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# PETROCHEMICALS
## – CHALLENGES, SOLUTIONS AND THE FUTURE

Warsaw 2019

# PETROCHEMICALS
## – CHALLENGES, SOLUTIONS AND THE FUTURE

This report was prepared by the Strategy and Investor Relations Department, the Development and Technology Department, and the Corporate Communication Department of PKN ORLEN S.A.

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# Petrochemicals: facts and myths

We live in a world dominated by plastics – almost everything we use in our everyday lives is made of plastic or contains plastic components. Accumulation of plastic waste has turned into a serious environmental problem that is not easy to tackle and will take time to solve. The intensity of emotions it arouses has been growing faster than understanding of how to get rid of plastic waste with benefit for the environment and the climate. Science and the petrochemical industry have been looking for long-term strategies in which advantages outweigh the downsides. Such strategies need to be based on a proper diagnosis of the problem. However, even though petrochemical production is a fast-growing branch of industry, knowledge of the subject is quite hermetic and its level is rising much slower than emotions. At PKN ORLEN, we have specialist knowledge of petrochemicals: we monitor the latest scientific developments in the area and base our business strategies on their findings. We have prepared this report in order to share this knowledge and get the discussion about plastics on the right track, because intuitive solutions, such as banning plastic production altogether, are only seemingly beneficial.

**Myth. There is good plastic and bad plastic. Good plastic can be found in syringes, bad plastic is used to make disposable bags.**

**Fact.** The distinction between bad (waste-generating) and good (reusable and recyclable) plastic is not based on differences between the types of material but rather on the end products it is used to manufacture and on how those end products are applied. Good plastic is one in the case of which benefits to the public exceed the environmental costs, while bad plastic is the opposite. Polyethylene used in the production of vacuum packaging for meat will be 'good' because it will lead to less food being thrown away, which means that less food will need to be produced in one of the most emission-intensive sectors of the economy – cattle breeding. Conversely, polyethylene in a disposable bag will be 'bad,' especially when it ends up in the ocean instead of being recycled.

For more information on the use of plastics in everyday life, see pp. 10-12.

**Myth. Bio-based plastics (bioplastics) are biodegradable.**

**Fact.** Not every bio-based plastic is biodegradable and not every biodegradable plastic is of biological origin. Bio-PE is an example of non-biodegradable plastic produced from renewable sources. Polyethylene, conventionally produced from fossil resources, can also be made from ethanol, and ethanol can be made from sugar cane, sugar beet or wheat. Ethanol-based polyethylene has exactly the same properties as its fossil-based equivalent, including non-biodegradability. Furthermore, bio-based plastics which are classified as biodegradable do not always decompose in the natural environment. PLA (polylactide, obtained mainly from corn starch and widely used as an alternative to conventional plastic cups and straws) needs a temperature of more than 50°C, high humidity, and the presence of microorganisms to degrade – under such conditions it will decompose in six weeks.

However, under room conditions the process will take hundreds of years.

For more information about bioplastics, see pp. 26-27.

**Myth. A paper bag is better for the environment than a plastic bag.**

**Fact.** The production of each of those bags leaves a trail of emissions and pollution in the natural environment. According to various studies, a paper bag would need to be used between 5 and 44 times in order to have a lower environmental impact than a single use of a disposable plastic bag.

For more information about alternatives to plastic bags, see p. 24.

**Myth. Banning the production of plastics will solve the problem of plastic waste.**

**Fact.** Waste is what we throw away, not what we produce. The solution to the problem of plastic, or in fact any waste, could be its reusing, properly collecting and recycling, i.e. transition from the linear to the circular economy. Responsibility for plastic waste lies not only with the producer of the plastic (who can reduce emission levels and the environmental impact of its production), but also with the manufacturer of the end product (whose task should be to design the product appropriately), the general public (who should demand only 'good' plastic), and local authorities (who should put in place appropriate waste collection and selection systems).

For more information on the circular economy concept, see pp. 32-33.

**Myth. We can live without plastic.**

**Fact.** The invention of plastic facilitated emergence of many technologies which are essential for modern civilization. Without plastics, the developments in the field of electronics, for example, would be completely different. The use of plastics affects more than just the visual appearance of our home electronics – it also ensures their safety because of electrical and thermal insulation, as well as quiet operation. Thanks to plastics, electric and electronic devices are lightweight and portable. Plastics also made it possible to create e.g. printed circuit board (used in assembling electronic components) and CDs.

For more information about living without plastic, see pp. 24-25.

**Myth. Plastics obtained from bio-components instead of petroleum are more climate- and nature-friendly.**

**Fact.** The use of bio-based feedstocks limits emissions of greenhouse gases in the full life cycle of the product, however bio-chemistry has a serious drawback of generating environmental costs in other areas (mainly soil and water pollution). Plastics made from bio-based feedstocks do not solve the problem of waste, either. Bio-chemistry is a transitional solution, which may be useful in the energy transition period when the availability of 'green energy' is limited. However, technological progress opens the way to thinking about zero-emission petrochemicals, based on the use of renewable energy and $CO_2$ capture and use (CCU). Moreover, the production of first-generation biocomponents competes with the production of food: the larger their production, the greater the probability of reduced food supplies. So by switching to first-generation chemicals , we only substitute one social problem for another, and a more serious one: hunger.

For more information on bio-based alternatives to everyday items made of plastic, see pp. 27-28.

**Myth. Petrochemical production based on crude oil has no future because of pollutant emissions.**

**Fact.** With the development of civilization, the demand for and the share of materials derived from crude oil and natural gas has been growing. Oil and gas are two widely available commodities that we can extract from underground deposits and process into usable products in a way that is less harmful to the environment and climate than is the case with other raw materials. Oil and gas are too useful to be given up. Given the current state of technology, oil and gas cannot be replaced by anything more environmentally friendly to produce the amount of materials needed by humans.

For more information on the future of petrochemical production, see pp. 34-39.

**Myth. The European petrochemical industry, which relies on crude oil, is less competitive than the gas-based petrochemical industry being developed in the US.**

**Fact.** In Europe, there are favourable conditions for growth of the petrochemicals industry. The relationship between oil and gas prices will be changing in favour of oil due to the long-term growth of demand for gas from the energy sector.

