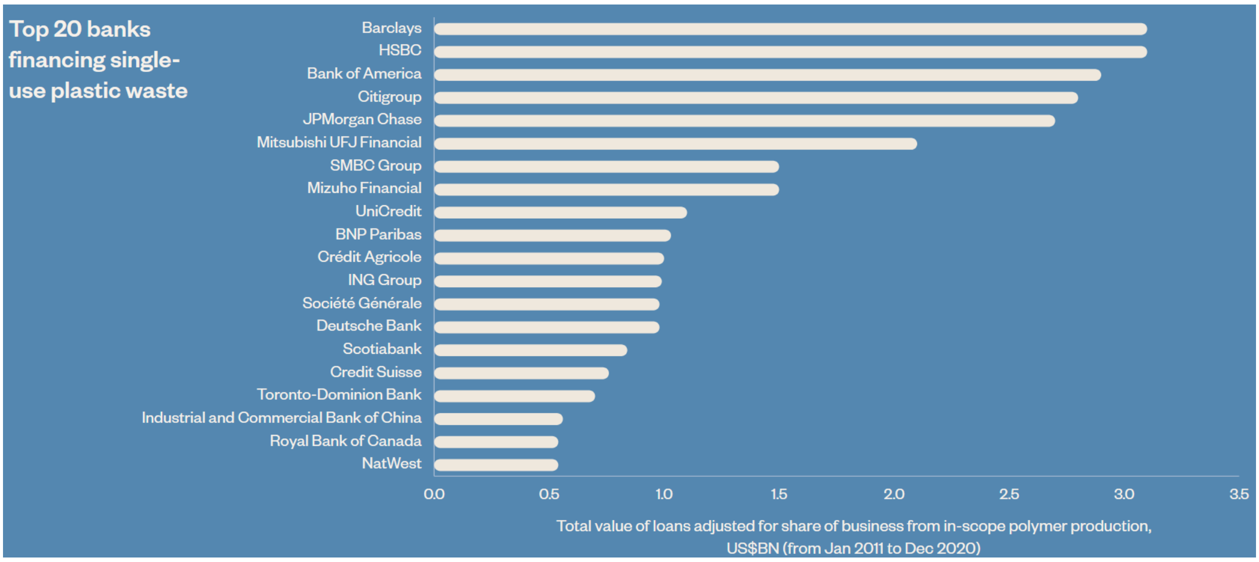
Source: Minderoo[126]

The same applies to banks financing single-use plastic waste (see figure below), on which we did not have visibility in our research for the companies identified in our Top-8.

[125] Meanwhile, Saudi Aramco owns 70% of SABIC, and private investors own the rest. SABIC, "Shareholders," 2022, https://www.sabic.com/en/reports/annual-2022/governance/shareholders.

[126] Minderoo, "Plastic Waste Makers Index 2021.", page 14

Figure 27: Top 20 banks financing single-use plastic waste



Source: Minderoo[127]

[127] Minderoo., page 14.

Conclusion

Understanding the processes involved in plastics production, uses, and waste management, as well as their prospects of future evolution, is essential for informed decision-making about this industry whose ecological and public health impacts are well documented.

Yet, few data are publicly available that allow to put together a systemic vision of the plastics value chain. Such a vision is however necessary to know what space to give to the plastics industry in a future in which phasing-out of fossil fuels is urgent. Indeed, our modelling shows that the plastics industry, if left unregulated, will drive fossil resources extraction in the coming years, as it will mobilise a growing share of these resources. The hypothesis that plastics are becoming an important source of profitability and a central element of business models for petrochemical companies seems to be confirmed.

For the industry, the unlimited growth of plastics consumption is nothing to worry about, as the sector would be on the course of becoming circular. Our analysis, although still to be extended, allows to doubt about the promise of circularity due to both the physical realities faced and the economic logics at play. The equation that plastics consumption will more than double by 2060 (as currently projected), while fossil resource extraction will decline so that we reach net zero by 2050 (as planned), seems impossible, even in pushing all the levers offered by circularity. Quantifying the real power of these levers would be a necessary next step to better plan the use and production of the plastics that the planet can afford.

In this planning of plastics production, attention should also be given:

- to conflicts of use (with the production of fertilizers for example) or knock-on effects (can fertilizers be made without producing some plastics as co-products?);
- to ripple effects on other sectors (for example, can our current food system stand without plastics?).

With these open questions, plastics appear as a particularly critical element of the socioecological transition to be realised.

Annex 1: Production and uses statistics

This section deals with the volumes of oil and gas production and consumption worldwide.

1.1. Crude oil production

The crude oil distillation route to plastics is based on world petroleum production. As of today, an estimated 100 million barrels of oil per day, if one includes gases found in the crude oil (Natural Gas Liquids, or NGLs). NGLs include our plastic precursors.

Figure 28. Estimated production of oil and Natural Gas Liquids (NGLs), in million barrels per day

82 757
Energy Institute (BP)
Year 2023
Crude oil only

+

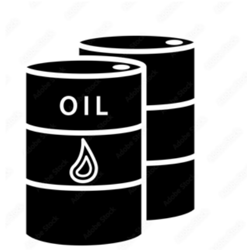
13 619
Energy Institute (BP)
Year 2023
*NGLs**

=

96 376
Energy Institute (BP)
Year 2023
Crude oil + condensates + NGL (ethane, LPG, naphtha)

101 810
US Energy Info. Admin.
Year 2023

102 200
IEA
Year 2023



**appears to include condensates + naphtha*

Source: BP Energy Institute,[128] US Energy Information Administration,[129] IEA[130]

[128] Energy Institute, "Statistical Review of World Energy."
[129] U.S. Energy Information Administration (EIA), "What Countries Are the Top Producers and Consumers of Oil?," April 11, 2024, https://www.eia.gov/tools/faqs/faq.php?id=709&t=6.
[130] IEA, "Oil 2024."

Table 6. Top 10 oil producers and share of total world oil production in 2023

Country	Million barrels per day	Share of world total
United States	21.91	22%
Saudi Arabia	11.13	11%
Russia	10.75	11%
Canada	5.76	6%
China	5.26	5%
Iraq	4.42	4%
Brazil	4.28	4%
United Arab Emirates	4.16	4%
Iran	3.99	4%
Kuwait	2.91	3%
Total top 10	74.59	73%
World total	101.81	

Source: US Energy Information Administration[131]

Table 7. Top 10 oil consumers and share of total world oil consumption in 2023

Country	Million barrels per day	Share of world total
United States	20.01	20%
China	15.15	15%
India	5.05	5%
Russia	3.68	4%
Saudi Arabia	3.65	4%
Japan	3.38	3%
Brazil	3.03	3%
South Korea	2.55	3%
Canada	2.41	2%
Germany	2.18	2%
Total top 10	61.08	61%
World total	99.95	

Source: US Energy Information Administration[132]

1.2. Gas production

Gas production stands at approximately 4,100 billion cubic meters per year, which equates to 3.526 billion tonnes petroleum equivalent per annum. Key producers include the US, Russia, Iran, China, and Canada.

[131] U.S. Energy Information Administration (EIA), "What Countries Are the Top Producers and Consumers of Oil?"
[132] U.S. Energy Information Administration (EIA).

Figure 29. Annual production of natural gas in billion cubic metres

Sources: IEA,[133] Enerdata,[134] and BP Energy Institute[135]

The U.S. alone accounts for a quarter of annual production, followed by Russia, which produces 15%. Iran and China follow at 6%, and Canada at 5%.

[133] IEA, "World Energy Outlook 2024," 2024, https://iea.blob.core.windows.net/assets/a5ba91c9-a41c-420c-b42e-1d3e9b96a215/WorldEnergyOutlook2024.pdf.
[134] Enerdata, "Global Natural Gas Production | World Gas Natural Statistics."
[135] Energy Institute, "Statistical Review of World Energy."

Table 8. Estimated natural gas production by country, in billion cubic metres

Country	2023 production (billion cubic metres)	Percent of world production
United States	1 072.33	26%
Russia	613.45	15%
Iran	265.09	6%
China	239.40	6%
Canada	194.11	5%
Qatar	171.80	4%
Australia	151.31	4%
Norway	121.64	3%
Saudi Arabia	121.22	3%
Algeria	104.90	3%
Turkmenistan	84.28	2%
Malaysia	74.32	2%
Indonesia	58.69	1%
Egypt	57.18	1%
United Arab Emirates	55.80	1%
Argentina	43.69	1%
Uzbekistan	43.25	1%
Oman	41.73	1%

Source: BASIC, based on U.S. Energy Information Administration[136]

According to the Energy Institute,[137] the annual consumption, meanwhile, is dominated by :

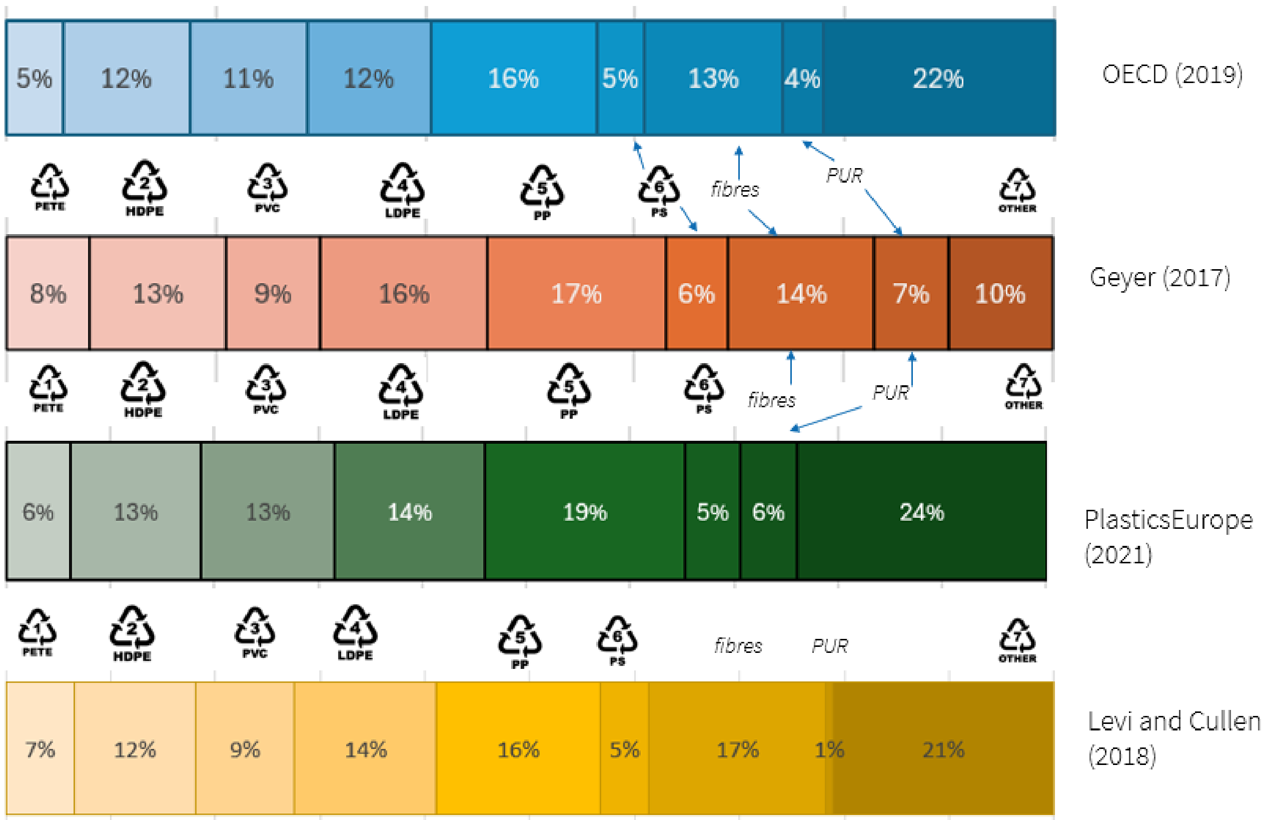
- United States (886 bcm)
- Russian Federation (453 bcm)
- China (404 bcm)
- Iran (245 bcm)
- Saudi Arabia (114 bcm)

1.3. Plastic final uses

We have data on how this plastic production is dispatched between the different kinds of plastics:

[136] U.S. Energy Information Administration (EIA), "Natural Gas."
[137] Energy Institute, "Statistical Review of World Energy."

Figure 30. Distribution of plastics produced, by type, in recent years



Source: BASIC, built on Geyer,[138] PlasticsEurope,[139] OECD,[140] and Levi and Cullen (2018)[141]

Note that the proportion for the first six types of plastics are relatively close to one another. Things become more complicated when one decides to separate out items such as **fibres,** which includes part of PET (type 1) but also polyamide (aka nylon – type 7), as well as acrylic (derived from ethylene – type 7). Some of the above distributions also isolate out "PUR," which stands for polyurethane. PUR is singled out because the quantity of PUR produced is nearly that of one of the six traditional plastics (PET).

[138] Geyer, "Production, Use, and Fate of Synthetic Polymers."
[139] Plastics Europe, "Plastics - the Facts 2022."
[140] OECD, "Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options."
[141] Levi and Cullen, "Mapping Global Flows of Chemicals."

Annex 2: Building a quantitative model of the plastics value chain

In order to obtain an overview of the plastics industry at the global level, from upstream to downstream, we modelled its flows, from raw resources to final uses, including the production of the various intermediaries. To do this, we relied on the work of Levi and Cullen (2018) , who used data on petrochemical flows from 2013. Levi and Cullen's approach, as well as the main modelling choices and assumptions made in this report based on their article, are detailed below.

2.1. Research and data collection

2.1.1. Rare and non-public data

The search for recent, comprehensive and sufficiently detailed data on petrochemical production from fossil fuel sources to final plastic use was fruitless. Indeed, public data are rare, as Levi and Cullen. themselves deplore. The lack of data seems to be due to:

- The complexity of supply chains[142]. The petrochemical sector is highly complex, with many different processes and products both within and at the end of the chain. Collecting and publishing detailed data can be difficult and costly.
- Some detailed data exists and is available but over a limited scope (country or group of countries).
- Regulations and standards: regulatory requirements vary from country to country, and some jurisdictions may not require companies to publish detailed data.

Finally, we found that detailed data was often behind a paywall.

2.1.2. Choosing Levi and Cullen (2018) as the primary data source

The flows modelled by Levi and Cullen (2018) are based on data from 2013. Despite the relative age of this data, we believe that relying on it is the best option available for our modelling of flows of matter within the petrochemical sector.

The authors wrote in 2018: "We provide the most up to date, comprehensive and transparent data set publicly available on virgin production routes in the chemical sector: from fossil fuel feedstocks to chemical products. […] The resulting data set partially addresses the dearth of publicly available information on the chemical sector's supply chain […]"[143].

The data from Levi and Cullen (2018) were collected at the finest possible level via their supporting information and were gathered in a database in Excel format.

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[142]"the highly intertwined nature of its complex supply chains" - Levi and Cullen (2018)
[143] Levi and Cullen (2018)

2.2. Database, model and hypotheses

2.2.1. Introduction

The database thus constructed allows various levels of aggregation, depending on the desired granularity for visualisation and analysis. Our database makes explicit, for each of the flows between building blocks of plastics, the origin and destination, on 3 levels of detail, filled only if the available information is sufficiently fine, as well as the quantities in Mt/year. For example :

Tableau 1. Sample of our database : example of a detailed flow

From : Niv 1	From : Niv 2	From : Niv 3	To : Niv 1	To : Niv 2	To : Niv 3	Quantity Mt/an
Basic Chemicals	(BTX) Aromatics	Benzene	Intermediates 1	Styrene	X	2,3

In this example, the destination category was not specific enough for level 3, so it was necessary to stop at level 2. The categories at level 1 correspond to the broad categories in Figure 2.

Each flow is thus reported at the finest level available, and aggregation can be done at the origin and/or destination level. The exact nomenclature used is detailed below.

In addition to the data taken from the work of Levi and Cullen (2018) , we make two major improvements:

- Connection to downstream plastic uses.
- The selection (via modelling) of fossil resources necessary for the production of plastics only (therefore excluding fertilisers, but also explosives, for example).

The nomenclature and main assumptions used appear below.

2.2.2. Nomenclature

The table below details the nomenclature used for database construction, then used for modelling and visualisations. Note that some lines are aggregates of other ones.

Table 2. Nomenclature used for modelling

Niv 1	Niv 2	Niv 3
Fossil fuel and material for plastic	All	X
Fossil fuel and material for plastic	Crude Oil for plastic	All
Fossil fuel and material for plastic	Crude Oil for plastic	For Gas oil
Fossil fuel and material for plastic	Crude Oil for plastic	For Naphtha
Fossil fuel and material for plastic	Crude Oil for plastic	For Oil (Ammonia)

Niv 1	Niv 2	Niv 3
Fossil fuel and material for plastic	Natural Gas & NGL for plastic	All
Fossil fuel and material for plastic	Natural Gas & NGL for plastic	For Butane
Fossil fuel and material for plastic	Natural Gas & NGL for plastic	For Ethane
Fossil fuel and material for plastic	Natural Gas & NGL for plastic	For Propane
Fossil fuel and material for plastic	Natural Gas & NGL for plastic	For methylalcohol
Fossil fuel and material for plastic	Natural Gas & NGL for plastic	For Ammonia
Fossil fuel and material for plastic	Coal for plastic	All
Fossil fuel and material for plastic	Coal for plastic	For Plastics
Fossil fuel and material for plastic	Coal for plastic	For Ammonia
Fossil fuel and material for plastic	Refinery feedstock for plastic	All
Fossil fuel and material for plastic	Refinery feedstock for plastic	For Propylene
Fossil fuel and material for plastic	Refinery feedstock for plastic	For C4 Stream
Fossil fuel and material for plastic	Refinery feedstock for plastic	For BTX aromatics
Feedstock	All	X
Feedstock	Refined Oil	All
Feedstock	Refined Oil	Gas oil (heavy feed)
Feedstock	Refined Oil	Naphtha (heavy feed)
Feedstock	Refined Oil	Oil (carbon black)
Feedstock	Processed Natural Gas & NGL	All
Feedstock	Processed Natural Gas & NGL	Butane (light feed)
Feedstock	Processed Natural Gas & NGL	Ethane (light feed)
Feedstock	Processed Natural Gas & NGL	Propane (light feed)
Feedstock	Natural Gas & NGL AND Carbonated Coal	For methylalcohol
Feedstock	Natural Gas & NGL	For methylalcohol
Feedstock	Carbonated Coal	For methylalcohol
Basic Chemicals	Methylalcohol	For propylene
Basic Chemicals	Ethylene	X
Basic Chemicals	Propylene	X
Basic Chemicals	Butadiene	X
Basic Chemicals	Other C4	Isobutene
Basic Chemicals	(BTX) Aromatics	Benzene