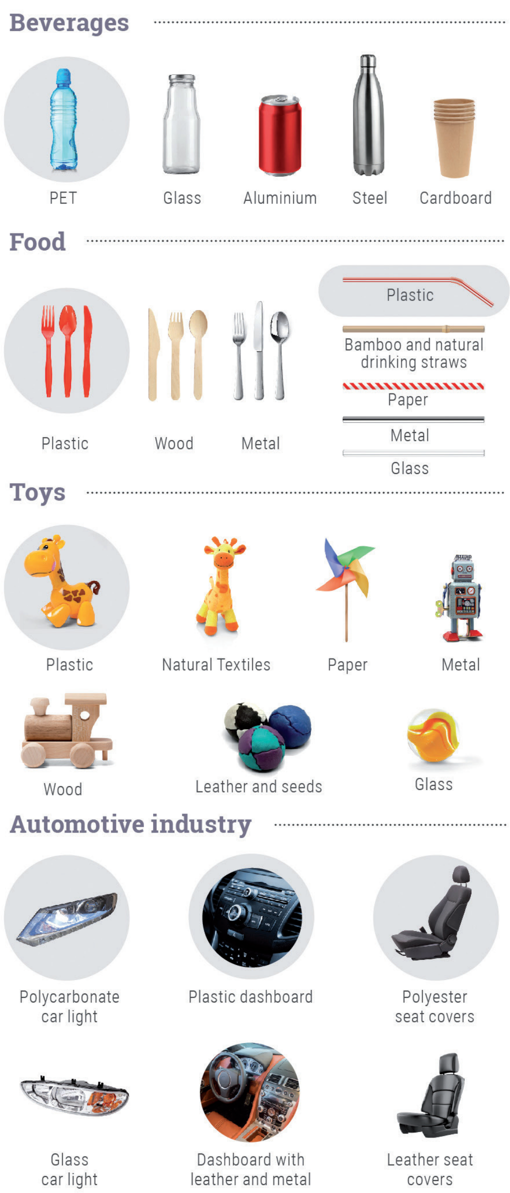
For more information on the profitability of petrochemical operations in Europe, see p. 40.

**Myth. Only High Value Petrochemicals have a future.**

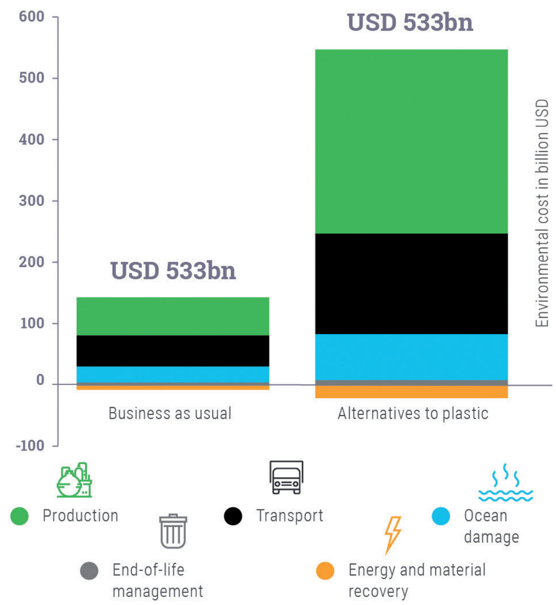
**Fact.** In the petrochemicals business, profits can be made by taking advantage of supply-demand gaps (in the case of production of base petrochemicals) or by offering new materials (protected by patents and licences). The first path is available to us immediately, the second one could open up in 10 to 15 years, provided that we gain various tools, including support from the Research and Development Centre in Płock which is currently being developed.

## What are the alternatives to plastic?

Plastics are used in virtually all areas of life, starting from packaging, through everyday items, to end with building and car parts. Most of those plastics could be replaced by alternative materials, such as glass, metals, paper, wood, natural textiles and leather.




**Contrary to popular belief, replacement of plastics with alternative materials would increase the environmental cost by 280%. The increase would be observed at every stage of the product life cycle.**




Despite the marginally lower environmental cost of alternative materials, substituting them for plastics would generate larger total cost to the environment. This would be due to higher required amounts of alternative materials compared with lightweight and durable plastics – we need on average 4.1 tonnes of metal, glass, paper, wood and other natural materials to replace one tonne of plastic.


Source: In-house analysis based on Trucost, *Plastics and Sustainability: A Valuation of Environmental Benefits, Costs and Opportunities for Continuous Improvement*, https://plastics.americanchemistry.com/Plastics-and-Sustainability.pdf (July 8th 2019).

## How to read this report?

This report is organised into three parts: **Challenges**, **Solutions** and **The future**. Apart from the main body of text, each of them contains grey boxes with term definitions and pink boxes filled with interesting facts.

The first part (**Challenges**) lists the areas of everyday life where petrochemical products are used and explains how the problem of plastic waste originated and how we are tackling it. This part opens with a brief history of petrochemicals, where the reader can learn about concepts such as petrochemicals, hydrocarbons and monomers. The difference between petrochemical products and plastics is discussed. This part also presents the areas of our everyday lives where we use petrochemicals, often without knowing it, and the wide range of products that can be obtained from a single barrel of oil. It explains what happened to all plastic produced since it was invented, and outlines the problem of disposable plastics, including plastic packaging, and microplastics. It further describes the environmental damage caused by the manufacture and disposal of various types of plastic and the new social movement that has led to the creation of plastic waste regulations.

The second part (**Solutions**) presents the possible ways of tackling the identified problems and potential environmental impacts of replacing plastic with alternative materials. Options for replacing petrochemical raw materials and fertilizers are also presented, along with an alternative solution – sustainable development, as well as potential benefits of manufacturing process improvements and closed-loop economy.

The final part of the report (**The future**) presents the outlook for the petrochemical industry in Poland, Europe and globally. It also explains the reasons why demand for petrochemical products is rising around the world and outlines the future of the petrochemical markets in Poland and the rest of Europe.

# Part 1. Challenges

USEFUL PRODUCTS AND HARMFUL WASTE. HOW TO KEEP THE FORMER AND GET RID OF THE LATTER?

## We live in the era of petrochemicals

The history of modern petrochemical industry dates back to 1835, when the French chemist and physicist Henri Victor Regnault discovered poly(vinyl chloride) – a material widely used today in window and door frames as well as other applications. But it was not until 74 years later that the first mass-produced plastic called Bakelite was invented, and the advancement of the petrochemical industry began to gather pace only in the 1950s[1]. The industry has grown tenfold since 1970, faster than any other manufacturing sector, surpassing world GDP growth by 60%. In 2017, 14% of crude oil and 8% of natural gas was used to produce petrochemicals[2]. The chemical industry today generates nearly EUR 3,500bn in sales revenue[3], 15 times more than the electronics giant Apple, and petrochemical products accompany us in every area of life.