Niv 1	Niv 2	Niv 3
Basic Chemicals	(BTX) Aromatics	Para-xylene
Basic Chemicals	(BTX) Aromatics	All
Basic Chemicals	(BTX) Aromatics	Meta-xylene
Basic Chemicals	(BTX) Aromatics	Ortho-xylene
Intermediates 1	Styrene	X
Intermediates 1	Ethylene glycol	X
Intermediates 1	Terephthalic acid	All
Intermediates 1	Terephthalic acid	Purified terephtalic acid
Intermediates 1	Terephthalic acid	Dimethyl terephthalate
Intermediates 1	Vinyl chloride	X
Intermediates 1	Other first intermediates	All
Intermediates 1	Other first intermediates	2-ethyl hexyl alcohol
Intermediates 1	Other first intermediates	Acetic acid
Intermediates 1	Other first intermediates	Acetone
Intermediates 1	Other first intermediates	Acrylonitrile
Intermediates 1	Other first intermediates	Adiponitrile
Intermediates 1	Other first intermediates	Cyclohexane
Intermediates 1	Other first intermediates	Phenol
Intermediates 1	Other first intermediates	Phthalic anhydride
Intermediates 2	Other second intermediates	All
Intermediates 2	Other second intermediates	Adipic acid
Intermediates 2	Other second intermediates	Caprolactam
Intermediates 2	Other second intermediates	Hexamethylenediamine
Intermediates 2	Other second intermediates	Aniline
Intermediates 2	Other second intermediates	Bisphenol A
Intermediates 2	Other second intermediates	Methyl methacrylate
Intermediates 2	Other second intermediates	Vinyl acetate
Intermediates 2	Polystyrene	All
Intermediates 2	Polystyrene	Expandable polystyrene (Thermoplastic)
Intermediates 2	Polystyrene	General purpose polystyrene (Thermoplastic)
Intermediates 2	Polystyrene	High impact polystyrene (Thermoplastic)
Intermediates 2	Polyethylene terephtalate	X
All	X	X
Intermediates 1	Polyethylene	All
Intermediates 1	Polyethylene	HDPE [2] (Thermoplastic)
Intermediates 1	Polyethylene	LDPE [4] (Thermoplastic)
Intermediates 1	Polyethylene	LLDPE [4] (Thermoplastic)
Intermediates 2	Polyvinyl chloride	All
Intermediates 2	Polyvinyl chloride	Flexible PVC [3]
Intermediates 2	Polyvinyl chloride	PVC Other [3]
Intermediates 1	Polypropylène	Polypropylène Thermo

Niv 1	Niv 2	Niv 3
Intermediates 1	Polypropylène	Polypropylène Fibers
Intermediates 2	Other second intermediates	Acrylonitrile butadiene styrene
Intermediates 2	Other second intermediates	Dioctyl phthalate
Intermediates 2	Other second intermediates	Styrene acrylonitrile
Intermediates 3	Polyamide	X
Intermediates 3	Other third intermediates	All
Intermediates 3	Other third intermediates	Polycarbonate
Intermediates 3	Other third intermediates	Polymethyl methacrylate
Intermediates 3	Other third intermediates	Polyvinyl acetate
Intermediates 3	Other third intermediates	Methylene diphenyl diisocyanate
Intermediates 1	Other first and second intermediates	All
Intermediates 3	Polyamide	All
Intermediates 1	Polypropylène	All
Intermediates 2	Polyethylene terephtalate	All
Intermediates 1	All other first intermediates	All
Intermediates 2	All other second intermediates	All
Intermediates 3	All other third intermediates	All
Intermediates 1	Other first intermediates	Formaldehyde
Intermediates 1	Other first intermediates	Isophthalic acid
Intermediates 1	Other first intermediates	Maleic anhydride
Intermediates 1	Other first intermediates	Phthalic anhydride
Intermediates 1	Other first intermediates	Polybutadiene
Intermediates 1	Other first intermediates	Polychloroprene
Intermediates 1	Other first intermediates	Propylene oxide
Intermediates 2	Other second intermediates	Bisphenol A
Intermediates 2	Other second intermediates	Melamine
Intermediates 2	Other second intermediates	Nitrile butadiene
Intermediates 2	Other second intermediates	Polyacrylonitrile
Intermediates 2	Other second intermediates	Styrene butadiene
Intermediates 2	Other second intermediates	Toluene diisocyanate
Thermoplastics	PS [6]	All
Thermoplastics	PET [1]	X
Fibres	PET [1] fibers	X
Thermoplastics	Polyethylene [2] [4] TP	LDPE [4] & LLDPE [4]
Thermoplastics	Polyethylene [2] [4] TP	HDPE [2]
Thermoplastics	PVC [3] TP	All
Thermoplastics	PP [5]	PP [5]
Fibres	PP [5]	PP Fibers
Other	X	X
Thermoplastics	Other TP [7]	X
Fibres	Other F	Polyamide Fibre
Thermosets	Methylene diphenyl diisocyanate	X

Niv 1	Niv 2	Niv 3
Thermosets	All TS from Other first and second intermediates except PUR	X
Elastomers	All E from Other first and second and intermediates	X
Fibres	All F from Other first and second intermediates	X
Thermosets	Polyurethane	X
Thermoplastics	Acrylonitrile butadiene styrene (ABS)	X
Thermoplastics	Styrene acrylonitrile (SAN)	X
Textile sector	X	X
Transportation	X	X
Packaging	X	X
Building & construction	X	X
Textile sector - clothing	X	X
Textile sector - others	X	X
Consumer & institutional products	X	X
Electrical & electronic	X	X
Industrial & machinery	X	X
Transportation - other	X	X
Transportation - tyres	X	X
Other (incl. Other, marine coatings, road markings, and personal care products)	X	X

Source: BASIC

2.2.3. Calculation of production data, and comparison to Levi and Cullen (2018)

The table below shows the fossil resources required for the production of plastic precursors but also for other products such as fertilisers, explosives, etc., according to Levi and Cullen (2018) , for a total of 420.1 Mt.

Indeed, some of these precursors (propylene, C4 stream, etc.) are actually used to produce not plastic but other products. Thus, it is necessary to apply ratios to arrive at an estimate of the fossil resources that are actually intended for the production of plastic, as opposed to fertilisers, explosives, etc. This is why we arrive at a lower estimate: approximately 361 Mt of fossil resources to produce plastic instead of 420.1 Mt.

Table 9. Flows from fossil fuels to olefins and aromatics

Source	Destination	Mt
Refinery-sourced olefins and aromatics	Propylene	31.8
Refinery-sourced olefins and aromatics	C4 stream	53.6
Refinery-sourced olefins and aromatics	BTX	77.2
Natural gas & NGLs	Ethylene	60.9
Natural gas & NGLs	Propylene	5.9
Natural gas & NGLs	C4 stream	4.1
Liquid oil products	Ethylene	71.1
Liquid oil products	Propylene	37.2
Liquid oil products	C4 stream	24.6
Liquid oil products	BTX	23.6
Coal	Methyl alcohol	30.1
	TOTAL	**420.1**

Source: Levi and Cullen (2018)

2.2.4. Calculation of usage data for different types of plastics

For the breakdown of plastic categories into end uses, we rely on OECD data[144] (see tables below). The OECD data details, in volume, the destinations (uses) of each category of plastic (PET, PP, HDPE…). From these quantities, we calculate distribution percentages, which we apply to our own quantities of plastics.

For example, the HDPE category is 58.3% in packaging. We apply this percentage to our own HDPE production figure (based on Levi and Cullen, 2018) to arrive at the final tonnage in HDPE that is used in packaging.

Note that the quantities produced in each category (PET, PP, HDPE, etc.) vary from one year to another and from one source to another. This is why, if we add up the quantities produced according to the OECD, we do not exactly end up with the quantities produced according to Levi and Cullen (2018) . And consequently, the final proportions of uses also differ. For example, according to our calculations, packaging represents 32% of uses, while according to the OECD, this use represents rather 31% of the total.

[144]The data set can be found at the URL: https://data-explorer.oecd.org/vis?tenant=archive&df[ds]=DisseminateArchiveDMZ&df[id]=DF_PLASTIC_USE_6&df[ag]=OECD&dq=..&to[TIME]=false

Table 3. Uses of different plastics, by volume (Mt/million metric tonnes)

	Packaging	Building & construction	Textile sector - clothing	Textile sector - others	Consumer & institutional products	Electrical & electronic	Industrial & machinery	Transportation - other	Transportation - tires	Other
PET	24.9									
LDPE_LLDPE	35.4	3.3			7.6	1.5	0.6	0.5		5.3
HDPE	32.4	10.4			5.3	0.5	0.6	2.3		4.1
PP	36.5	5.4			16.1	3.5	0.8	10.6		0.0
PVC	3.8	35.8			2.4	1.4		1.5		6.5
FIBERS			28.5	15.1				6.1		10.8
PS	6.3	6.3			5.0	1.6				1.9
PURE	0.4	5.3			2.1	0.9	0.7	3.4		5.3
ABS / ASA / SAN		0.3			4.0	2.4		1.5		0.7
BIOPLASTICS	1.3	0.1	0.3		0.2	0.0		0.2		0.3
ELASTOMERS (TYRES)									7.7	
OTHER	1.6	10.0			4.0	5.5		28.4		31.5

Source: OECD[145]

Table 4. Uses of different plastics, in proportions

	Packaging	Building & construction	Textile sector - clothing	Textile sector - others	Consumer & institutional products	Electrical & electronic	Industrial & machinery	Transportation - other	Transportation - tires	Other
PET	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LDPE_LLDPE	65.3%	6.2%	0.0%	0.0%	14.0%	2.7%	1.1%	0.9%	0.0%	9.8%
HDPE	58.3%	18.7%	0.0%	0.0%	9.6%	0.9%	1.0%	4.2%	0.0%	7.3%
PP	50.1%	7.4%	0.0%	0.0%	22.1%	4.8%	1.1%	14.5%	0.0%	0.0%
PVC	7.4%	69.7%	0.0%	0.0%	4.6%	2.7%	0.0%	2.8%	0.0%	12.7%
FIBERS	0.0%	0.0%	47.2%	25.0%	0.0%	0.0%	0.0%	10.1%	0.0%	17.8%
PS	29.7%	29.9%	0.0%	0.0%	23.6%	7.7%	0.0%	0.0%	0.0%	9.1%
PURE	2.0%	29.5%	0.0%	0.0%	11.7%	4.8%	3.9%	19.0%	0.0%	29.1%
ABS / ASA / SAN	0.0%	3.2%	0.0%	0.0%	44.9%	27.1%	0.0%	16.7%	0.0%	8.2%
BIOPLASTICS	58.0%	4.2%	10.8%	0.0%	7.0%	2.0%	0.0%	7.1%	0.0%	10.9%
ELASTOMERS (TYRES)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
OTHER	2.0%	12.3%	0.0%	0.0%	4.9%	6.7%	0.0%	35.1%	0.0%	39.0%

Source: BASIC, based on OECD[146]

The table above must be read, e.g. : 100% of PET is used in packaging, or 50.1% of PP is used in packaging.

2.2.5. Other modelling hypotheses

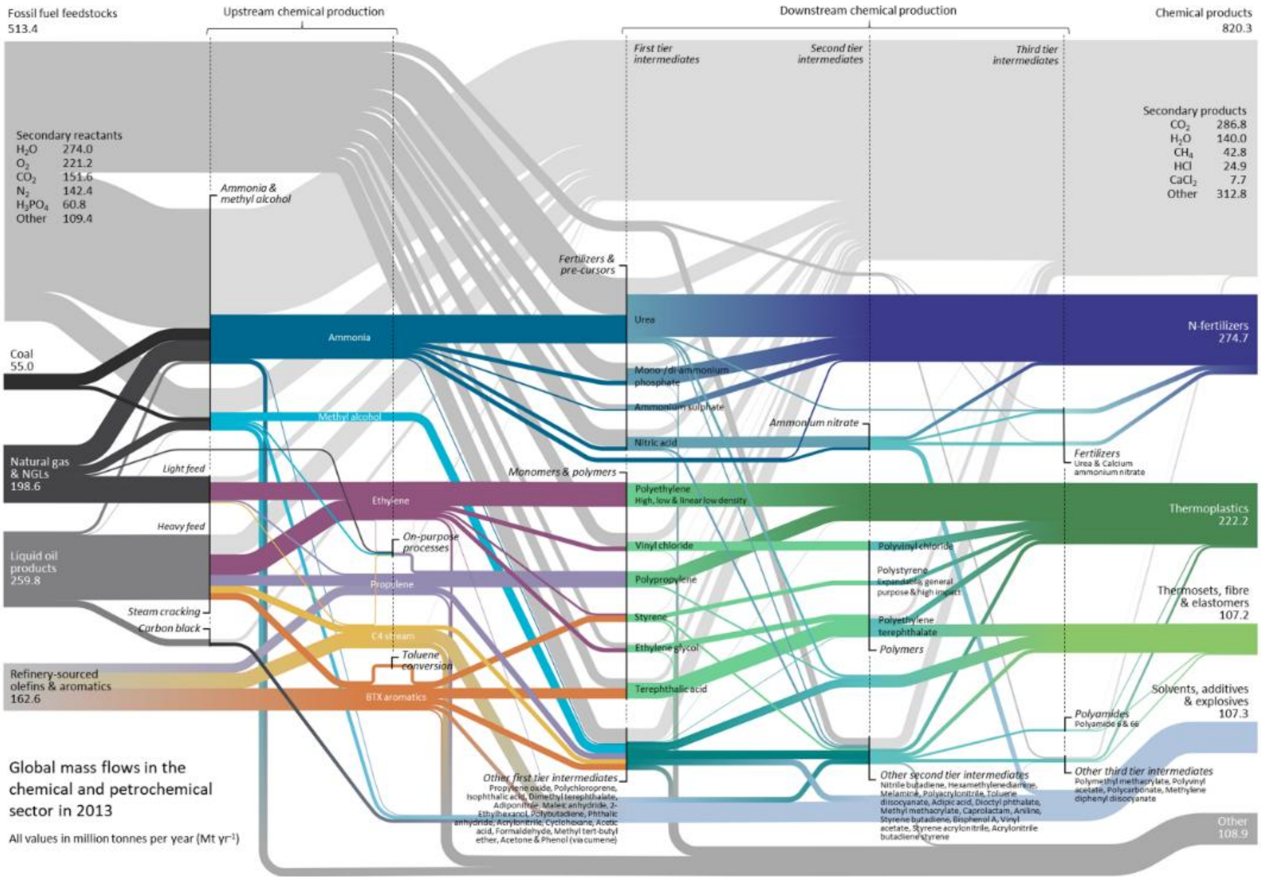
- PUR is considered 100% thermoset although it can also be elastomer or thermoplastic.

2.3. Visualisation: Sankey diagram

2.3.1. Levi and Cullen (2018)

The Sankey diagram constructed by Levi and Cullen (2018) is reproduced below.

Figure 31: A Sankey diagram depicting the passage of feedstock through the chemical sector: from fossil fuel feedstocks to chemical products.



Source: Levi and Cullen (2018)
NGLs: Natural gas liquids, N-fertilisers: Nitrogenous fertilisers

As mentioned above, the scope of their study is broader than ours, since it includes the production of plastic but also other products from fossil resources.

[145]The data set can be found at the URL: https://data-explorer.oecd.org/vis?tenant=archive&df[ds]=DisseminateArchiveDMZ&df[id]=DF_PLASTIC_USE_6&df[ag]=OECD&dq=..&to[TIME]=false

[146]The data set can be found at the URL: https://data-explorer.oecd.org/vis?tenant=archive&df[ds]=DisseminateArchiveDMZ&df[id]=DF_PLASTIC_USE_6&df[ag]=OECD&dq=..&to[TIME]=false

2.3.2. Tailor-made visualisation

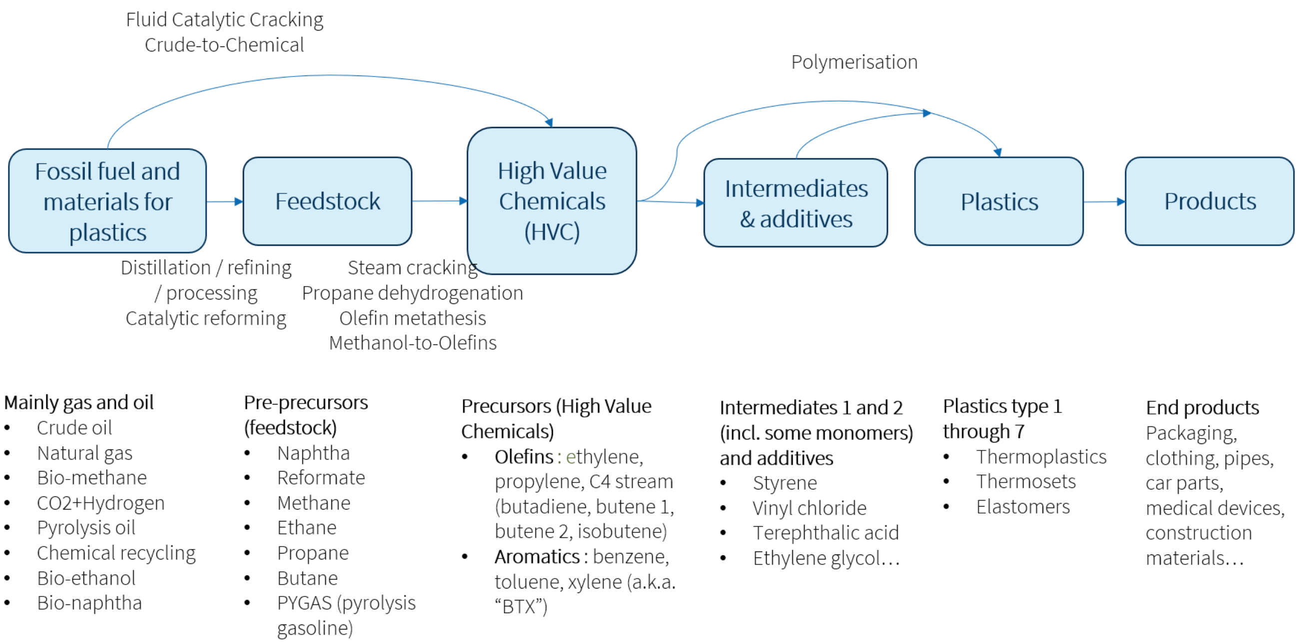
For our own visualisation, we first collected, aggregated the data and modelled the missing information. Then, visualisations in the form of Sankey diagrams were produced using **Open Sankey** [147]: this tool allows visualisation from an excel database. An example of a visualisation created representing our flows is presented in the body of the document, in Figure 21.