### WHAT ARE PETROCHEMICALS AND ARE ALL PETROCHEMICALS PLASTICS?

Simply put, petrochemicals are chemical products derived from oil, natural gas or coal, excluding fuels. Petrochemical raw materials are used to produce a wide range of other chemicals and comprise linear hydrocarbons (ethylene, propylene, butadiene), cyclic hydrocarbons (benzene, phenol), as well as synthesis gas (a mixture of gases, mainly hydrogen and carbon monoxide) and inorganic chemicals, such as ammonia and sulphur. In many cases, substances considered as petrochemicals can be obtained from other sources, including plants and animals[4].

**Chemical industry** is a branch of the manufacturing sector where the basic manufacturing processes are of a chemical nature.

**Petrochemical industry** comprises the manufacturing and converting chemical raw materials derived from crude oil, natural gas and coal.

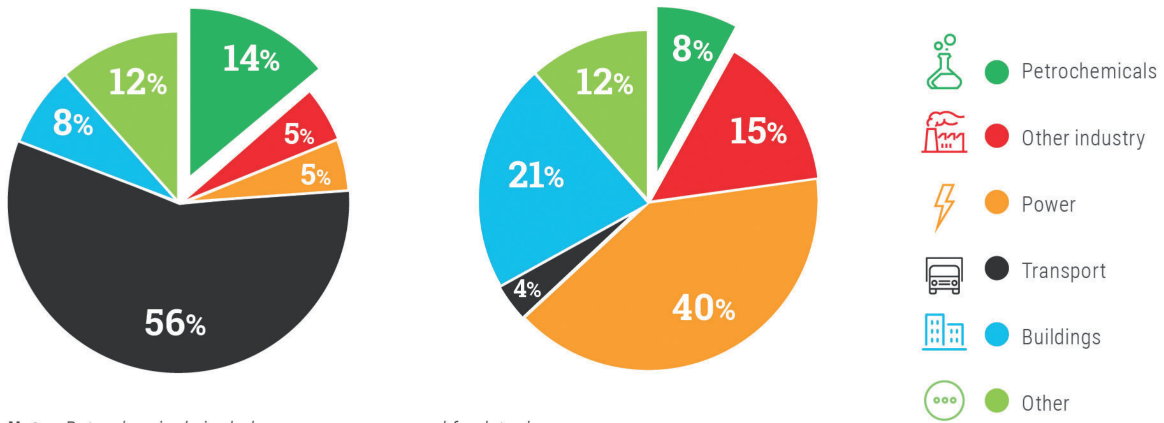
1 World Petroleum Council Guide, *World Petroleum Council Guide: Petrochemicals and Refining*, http://www.world-petroleum.org/docs/docs/publications/petrochemicals/ wpc-guide2_layout_lo-res.pdf (July 12th 2019).

2 International Energy Agency, *The Future of Petrochemicals: Towards more sustainable plastics and fertilisers*, https://webstore.iea.org/download/direct/2310?fileName- =The_Future_of_Petrochemicals.pdf (July 18th 2019).

3 Center for International Environmental Law, *Facts & Figures of the European chemical industry 2018*, https://cefic.org/app/uploads/2018/12/Cefic_FactsAnd_Figures_2018_ Industrial_BROCHURE_TRADE.pdf (July 12th 2019).

4 Encyclopaedia Britannica, *Petrochemical*, https://www.britannica.com/science/petrochemical (July 15th 2019).

**Primary oil (left) and natural gas (right) demand in 2017 by sector**




**Note:** *Petrochemicals includes process energy and feedstock.*

Source: In-house analysis based on International Energy Agency, op.cit.

**Organic compounds** are chemical compounds containing carbon, excluding carbon oxides and sulphides, carbonic acid and its inorganic derivatives, metal carbides, hydrogen cyanide, cyanamide and cyanic acid and their inorganic salts, and metal carbonyls.

**Inorganic compounds** are chemical compounds of any element other than carbon and the inorganic carbon compounds listed above.

**Hydrocarbons** are organic compounds with molecules made up exclusively of carbon and hydrogen atoms. There are aliphatic (chain) hydrocarbons, in which carbon atoms form open chains (linear or branched), and cyclic hydrocarbons, in which carbon atoms form rings.

Source: PWN Encyclopedia.

Thus, plastics are just a part of a larger petrochemical product group, which also includes detergents, solvents, pharmaceuticals, fertilisers and crop protection products, as well as synthetic fibres, synthetic rubber, and elastomers.

## WHAT ARE PLASTICS?

Plastic is a polymeric material, which is built of repetitive parts, called monomers, and which has the capability of being molded or shaped, usually by the application of heat and pressure. Most plastics are characterised by low density, low electrical conductivity, high strength and transparency[5]. Plastics are divided into two groups – thermoplastics and thermosets. The former melt when heated and harden when cooled. The molding of thermoplastics is reversible – they can be heated, remolded and cooled again. Thermosets, on the other hand, undergo irreversible chemical changes when heated and develop a lattice structure[6].

**Monomer** is a molecule of any of a class of compounds, mostly organic, that can react with other molecules to form **polymers.**

## PETROCHEMICALS IN OUR DAILY LIVES

Petrochemical products are used in every area of our lives. The buildings in which we live are insulated with polystyrene, commonly known as styrofoam, or polyurethane foams. Window and door frames are increasingly made of poly(vinyl chloride), and the materials used to make glazing gaskets include synthetic rubber, thermoplastic elastomers or plasticised PVC. Petrochemicals not only contribute

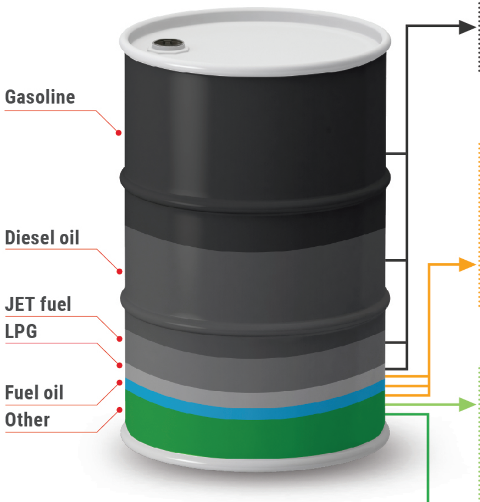
5 Encyclopaedia Britannica, Plastic, https://www.britannica.com/science/plastic (July 15th 2019).