This visualisation makes use of the **level 1 categories** of our database. These correspond to the broad categories that appear in the rectangles in Figure 2(from upstream to downstream), with a colour per category:

- Fossil fuel and material for plastics.
- Feedstock.
- High Value / basic chemicals.
- Intermediates (1, 2 and 3).
- Plastics.
- Products.

Below, we present each of the large categories, detailing under each one which products were chosen to be included for our visualisation. The steps used to move from one major category to another are detailed in part 1.

Figure 32: Main steps in the plastic production process



Source: BASIC

[147] https://open-sankey.fr

The main **fossil fuel and material** used for the production of plastic are crude oil, natural gas & NGL, refinery-sourced feedstocks[148], but also, to a lesser extent, coal (as mentioned above).

For the purposes of simplification, on the visualisation of the Sankey we have grouped in the next category – the "**feedstock**" category (also called "pre-precursors") – both the first products of oil refining ("Refined oil" item – naphtha in particular) and gas processing ("Processed natural gas and NGL" item), and the simple chemicals (methane (C1), ethane (C2), propane (C3), and the butanes (C4) that are derived from this refining and processing. The main technique used to convert the oil/gas into C1 to C4 feedstocks is steam cracking.

Some olefins and aromatics are also obtained as by-products of fluid catalytic cracking (FCC) and from PYGAS – a by-product of high-temperature naphtha cracking during ethylene and propylene production which habitually yields BTX (benzene, toluene, and xylene). This corresponds to the third vertical segment of the Sankey diagram ("Refinery Feedstocks (crude oil, gas and NGL)"). Another route to BTX is catalytic reforming of naphtha, which yields reformate, which can be further processed into BTX.

"Basic chemicals", also known as **High Value Chemicals/precursors,** can be produced from feedstock, or directly from raw fossil fuel. Examples of basic chemicals include:

- Ethylene.
- Propylene.
- Butadiene.
- The aromatics BTX: benzene, toluene, and xylene (including para-, meta-, and ortho-xylene).

In particular, propylene can be produced from processed natural gas & NGL or from coal, via methanol.

The **intermediate category** display in the chart above actually groups together 3 levels of intermediates. Here again, some production paths go through all the steps while others take shortcuts. The majority path is the creation of a monomer (intermediate 1) from a basic chemical which is then polymerised (intermediate 2) then assembled into plastic, and finally transformed into a final product.

There are different possible categorisations of **plastic**, as explained above. We choose a categorisation consistent with the Levi and Cullen (2018) model and the OECD end-use model[149]:

- Thermoplastics except fibers: PET [1], HDPE [2], PVC [3], LDPE & LLDPE [4], PP [5], PS [6].
- Fibers: PET, PP, Other.
- Thermosets: PUR
- Mix of thermoplastics, thermosets and elastomers.

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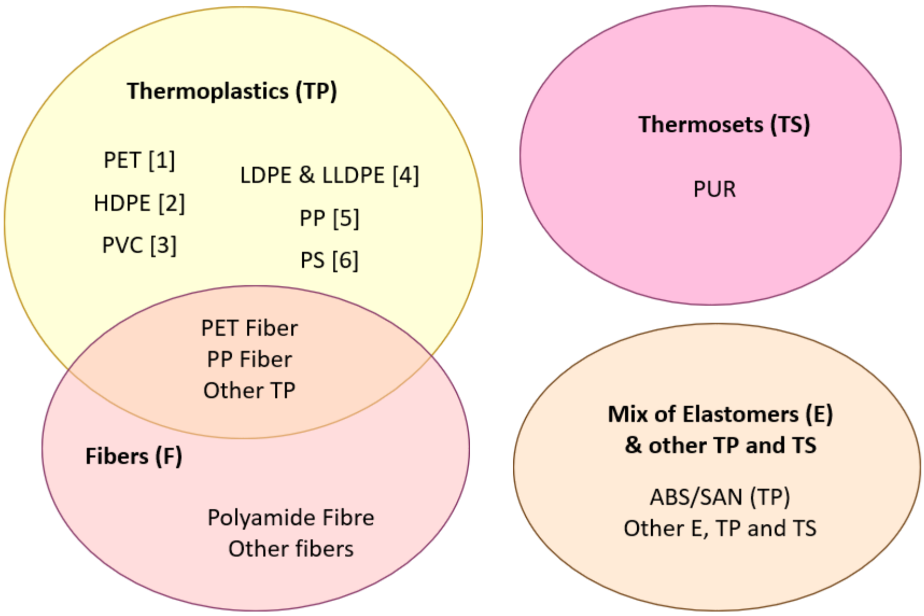
[148] The so-called "refinery-sourced olefins and aromatics" are constituted of "those [olefins and aromatics] produced as by-products from fluid catalytic cracking, those extracted from PYGAS streams and those produced from toluene hydrodealkylation (TDH) and disproportionation (TDP) (both converting toluene to benzene and mixed xylenes). Since global quantities for each of these streams are not available, the quantities are calculated by taking the total global production of each olefin/aromatic and subtracting the steam cracking and TDP/TDH streams, on which is there is better information. This leaves the 'refinery-sourced' portion as the residual." This definition of refinery-sourced olefins and aromatics was obtained in written correspondence with the authors, 24 February 2025.

[149] https://data-explorer.oecd.org/vis?tenant=archive&df%5bds%5d=DisseminateArchiveDMZ&df%5bid%5d=DF_PLASTIC_USE_6&df%5bag%5d=OECD

Some plastics other than thermoplastics may belong to several categories (e.g. elastomers and thermosets) and the details are not always given. In this case, an assumption is made that they are assigned to a single category. This means that it is more correct to consider the categories thermosets, fibres and elastomers as one (the total sum is correct) rather than separately.

See the summary diagram below of the categories of plastic that we use:

Figure 33: Summary diagram of the categories used for the flow diagram



Source: BASIC

We break down our quantities of plastics into **end-use products**, via the OECD end-use proportions [150].

We take the OECD categories, with two exceptions:

- Bioplastics are excluded, since we have not included them in our scope.
- Their category “ABS/ASA/SAN” is assigned to our 2 categories ABS (Acrylonitrile Butadiene Styrene) and SAN (Styrene Acrylonitrile), but ASA (Acrylonitrile Styrene Acrylate) is absent from our data[151].

[150]The OECD data can be found online here: https://data-explorer.oecd.org/vis?tenant=archive&df%5bds%5d=DisseminateArchiveDMZ&df%5bid%5d=DF_PLASTIC_USE_6&df%5bag%5d=OECD

[151] More precisely, following Levi and Cullen (2018) : «ASA omitted in this study, but is very low volume».

Table 5: Final plastics and comparison to OECD nomenclature

BASIC Name (in the visualisation)	Category*	Name OECD
PET [1]	TP	PET
HDPE [2]	TP	HDPE
PVC [3] Thermo	TP	PVC
LDPE [4] & LLDPE [4]	TP	LDPE LLDPE
PP [5]	TP	PP
PS [6]	TP	PS
Other TP [7] (including ABS / ASA / SAN)	TP	OTHER
PUR	TS	PUR
Elastomers	E	OTHER
PP [5] Fibers	F	FIBERS
PET [1] Fibers	F	FIBERS
Other Fibers	F	FIBERS
Other TS	TS	OTHER

Source: BASIC

**TP: thermoplastics; TS: thermosets; E: elastomers, F: fibers.*

Note: in the OECD nomenclature, “Other” is a mixture of thermoplastics, thermosets and elastomers.

Annex 3: Updating the modelled flows of the petrochemicals industry

Since the data used dates from 2013, an update of the plastics industry flows could be considered. We have listed several technical options, from the simplest and quickest to the most complex and time-consuming. This updating work could thus be an extension of this actual study.

3.1. Conservative updating of flows

This option consists of calculating a global multiplication coefficient, by making the ratio of recent global plastic use (latest year available: 2021[152]) with the total plastic used in Levi and Cullen (2018). This ratio would then be applied to all flows. The underlying hypothesis is the conservation of the equations (conservative scenario). In other words, no technological leap, and the same proportion of the different resources.

NB: One could also calculate a ratio from upstream, by comparing the amount of fossil resources used to produce plastic today vs. in 2013, and then apply this ratio to the entire chain. The preference for downstream is motivated by Dr. Peter Levi[153], co-author of Levi and Cullen (2018). However, this approach requires finding updated production data for all the downstream products, which was not available to us.

3.2. Updating a minimum number of data points

In this option, the use of an advanced version of the Open Sankey tool is proposed for a "reconciliation" of the data. With this option, it is possible to update a minimum number of data points (those for which the information is available) and the tool performs the reconciliation, that is, it deduces the missing flows from the reported flows.

3.3. Full update

In this option, one would recreate the entire equation system of Levi and Cullen (2018) to have control over all the parameters. This option would make it possible to implement precisely, not only the quantitative evolutions of the flows, but also the technological leaps. However, this option comes up against the lack of public data.

According to Dr. Peter Levi[154], co-author of Levi and Cullen (2018) , there are no innovations that he is aware of that would fundamentally change the balances/equations. Thus, the equations of Levi and Cullen (2018) would still be valid. Since the plastics industry is a heavy industry, which takes time to change, there is according to Dr. Levi no monumental change since 2013 in either industrial process or types of plastics.

[152] Plastics Europe, "Plastics - the Facts 2022."
[153] BASIC Interview with Dr. Peter Levi, November 2024.
[154] BASIC Interview with Dr. Peter Levi, November 2024.

Annex 4: Key petrochemical companies

4.1. General information

The petrochemical sector includes dozens of companies worldwide.[155] In order to identify the world's top plastic producers, we triangulated various sources of publicly available information. We based ourselves on four types of sources:

- Minderoo's "Plastic Waste Makers Index," both the 2021[156] and the 2023[157] editions.
- Unearthed/Greenpeace's investigative report on the quantity of plastics produced by major members of the Alliance to End Plastic Waste.[158]
- Data produced by academic research on the volumes of chemicals produced by petrochemical companies worldwide.[159] While this did not represent petrochemicals only, it was a valuable springboard into in-depth research on the leading companies.
- Data published by petrochemical companies themselves on their production of petrochemicals used in plastic. (For instance, it is due to the small self-report of plastic/precursor production – about 14 Mt in the absolute and around 12 Mt when adjusted for joint ventures[160] – that we have excluded BASF from the top eight plastic producers, although it is a behemoth in the world of chemicals alone[161]).

SCOPE: In the detailed table below, we have aggregated all available information on what appear to be the top eight producers of plastics, plastic intermediates, and plastic precursors. We base ourselves on both the quantity of single-use plastics that they generate (Minderoo) and all available information on these companies' raw production of products such as, but not limited to:

- Ethylene, propylene, and C4 stream derivatives
- Benzene, toluene, and xylene
- Styrene monomer

[155] Minderoo, "Plastic Waste Makers Index 2021." Minderoo.
[156] Minderoo. "Plastic Waste Makers Index 2021," 2021. https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf
[157] Minderoo. "Plastic Waste Makers Index 2023," 2023. https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf.
[158] Unearthed. "Companies behind Campaign to 'End Plastic Waste' Produced 1,000 Times More Plastic than It Cleaned Up," November 20, 2024. https://unearthed.greenpeace.org/2024/11/20/alliance-to-end-plastic-waste-oil-chemical-exxon-shell-total/.
[159] Tilsted, Joachim Peter, and Fredric Bauer. "Connected We Stand: Lead Firm Ownership Ties in the Global Petrochemical Industry." Ecological Economics 224 (October 2024): 108261. https://doi.org/10.1016/j.ecolecon.2024.108261.
[160] BASF, "Petrochemicals: Major Nameplate Capacities of BASF," 2025, https://www.basf.com/basf/www/global/en/investors/calendar-and-publications/factbook/segments/chemicals/petrochemicals.
[161] Tilsted, Joachim Peter, and Fredric Bauer. "Connected We Stand: Lead Firm Ownership Ties in the Global Petrochemical Industry." Ecological Economics 224 (October 2024): 108261. https://doi.org/10.1016/j.ecolecon.2024.108261. According to this paper, BASF is the leading producer of chemicals by value, with over 66 billion USD in sales in 2019.

- Polyethylene (high-density/HDPE, low-density/LDPE, and linear low-density/LLDPE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS), and polyethylene terephthalate (PET) – types 1 through 6 plastics – as well as any type 7 plastics
- Polyester and acrylic fibres (we found no information on nylon or other fibres)
- Chemicals used in polymer production, such as vinyl acetate, ethylene glycol, ethylene oxide, terephthalic acid, PPPBP,[162] and others.

This is the scope of items retained in the calculation of total plastics, plastic intermediates, and plastic precursors; for brevity, we use the moniker "plastics/precursors" to refer to this scope. Note that we are not able to identify whether outputs of one company's business – in particular the olefin ethylene – are inputs into another company's business.

In the diagram below on top polymer producers, we have distinguished between companies that are integrated oil and gas/petrochemical companies (the majority), versus those companies that do not extract oil and gas.

- Five companies (Sinopec, ExxonMobil, INEOS, PetroChina, and Saudi Aramco) are integrated oil and gas companies. All are involved in converting oil and gas into plastic feedstock, HVCs, intermediates, and plastics; all but INEOS (to the best of our knowledge) also have an ethylene business.
- Three companies (Dow Chemical, LyondellBasell, and Chevron Phillips Chem (CPChem)) are not oil and gas extractors. They purchase either feedstocks or High Value Chemicals and transform them into ethylene, propylene, other intermediates, and/or plastics. For detail, see the table below.

Next to the line representing each company's activity by link in the value chain, we have given our best estimate of total plastics and plastic precursor production per annum (2021 or later), as well as a recap of the total Single-Use Plastic (SUP) footprint of each entity as found by Minderoo in its 2023 Plastic Waste Makers Index.[163]

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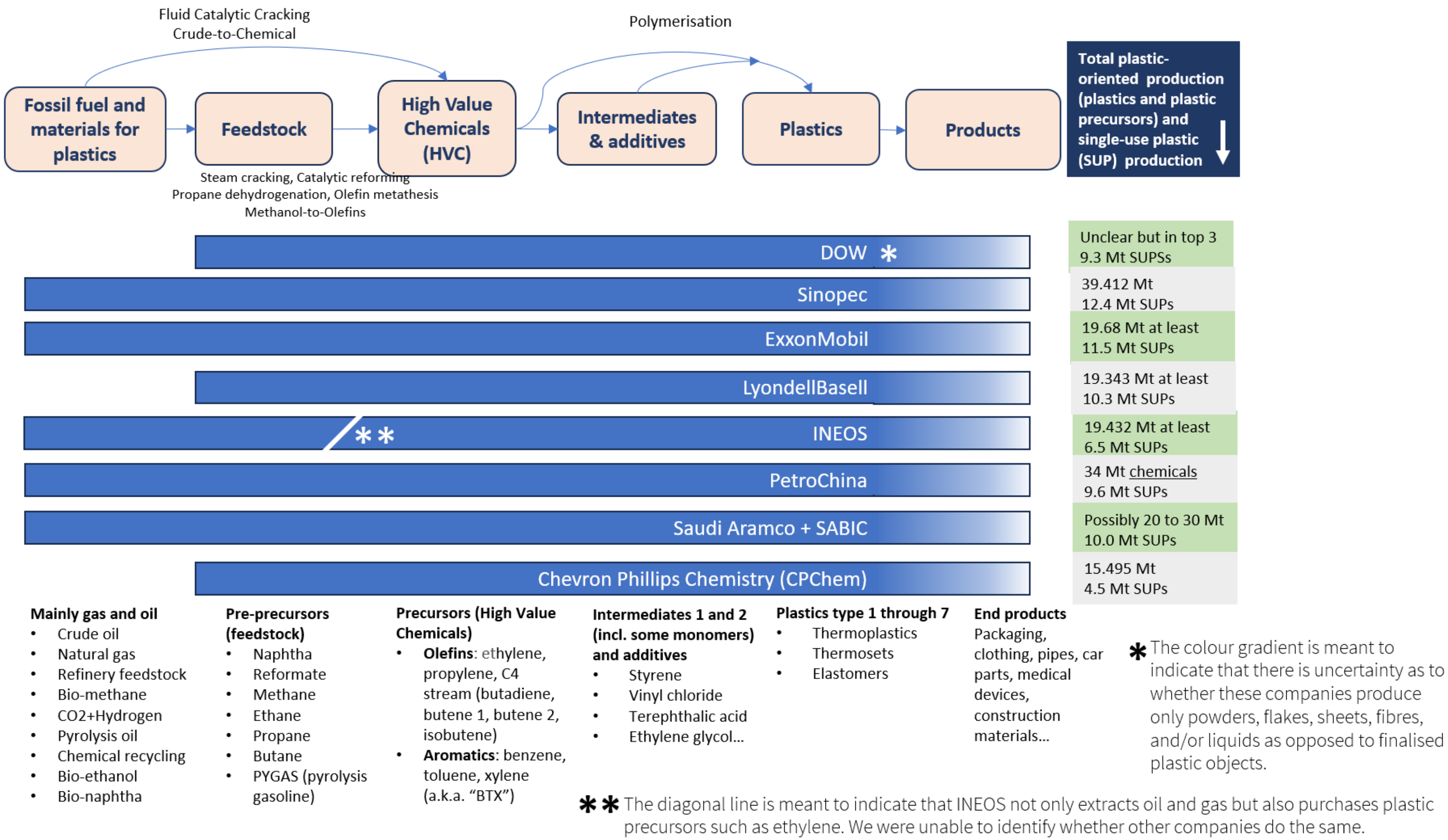
[162] PPPBP, or 2-phenyl-3,3-bis(4-hydroxyphenyl)phthalimidine, is a specialty chemical with several important applications in the polymer and materials industry, in particular as a flame retardant and a building block of polycarbonate. SABIC, "Specialty Bisphenols - PPPBP," 2025. General Electric Co, Process for purifying PPPBP, United States US7884220B2, filed March 19, 2007, and issued February 8, 2011, https://patents.google.com/patent/US7884220B2/en.

[163] Minderoo. "Plastic Waste Makers Index 2023," 2023. https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 49.