6 United Nations Environment, Single-Use Plastics, A Roadmap for Sustainability, https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustaina- bility.pdf?isAllowed=y&sequence=1 (July 15th 2019).

# What's in a barrel of oil?

Crude oil is a mixture of hydrocarbons. Having been purified of sulfur and other compounds, oil is distilled into hydrocarbon fractions with different properties. These fractions, or products of their further processing, become commercial products.
**Thus, fuels, kerosene, fuel oils, lubricating oils, slack wax, bitumens, coke and solid lubricants are manufactured at the same time.**

## What can you get simultaneously from a barrel of oil?




### Fuels

**80 km** distance travelled by a truck fuelled with diesel oil including the JET fraction

**450 km** distance travelled by a passenger car fuelled with gasoline

### Energy

**12** small bottles of propane

**about 1,8 kg** of charcoal briquette

**70 kWh** of electricity

### Other

**4.5 l** of motor oil

**3785 cm³** of asphalt

### Petrochemicals

Apart from the production of fuels, energy carriers and asphalts, crude oil refining leads to the distillation of the naphtha fraction that is used for the manufacture of petrochemicals. **From one barrel of oil, apart from above mentioned products, we can simultaneously obtain the following:**

**39** polyester shirts

**750** pocket combs

**540** toothbrushes

**170** birthday candles

**65** plastic cups

**65** brush and dustpan sets

**11** routers

**23** hula hoops

**195** measuring cups

**135** four-inch rubber balls

Source: In-house analysis based on International Energy Agency, op. cit.; Petroleum Service Company, *What's in a Barrel of Oil? The 42- Gallon Breakdown*, https://petroleumservi- cecompany.com/blog/oil- barrel-42-gallon-breakdown/ (July 18th 2019) and Visual Capitalist, What Can Be Made from One Barrel of Oil?, https://www.visualcapitalist.com/can-made -one -barrel-oil/ (July 17th 2019).

## Two categories of plastics

### Thermoplastics

The most common Thermoplastics are:

| | |
|---|---|
| **(PET)** | polyethylene terephatale |
| **(PE)** | low density polyethylene |
| **(LDPE)** | low density polyethylene |
| **(HDPE)** | high density polyethylene |
| **(PS)** | polystyrene |
| **(EPS)** | expanded polystyrene |
| **(PVC)** | poly(vinyl chloride) |
| **(PP)** | polypropylene |
| **(PLA)** | polyactic acid |
| **(PHA)** | polyhydroxyalkanoates |

### Thermosets

The most common Thermosets are:

| | |
|---|---|
| **(PUR)** | polyurethane |
| | phenolic resins |
| | epoxy resins |
| | silicone |
| | vinyl ester |
| | acrylic resins |
| **(UF)** | ureaformaldehyde resins |

Source: In-house analysis based on United Nations Environment, op. cit.

**On average, every car contains 10,000 plastic parts, which account for 50% of the vehicle volume, but only 10% of its weight.**

Source: American Fuel & Petrochemical Manufacturers, How Much Oil is in an Electric Vehicle?, https://www.visualcapitalist.com/ how-much-oil-electric-vehicle/ (July 17th 2019), and Plastics Industry Association, Plastics Market Watch Transportation A Series On Economic - Demographic Consumer & Technology Trends In Specific Plastics End Market, https://www.plasticsindustry.org/sites/ default/files/2019-TransportationMarketWatch.pdf (July 25th 2019).

to the thermal comfort in our homes, but also ensure the supply of running water and electricity. Both water pipes and insulation of electrical wires, those in the home wiring and in power cables of household appliances and TV and radio sets, are made of polyethylene. The appliances and sets themselves are at least enclosed in plastic. Furniture, even wooden furniture, also contains petrochemical products. Varnishes, paints and adhesives, mattresses and upholstery – all contain petrochemicals. Similarly, in our cars we can find a broad range of such compounds – from organic carbonates in batteries, polypropylene bumpers, styrene-butadiene tyres, polycarbonate headlights, to polyurethane seats and polyamide safety belts. The average content of petrochemical products in vehicles is constantly increasing. As recently as in 1960, an average American passenger car contained 8 kg of plastics and composites. In 2016, the amountwas almost 19-fold higher, at 151 kg[7].

Petrochemicals also play a big role in our everyday lives. Artificial fertilisers allow us to produce food in the right amounts, and plastic packaging extends its shelf life. Also some food colourings and flavourings are manufactured with use of petrochemicals. Petrochemicals are used in cosmetics and cleaning products, and all household chemicals are packaged in polyethylene or PET. Polyester, nylon or spandex are materials commonly used in the production of clothing and all of them are of petrochemical origin. The contemporary pharmacy would not have been possible without petrochemicals either – phenol and cumene are used in the production of penicillin and aspirin, and the use of petrochemical resins has enabled cheaper and faster drug purification. Petrochemicals made it possible to develop air-tight packaging for pharmaceuticals. Other applications in medicine include the manufacture of syringes and insulin pumps.

The widespread use of petrochemical products in our everyday lives and environment is made possible by the following two factors: their physical and chemical properties, which make them suitable for various applications, and low manufacturing costs when compared with alternative solutions. Plastic products are so cheap that there is no sufficient economic incentive for reusing or recycling many of them. This situation has led to an accumulation of waste on a scale requiring radical measures. Let us take a closer look at the problem.

## We live in the era of plastic waste

Plastics have become an integral part of our lives, and along with them, plastic waste has emerged. Research shows that since the 1950s, when petrochemistry as we know it today is said to have been born, 8.3 billion tonnes of plastic have been produced, of which about 30% is still in use[8]. The remaining 70% is simply waste. Each piece of plastic waste can be disposed of in three ways: stored (legally landfilled or illegally dumped), incinerated or recycled.

7 Plastics Industry Association, op. cit.

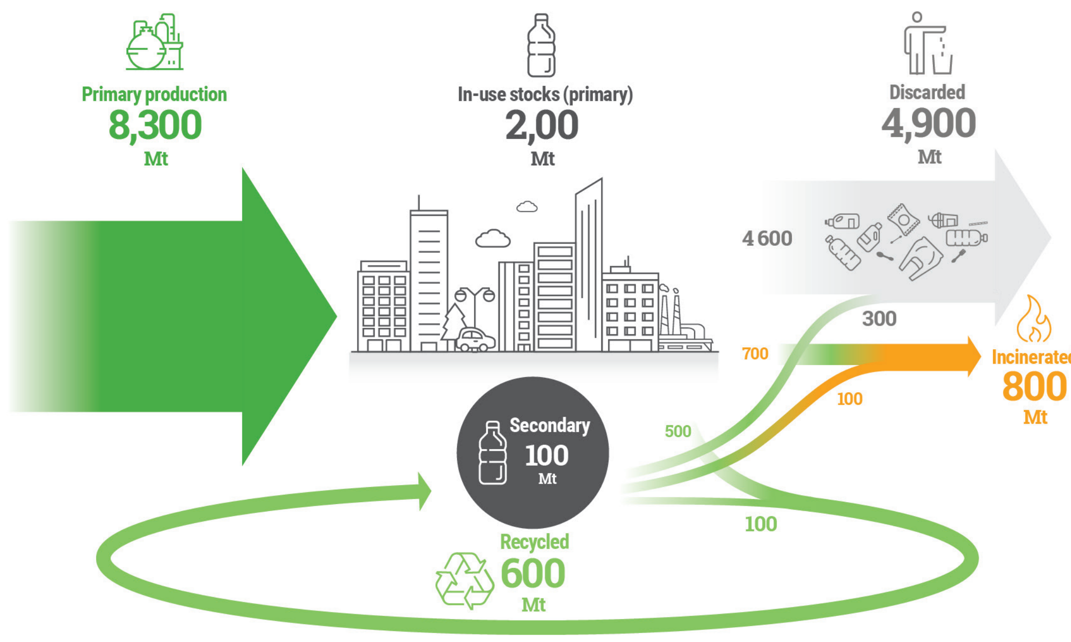
8 United Nations Environment & Beat Plastic Pollution, *Our planet is drowning in plastic pollution*, https://www.unenvironment.org/interactive/beat-plastic-pollution/ (July 15th 2019).

The recycling process will result in obtaining new products, and each of them will suffer a similar fate to that of the 'primary' waste – recycled waste can be landfilled, incinerated or recycled again. The graphic below shows what has happened to every tonne of plastic produced.

**In 1960, plastic waste accounted for less than 1% of all municipal waste in mid- and high-income countries. The figure went up to 10% in 2005, with a parallel increase in the total weight of waste.**

Source: R. Geyer, J. R. Jambeck, K. L. Law, Production, use, and fate of all plastics ever made, https://advances.sciencemag.org/content/3/7/e1700782 (July 15th 2019).

## What has happened to the plastic we have produced so far?



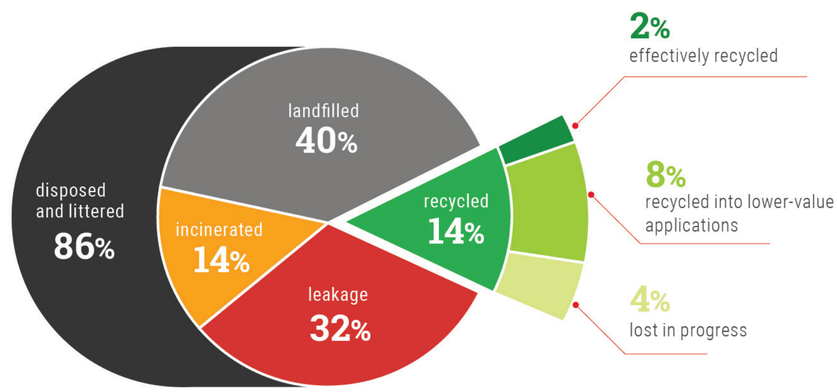

Source: In-house analysis based on R. Geyer, J.R. Jambeck, K.L. Law, op.cit.

## Plastic waste management globally


Source: In-house analysis based on United Nations Environment & Beat Plastic Pollution, op.cit.

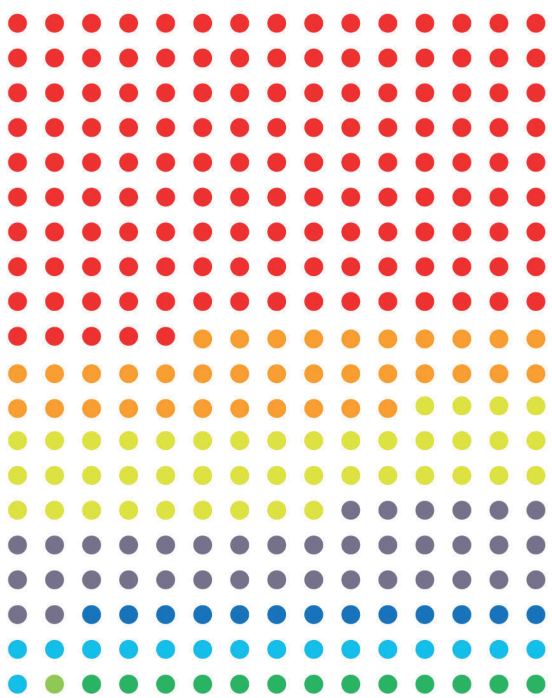
## Global flow of plastic packaging waste, 2015

Total packaging waste in 2015:
**141Mt**

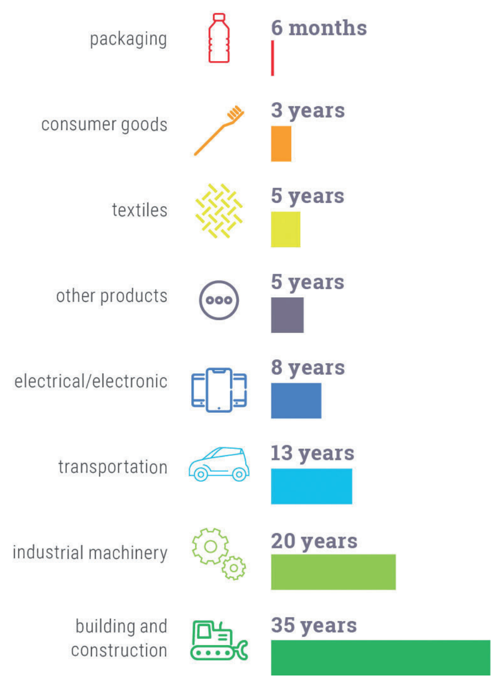



Source: In-house analysis based on United Nations Environment, op. cit.

## Weight of plastic waste by origin in 2015



## Mean lifetime of plastic products by sector in 2015




Source: R. Geyer, J. R. Jambeck, K. L. Law, op.cit.