Figure 34. Top eight plastic/precursor producers



Source: BASIC, based on bibliographical research

4.2. Detailed company information

In the below table, we present the information we compiled to obtain the list of the top eight companies involved in plastic/precursors of all kinds (for the meaning of plastic/precursor, see scope bullet points above). Numbers are not perfect: Some figures are too high (such as PetroChina's information which is only "chemicals" of all kinds), some are too low (such as ExxonMobil, LyondellBasell, and Saudi Aramco, where not all businesses or processing facilities were able to be identified); others are missing (as with Dow, although we know it is a major player in plastics production). Only for INEOS, Sinopec, and CPChem are we relatively confident that the numbers cover all plastic/precursor production – for these three companies the source is the company itself and there are no major confusions as to product categories.

Company name	Type	Key production statistics	Ownership
Dow	(Petro)chemical only[164]	• 9.3 Mt single-use plastics[165] • Approximately 30 Mt polyethylene and polypropylene between 2019 and 2023[166], i.e. approximately 6 Mt per year • In 2023, packaging & Specialty Plastics generated $23.15B in revenue, representing 52.39% of its total revenue.[167]	• Based on publicly available information, we have been able to identify 35% of Dow Chemical's shareholders.[168] • Leading shareholders include Berkshire Hathaway (W. Buffett) (6.00%), Vanguard (5.72%), Capital World Investors (4.24%), State Street Corp. (4.09%), and BlackRock (2.98%)[169]
Sinopec Corp.	Integrated oil and gas[170]	• 12.4 Mt single-use plastics[171] • 39.412 Mt ethylene [prorated at 68%], synthetic resin, synthetic monomer and polymer, fibre, rubber (self-declared)[172]	• According to one source, fully owned by the state[173] • According to Sinopec, the state (the Sinopec Group) is only the "largest shareholder"[174]

[164] Browsing on their website, there is no mention of oil or gas extraction. Instead, they offer *products and "solutions"* for oil and gas companies. DOW Chemical. "Oil and Gas Production," 2024. https://www.dow.com/en-us/market/mkt-oil-gas-mining/sub-ogm-oil-gas-production.html.

[165] Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57

[166] Unearthed. "Companies behind Campaign to 'End Plastic Waste' Produced 1,000 Times More Plastic than It Cleaned Up," November 20, 2024. https://unearthed.greenpeace.org/2024/11/20/alliance-to-end-plastic-waste-oil-chemical-exxon-shell-total/.

[167] Bullfincher. "Dow Revenue Breakdown By Segment," 2024. https://www.bullfincher.io/companies/dow/revenue-by-segment.

[168] BFM Bourse. "Actionnaires de La Société Dow Chemical," 2025. https://www.tradingsat.com/dow-chemical-US2605431038/actionnariat.html.

[169] BFM Bourse. "Actionnaires de La Société Dow Chemical," 2025. https://www.tradingsat.com/dow-chemical-US2605431038/actionnariat.html.

[170] Minderoo. "Plastic Waste Makers Index 2021," 2021, https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf, Figure 7

[171] Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57

[172] We have retained all of these individual products as plastics or plastics precursors because this is the information available on the Sinopec website: Sinopec. "Products & Services," June 15, 2024. https://web.archive.org/web/20240615144559/http://spc.sinopec.com/spc/en/pro_service/. As for the figures on production: Sinopec. "Sinopec Delivered Promising 2024 Interim Results," August 25, 2024. http://www.sinopec.com/u/cms/gfyw/202411/29163404x6i0.pdf. Average of 2023 and 2024 data.

[173] Fitch Ratings. "China Petroleum & Chemical Corporation (Sinopec)," November 20, 2023. https://www.fitchratings.com/research/corporate-finance/china-petroleum-chemical-corporation-sinopec-20-11-2023.

[174] Sinopec. "Our Company | Sinopec Corp," 2024. http://www.sinopec.com/listco/en/000/000/041/41662.shtml. On this webpage, Sinopec Group, the parent entity, is described as "Funded by the State, it is a State authorised investment arm and State-owned controlling company."

ExxonMobil	Integrated oil and gas[175]	• 11.5 Mt single-use plastics[176]
		• Approximately 47 Mt polyethylene and polypropylene between 2019 and 2023,[177] i.e. approximately 9.4 Mt per year
		• In 2023 (these are the three chemicals listed p. 45):[178]
		  • 10.550 Mt ethylene → prorates to 7.714 Mt ethylene for LDPE and HDPE
		  • 9.520 Mt polyethylene
		  • 2.446 Mt polypropylene
		• "Exxon's new petrochemical complex in China is expected to open in 2025 and will bring at least 2.5 Mt of polyethylene and polypropylene capacity online."[179]
			• Based on publicly available information, we have been able to identify 37% of ExxonMobil's shareholders[180]
			• Leading shareholders include Vanguard (9.83%), BlackRock (5.76%), SSgA (5.05%), State Street Corp. (5.04%), and Fidelity (3.45%)[181]

PetroChina	Integrated oil and gas[182]	• 9.6 Mt single-use plastics[183] • "In 2023, we produced 34.308 million tons of chemical products in China."[184]	• PetroChina is controlled overwhelmingly by the State (94.81%), plus a handful of Chinese asset management firms[186]

[175] Minderoo. "Plastic Waste Makers Index 2021," 2021, https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf, igure 7
[176] Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57
[177] Unearthed. "Companies behind Campaign to 'End Plastic Waste' Produced 1,000 Times More Plastic than It Cleaned Up," November 20, 2024. https://unearthed.greenpeace.org/2024/11/20/alliance-to-end-plastic-waste-oil-chemical-exxon-shell-total/.
[178] ExxonMobil. "ExxonMobil: Financial and Operating Data 2023," 2024. https://d1io3yog0oux5.cloudfront.net/_bb54b6c8a6e86edf258b9b1b59128702/exxonmobil/files/491682/2023_Financial_and_Operating_Data_-_Final.pdf. Page 45
[179] Unearthed, https://unearthed.greenpeace.org/2024/11/20/alliance-to-end-plastic-waste-oil-chemical-exxon-shell-total/
[180] MarketScreener. "Exxon Mobil Corporation: Shareholders, Shareholding Structure," 2025. https://www.marketscreener.com/quote/stock/EXXON-MOBIL-CORPORATION-4822/company-shareholders/.
[181] MarketScreener. "Exxon Mobil Corporation: Shareholders, Shareholding Structure," 2025. https://www.marketscreener.com/quote/stock/EXXON-MOBIL-CORPORATION-4822/company-shareholders/.
[182] Minderoo. "Plastic Waste Makers Index 2021," 2021, https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf, Figure 7
[183] Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57
[184] PetroChina. "PetroChina Environmental, Social, and Governance Report 2023," 2024. https://www.hkexnews.hk/listedco/listconews/sehk/2024/0325/2024032501707.pdf.
[186] MarketScreener. "PetroChina Company Limited: Shareholders, Shareholding Structure," 2025. https://www.marketscreener.com/quote/stock/PETROCHINA-COMPANY-LIMITE-6499999/company-shareholders/.

		• "In 2019, we produced 25.756 million tons of chemical products and 5.863 million tons of ethylene"[185]	
LyondellBasell	(Petro)chemical only[187]	• 10.3 Mt single-use plastics[188] • 4% of world's 206 Mt ethylene capacity in 2021 = 8.24 Mt[189] * 68% = 5.603 Mt • 6% of world's 229 Mt PE + PP capacity in 2021 = 13.74 Mt[190]	• Based on publicly available information, we have been able to identify 54% of LyondellBasell's shareholders[191] • Leading shareholders include Access Industries (20.10%), Vanguard (9.78%), BlackRock (5.77%), Dodge & Cox (4.96%), and State Street Corp (3.76%)[192]
INEOS	Integrated oil and gas[193] but also purchases High Value Chemicals[194]	• 6.5 Mt single-use plastics[195] • 19.432 Mt plastics and plastic precursors[196] (no ethylene listed)	• All shareholders are individuals: founder James Ratcliffe (61.3%) alongside Andrew Currie (19.19%) and John Reece (19.08%)[197]

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185 PetroChina. "PetroChina Environmental, Social, and Governance Report 2019," 2020. https://www.petrochina.com.cn/ptr/xhtml/images/2019kcxfzbgen.pdf

187 Minderoo. "Plastic Waste Makers Index 2021," 2021, https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf, Figure 7

188 Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57

189 LyondellBasell. "LyondellBasell Data Book 2021," 2022. https://www.lyondellbasell.com/4a521e/globalassets/investors/data-book-2021.pdf, page 20

190 LyondellBasell. "LyondellBasell Data Book 2021," 2022. https://www.lyondellbasell.com/4a521e/globalassets/investors/data-book-2021.pdf, page 20

191 MarketScreener. "LyondellBasell Industries N.V.: Shareholders, Shareholding Structure," 2025. https://www.marketscreener.com/quote/stock/LYONDELLBASELL-INDUSTRIES-6742278/company-shareholders/.

192 MarketScreener. "LyondellBasell Industries N.V.: Shareholders, Shareholding Structure," 2025. https://www.marketscreener.com/quote/stock/LYONDELLBASELL-INDUSTRIES-6742278/company-shareholders/.