Out of every 100 pieces of plastic waste, on average 79 have been landfilled, 12 have been incinerated, and 9 have been recycled. Of those nine, 2 have been incinerated after reuse, 5 have been landfilled and only 2 have been recycled again[9]. Hence, only 9% of all plastic waste has been recycled since the beginning of production, which means that most of the waste is accumulated in the natural environment.

Plastic waste is made up mainly of single-use products. Because of the ease of production and convenience of use, we have become addicted to plastic, especially single-use plastic products. Around the world, one million plastic bottles are sold every minute, while five trillion single-use plastic bags are used every year. In total, half of all plastic produced is designed to be used only once[10].

In addition to typical drinking bottles and disposable plastic shopping bags, single-use plastics include plastic food packaging, disposable plates and cutlery, takeaway food packaging, as well as bottles and packaging for cosmetics, drugs and household chemicals[11]. Single-use plastics are therefore mainly used in two segments: packaging and consumer products.

These two segments were responsible for almost 60% of all plastic waste generated in 2015, of which plastic packaging represented, according to various sources, 40% to 47% of the total.

The mean lifetime of plastic packaging is 6 months  and about 3 years for a typical consumer product[12]. This includes not only the time when plastic is used by the end customer, but also the time spent on a shelf in a shop or  warehouse, and time in transit. From purchase to disposal, a plastic bag is used for an average of 12 minutes[13].

The textile industry is another large sector generating plastic waste. We throw away more than 40 million tonnes of clothes and other textiles made of man-made fibres every year. We replace our electronics once every 8 years, and the plastics contained in this equipment accounts for as little as 4% of waste. Plastic parts have the longest lifetime, of around 35 years, in buildings and in the construction industry.

Therefore, plastic packaging is the most frequently discarded and accounts for the largest part of total waste by weight. Out of 141 million tonnes disposed of in 2015, 14% to 21% were recycled and only a small proportion was reprocessed into full-value products[14].

Further 14% was incinerated for energy recovery. This means that 7 out of 10 pieces of packaging are accumulated somewhere in our environment after they are discarded. Every third packaging is thrown away illegally and ends up in forests, parks, rivers and oceans. A long decomposition process begins there, usually taking the form of slow disintegration, as most plastics are not biodegradable. After disintegrating into sufficiently small pieces, under the right conditions plastic can break

## Singe-use plastics

**Polyethylene terephthalate**
**(PET)**
water bottles, dispensing containers, bisquit, trays

**High–density polyethylene**
**(HDPE)**
shampoo bottles, milk bottles, freezer, bags, ice cream containers

**Low–density polyethylene**
**(LDPE)**
bags, trays, containers, food packaging film

**Polypropylene**
**(PP)**
Potato chip bags, microwave dishes, ice cream tubs, bottle caps

**Polystyrene**
**(PS)**
cutlery, plates, cups

**Expanded polystyrene**
**(EPS)**
protective packaging, hot drink cups

Source: ibidem.

9 R. Geyer, J.R. Jambeck, K.L. Law, op.cit.

10 Ibidem.

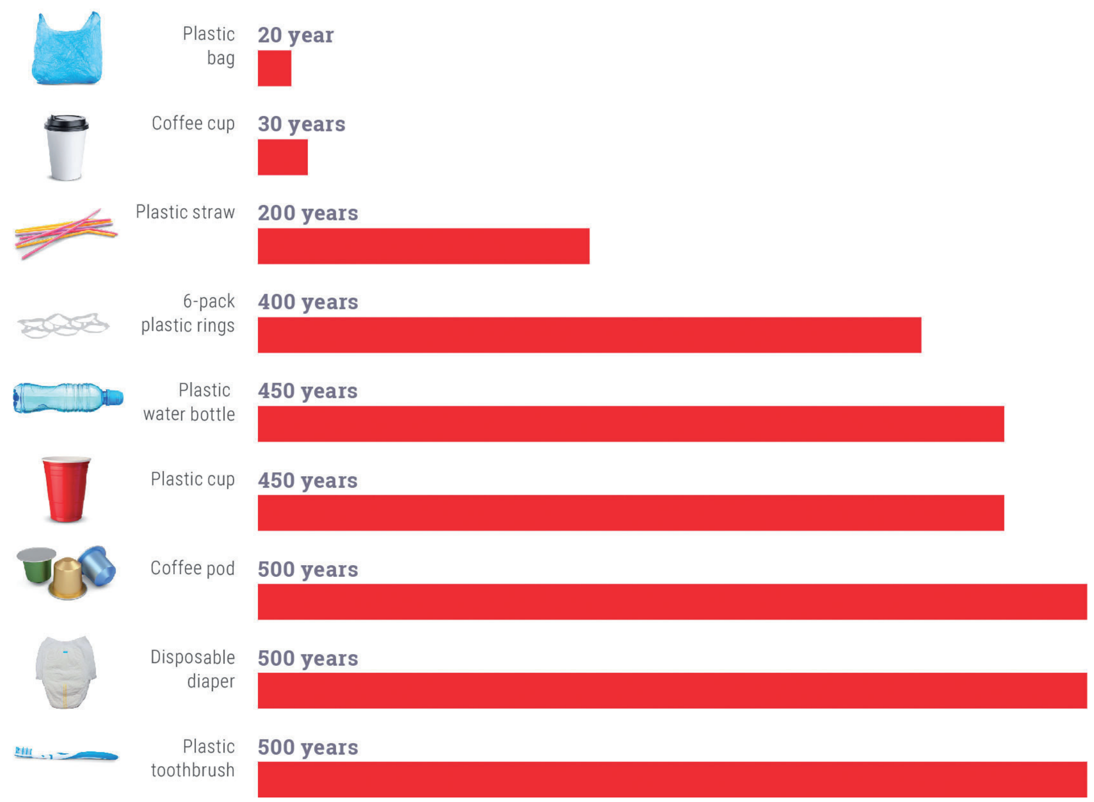
11 Ibidem.

12 R. Geyer, J.R. Jambeck, K.L. Law, op.cit.

13 Business Insider, *In some countries, people face jail time for using plastic bags. Here are all the places that have banned plastic bags and straws so far*, https://www.businessinsider.com/plastic-bans-around-the-world-2019-4?IR=T (August 5th 2019).

14 Center for International Environmental Law, *Plastic & Climate The Hidden Costs of a Plastic Planet*, https://www.ciel.org/wp-content/uploads/2019/05/Plastic-and-Climate-FINAL-2019.pdf (15.07.2019) oraz United Nations Environment, op.cit.

### The Lifecycle of Plastics




Source: In-house analysis based on: *The lifecycle of plastics* , https://www.wwf.org.au/news/blogs/the-lifecycle-of-plastics (July 16th 2019).

down into carbon dioxide, water and other substances, but this can even take more than 500 years.

Plastic is broken down into smaller pieces by sunlight, wind, waves, or animals, producing tiny particles called microplastics. Microplastics are all plastic particles ranging from 1 nm to 5 mm in size, regardless of whether they have resulted from fragmentation or have been intentionally manufactured as such. Plastic waste and microplastics are carried by wind and rain and subsequently accumulate in water bodies. Further breakdown of microplastics does not lead to their degradation into monomers. Instead, the particles become ever-smaller. Under appropriate conditions, micro-particles can break down into carbon dioxide, water, methane, hydrogen, ammonia and other inorganic compounds, but such degradation does not usually occur in the aquatic environment where the concentration of microplastics is greatest. It is estimated that, on average, every square kilometre of the ocean has more than 63 thousand microplastic particles floating in the water, while locally, mainly in East Asia, the concentrations can be 27 times higher. The biodegradable fraction of plastics often requires special conditions that

**As much as 70-80% of microplastics in the oceans are microfibres from decomposition and washing of garments and other textiles. Research shows that a single synthetic garment sheds more than 1,900 microplastic fibres in just one wash.**

Source: United Nations Environmental Protection, Microplastics: Trouble in the Food Chain, https://uneplive.unep.org/media/docs/early_warning/microplastics.pdf (July 15th 2019).

**Intentional production of microplastics**
Microplastics have great abrasive properties, hence their use in cosmetics and household chemicals as microgranules. They are also used to control the viscosity of liquids and product stability, for instance in paint manufacturing.

rarely occur in the natural environment (such as being subjected to prolonged temperatures above 50°C)[15].

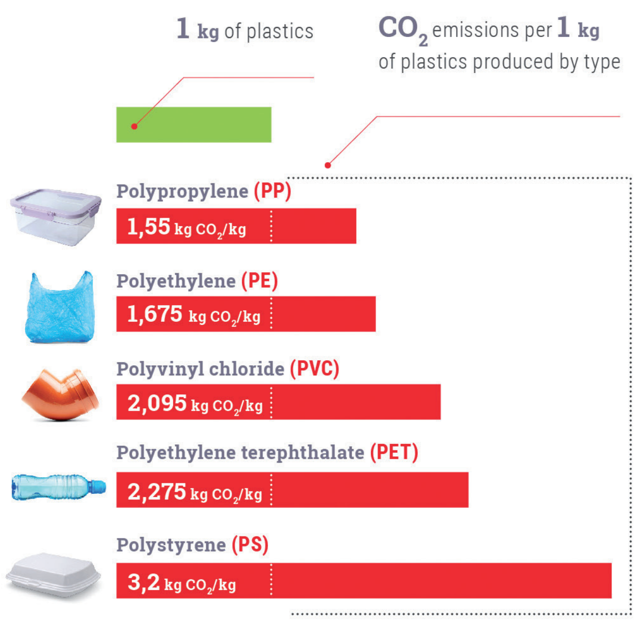
The environmental damage already caused by inadequate storage of plastic waste calls for immediate response. It is a natural thing to demand that an end be put to the production of plastics, all the more so because it additionally entails greenhouse gas emissions.

## PLASTIC EMISSION LEVELS

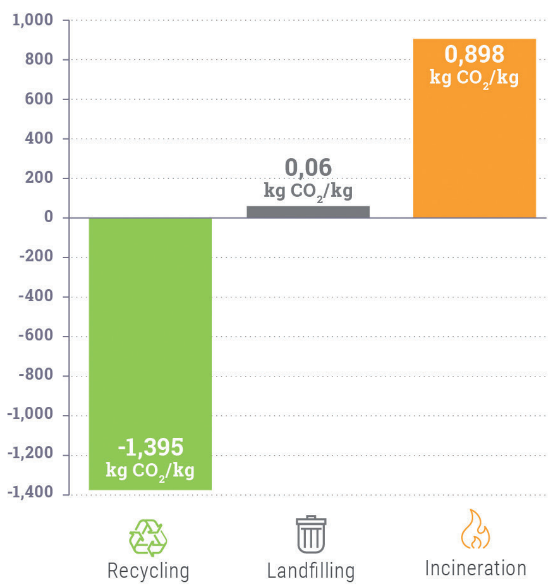
Over 99% of plastics are derived from fossil fuels: oil, natural gas and coal. Therefore, emissions start already with the extraction of raw materials. Greenhouse gas emissions from the extraction to the production of the resin, from which an end product is obtained, are estimated at 1.89 kg $CO_2e$ per kg of resin (which is an equivalent of greenhouse gases that are just as harmful to the environment as 1.89 kg of $CO_2$). Emissions from the production of electricity and heat that power plastics production processes play a significant role, and switching from fossil fuels to low-carbon or renewable energy sources can bring the figure down to 0.90 kg $CO_2e$ per kg of resin[16]. The emission level depends on the production process, feedstock material and end product.

Emissions from plastics do not end at the production stage, but with the disposal of plastic waste. As already mentioned, waste can be recycled, landfilled or incinerated. Recycling reduces plastics emission rates by 1.395 kg $CO_2e$ per kg of resin,

### $CO_2$ emissions per 1 kg of plastics produced




### CO2 emissions per 1 kg of plastic waste disposed




Source: In-house analysis based on Center for International Environmental Law, *Plastic & Climate The Hidden Costs of a Plastic Planet.*

15 United Nations Environmental Protection, op.cit.

16 Center for International Environmental Law, *Plastic & Climate The Hidden Costs of a Plastic Planet.*

as it eliminates the need for new plastic manufacturing. Incineration, in contrast, increases emissions by about 50% despite replacing a fossil fuel (here: natural gas) with waste. Landfilling of plastic waste has only a marginal effect on emissions from plastics[17].