193 INEOS. "Oil and Gas," 2024. https://www.ineos.com/businesses/ineos-energy/oil-and-gas/.

194 INEOS may not be the only company that does this – it occurs when an oil/gas source operated by another company is near a petrochemical plant. In this case, INEOS purchases ethylene for its chemical production but also extracts oil and gas (it is unclear whether this oil and gas extraction leads directly to High Value Chemical production. Here, we have made the assumption that it does, at least in part. Whatever the answer to this question, it does not affect our statistics on production of petrochemicals). INEOS. "Ineos Quattro Annual Report 2023," 2024. https://www.ineos.com/globalassets/investor-quattro-ir/public/annual-reports/ineos-quattro-annual-report-2023.pdf, page 13

195 Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57

196 INEOS. "Ineos Quattro Annual Report 2023," 2024. https://www.ineos.com/globalassets/investor-quattro-ir/public/annual-reports/ineos-quattro-annual-report-2023.pdf, page 66

197 INEOS. "INEOS Group Holdings 2023 Annual Report," 2024. https://www.ineos.com/globalassets/investor-relations/public/annual-reports/annual-report-blocks/ineos-group-holdings-s.a._audit-report-conso_2023_signed.pdf, page 106

Saudi Aramco	Integrated oil and gas[198]	10.0 Mt single-use plastics[199] • In 2022, Saudi Arabia was the world's largest exporter of polypropylene both in terms of value ($6.2 billion) and quantity (4.9 million tons).[200] *Note: not all of this is Aramco alone, there are a variety of joint ventures involving Saudi Aramco. Sipchem only produces 0.45 Mt,[201], Tasnee produces 0.455 Mt.[202]* • Joint venture with Total; the Amiral petrochemical complex = 1.65 Mt/year ethylene in 2027[203]. "It will also include two state-of-the-art polyethylene units using Advanced Dual Loop technology, a butadiene extraction unit, and other associated derivatives units."[204] • PetroRabigh (joint venture with Japan)[205]: 1.965 Mt polymers+ 1.340 Mt para xylene	• Based on publicly available information, we have been able to identify 97% of Saudi Aramco's shareholders[212] • In Aramco's lates official statistics (2024), the Government of Saudi Arabia controls 97.62% of issued shares.[213], [214]

[198] Minderoo. "Plastic Waste Makers Index 2021," 2021, https://cdn.minderoo.org/content/uploads/2021/05/27094234/20211105-Plastic-Waste-Makers-Index.pdf, Figure 7
[199] Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57
[200] Plastics Industry Association. "A Conversation on Trade with Saudi Arabia: Economic Insights, Energy, and Plastics," May 2, 2024. https://www.plasticsindustry.org/blog/a-conversation-on-trade-with-saudi-arabia-economic-insights-energy-and-plastics/.
[201] According to an article on IAFES, Sipchem produces 450 000 tonnes of polypropylene annually, with another acquisition aiming to produce 2.2 Mt/year plastic precursors. IAFES. "SABIC Expands Propylene and Polypropylene Plants," August 27, 2024. https://sbhcenter.com/en/news/sabic-expands-propylene-and-polypropylene-plants/. And MEED. "Jacobs Wins Saudi Petrochemicals Contract," July 18, 2016. https://www.meed.com/jacobs-wins-saudi-petrochemicals-contract.
[202] Tasnee. "Petrochemicals | Tasnee," 2025. https://www.tasnee.com/en/products/petrochemicals.
[203] Total Energies. "Amiral: A Petrochemical Complex Integrated With the SATORP Refinery," February 6, 2025. https://totalenergies.com/company/projects/oil/amiral-petrochemical-complex-integrated-satorp-refinery.
[204] Total Energies. "Aramco and TotalEnergies to Build a Giant Petrochemical Complex in Saudi Arabia," December 15, 2022. https://totalenergies.com/media/news/press-releases/aramco-and-totalenergies-build-giant-petrochemical-complex-saudi-arabia.
[205] Petro Rabigh. "Petro Rabigh - Products," 2024. https://www.petrorabigh.com/en/OurProducts/Polymer.
[212] Aramco. "Saudi Aramco Announces Breakdown of Shareholding Post Allocation," June 9, 2024. https://www.aramco.com/en/news-media/news/2024/saudi-aramco-announces-breakdown-of-shareholding-post-allocation.
[213] Aramco. "Saudi Aramco Announces Breakdown of Shareholding Post Allocation," June 9, 2024. https://www.aramco.com/en/news-media/news/2024/saudi-aramco-announces-breakdown-of-shareholding-post-allocation.
[214] Other statistics from MarketScreneer: Lead shareholders are the Government of Saudi Arabia (81.48%) and "Public Investment Fund" (unidentified – 16%). MarketScreener. "Aramco: Shareholders, Shareholding Structure," 2025. https://www.marketscreener.com/quote/stock/ARAMCO-103505448/company-shareholders/.

		• Sadara: 70% Stake in 3 Mt chemicals, polyethylene and polyurethane[206]
		• SATORP: 62.5% stake; produces “22 million tons of refined petroleum products, including 700,000 tons of paraxylene, 150,000 tons of benzene and 210,000 tons of high-purity propylene.”[207]
		• SABIC: 4.01 Mt polyethylene and 6.11 Mt “performance polymers and industrial solutions”[208]
		  ◦ “In the year ended 31 December 2022, SABIC’s total production was 61.4 million tonnes, 47.9 million tonnes, or 78.0 per cent., of which was produced by its petrochemicals division, compared to a total production of 58.2 million tonnes in the year ended 31 December 2021, 45.9 million tonnes, or 78.9per cent., of which was produced by its petrochemicals division.”[209]
		  ◦ See website of SABIC for their intermediates and other solutions[210]
		  ◦ *Remark: Saudi Aramco owns 70% of SABIC.*[211]
		• Summary, post prorating:
		  ◦ Known plastic-precursor and polymer production is at a minimum 14.582 Mt
		  ◦ But the above statement suggests that production is significantly higher (both SABIC’s 47.9 Mt petrochemicals	

[206] “Products - Sadara.” Accessed February 7, 2025. https://www.sadara.com/Home/ProductsHome/Products. And Sadara. “ISO 50001 Energy Management System – 2024 Case Study,” 2024.
[207] Total Energies, “SATORP: An Exceptional Partnership,” February 12, 2025, https://totalenergies.com/energy-expertise/projects/refining-petrochemical-platform/satorp.
[208] SABIC. “SABIC Annual Report 2021,” 2021. https://www.sabic.com/en/reports/annual-2021/our-businesses/petrochemicals.
[209] Kingdom of Saudi Arabia. “Ministry of Finance - Global Medium Term Note Programme,” 2023. https://ndmc.gov.sa/IssuancePrograms/Documents/KSA%20GMTN%20Programme%20-%20Final%20Offering%20Circular%20(8%20Jan%202024)%20(1).pdf, page 174
[210] SABIC. “Sabic: Products,” 2024. https://www.sabic.com/en/products.
[211] SABIC. “Saudi Basic Industries Corporation (SABIC) Announces the Completion of Saudi Aramco Acquisition of Public Investment Fund (PIF) Stake in (SABIC),” June 21, 2020. https://www.sabic.com/en/news/23759-sabic-announces-the-completion-of-saudi-aramco-acquisition-of-public-investment-fund.

		and SATORP's 22 Mt must include a significant share of plastics and plastic precursors). Prorated at 70% Aramco ownership, 47.9 Mt becomes 33.53 Mt, and SATORP's 22 Mt prorated at 62.5% becomes 13.75 Mt, in addition to the 6.43 Mt non-SABIC and non-STORP Aramco projects	

Chevron Phillips Chemical (CPChem)	(Petro)chemicals only	• CPChem: 15.492 Mt High Value Chemicals and plastics[215]
		• The companies listed in Minderoo's table of companies do not include CPChem. Instead there is information[216] on CPChem's two owners, Chevron and Philipps 66[217]
		  • "Chevron Corporation" – 2.2 Mt single-use plastics
		  • "Phillips 66" (50% owned by Chevron) – 2.3 Mt single-use plastics
			• Ownership 50% Chevron, 50% Phillips 66.[218]
			• Based on publicly available information, we have been able to identify 40% of Chevron's shareholders and 38% of Phillips 66's shareholders[219]
			• Leading shareholders in Chevron are State Street Corp. (8.85%), Vanguard (8.82%), Berkshire Hathaway (W. Buffett) (6.60%), BlackRock (5.83%), and Goede (2.00%)
			• Leading shareholders in Philipps 66 are Vanguard (9.86%), State Street Corp. (6.74%), BlackRock (6.01%), Wells Fargo (4.28%), and Harris Associates LP (2.37%=

[215] CP Chem, "CPChem Form 10K - 2022," December 31, 2022, https://d18rn0p25nwr6d.cloudfront.net/CIK-0001534701/e2080215-7673-4558-8cd4-c4017d219032.pdf., page 12. Our figure (15.495 Mt) is slightly lower than IEEFA's (38 780 000 lbs = 17 590 Mt) because we prorated ethylene at 68%.

[216] Minderoo, "Plastic waste makers index 2023," 2023, https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf, page 57

[217] "We are a limited liability company formed in 2000 under Delaware law, and we are owned 50 percent by Chevron U.S.A. Inc. (Chevron), an indirect wholly owned subsidiary of Chevron Corporation, and 50 percent by Phillips 66 Company (P66Co), a wholly owned subsidiary of Phillips 66." Chevron Phillips Chemical. "Financials," 2025. https://www.cpchem.com/who-we-are/financials.

[218] Chevron Phillips Chemical. "Financials," 2025. https://www.cpchem.com/who-we-are/financials.

[219] MarketScreener. "Phillips 66: Shareholders Board Members Managers and Company Profile," 2025. https://www.marketscreener.com/quote/stock/PHILLIPS-66-10447684/company-shareholders/.

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