Aside from the growing heaps of plastic waste and $CO_2$ emissions, the most commonly mentioned risks associated with the production of plastics are:

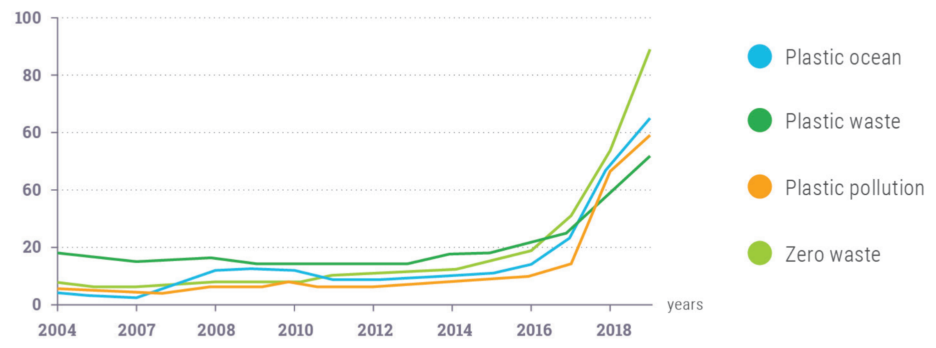
- harmful substances released during oil and gas extraction, especially in the process of hydraulic fracturing (used in shale gas and oil extraction) and oil production from bituminous sands,
- emission of $CO_2$ and toxic substances in the refining process and petrochemical production,
- toxic substances released in plastic waste disposal processes, mainly incineration and gasification,
- accumulation of plastics and additives in the environment and human food chain, leading to the ingestion and inhalation of harmful microparticles[18].

Plastics are obtained from crude oil, which has already been blacklisted due to emissions from transport, so the 'stop plastic' slogan can easily turn into 'stop petrochemicals'. However, if we follow this line of thinking, we will fail to get to the core of the problem:which is how we use the plastics. We discard plastic products after a single use, as they are too cheap, but they are so durable that they will last for decades. It might seem that replacing a plastic bag with a paper bag – which will be discarded as well – is beneficial for the environment because paper is biodegradable. Unfortunately, as we will discuss later, a paper bag used in this way leaves a bigger environmental footprint than a plastic bag! Waste is not waste until we waste it. The solution to the problem of plastic waste lies in product usage: designing products for reuse, then actually reusing them, and finally having them recycled. We discussed this topic more thoroughly in the previous report[19] and we will explore it further below.

# Fighting waste

The ubiquity of plastic waste makes people want to fight not only the waste itself, but also plastics and – more and more often – petrochemicals. In developed countries, the awareness of the problem is growing with the increasing media coverage. More and more often, we search for information about the plastic waste problem. Today, the terms 'plastic waste', 'plastic ocean' (representing searches for all terms related to plastic waste in the oceans), 'plastic pollution', and 'zero waste' (a movement promoting a lifestyle where people strive to minimise waste and thus their environmental footprint[20])

**Google searches for plastic waste-related terms**




Source: In-house analysis based on Google Trends data.

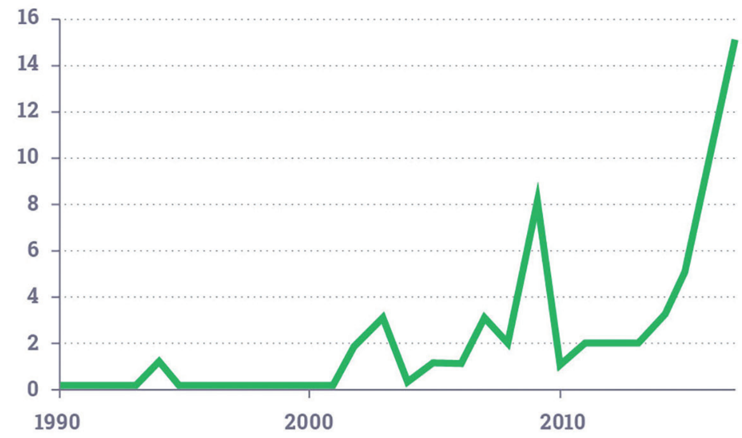
17 Ibidem.

18 Ibidem.

19 PKN ORLEN, *Filary trwałego rozwoju przedsiębiorstw. Wizja, surowce, talenty* [*Pillars of business sustainability. Vision, raw material resources, talent*], vol. 11, https://napedzamyprzyszlosc.pl/files/Filary_trwaego_rozwoju_przedsibiorstw_-_Wizja_surowce_talenty.pdf (August 28th 2019).

20 Polskie Stowarzyszenie Zero Waste, *Czym jest zero waste?* [*What is Zero Waste?*], http://zero-waste.pl/czym-jest-zero-waste/ (August 5th 2019).

**Number of new regulations on single-use plastics at the national level**




Source: In-house analysis based on United Nations Environment, op.cit.

are searched for respectively 3, 16, 8 and 11 times more often than back in 2004[21], and Greenpeace's petition to ban the use of microplastics in the UK in 2016 was signed by 365,000 people in just four months, becoming the largest environmental petition ever submitted to Parliament[22].

Public awareness of plastic waste is a relatively new development. We have had plastics for 70 years, but the movement against their continued use did not emerge until a few years ago. Major environmental organisations, such as Greenpeace or Friends of the Earth, did not even have dedicated teams or programmes addressing plastics until 2015[23]. However, a sharp rise in public interest was seen in 2017, when the BBC published the second part of its Blue Planet documentary. In the last episode, six minutes were devoted to the impact of plastics on marine fauna, showing scenes such as the infamous image of a turtle entangled in a plastic bag and an albatross feeding plastics to its chicks. According to the UK supermarket chain Waitrose, after watching this episode 9 out of 10 people altered their consumer behaviours and the customers' interest in the subject of plastics increased eightfold[24].

## REGULATIONS

Public pressure has triggered a number of regulations and bans at the national and global level. Just like the number of search terms related to plastic waste, the number of new plastics regulations has only started to grow recently. While only one restriction on the use of single-use plastics was introduced before 2000, between 2001 and 2010 as many as 21 new regulations were established, followed by further 39 until 2017[25].

In 2015, the European Union introduced a directive limiting the use of plastic bags, resulting in a number of national regulations, which vary from one region to another. For example, Italy and France banned the sale and free distribution of plastic bags, while the Austrian government came to an agreement with the private sector to reduce the consumption of plastic bags. Today, more than 90 countries worldwide have banned them, and further 36 seek to control their use by imposing charges and taxes[26].

21 Google Trends, https://trends.google.com/trends/explore?date=2004-01-01%202019-07-31&q=plastic%20ocean,plastic%20waste,plastic%20pollution,zero%20waste (August 5th 2019).

22 The Guardian, *The plastic backlash: what's behind our sudden rage – and will it make a difference?*, https://www.theguardian.com/environment/2018/nov/13/the-plastic-backlash-whats-behind-our-sudden-rage-and-will-it-make-a-difference (August 5th 2019).

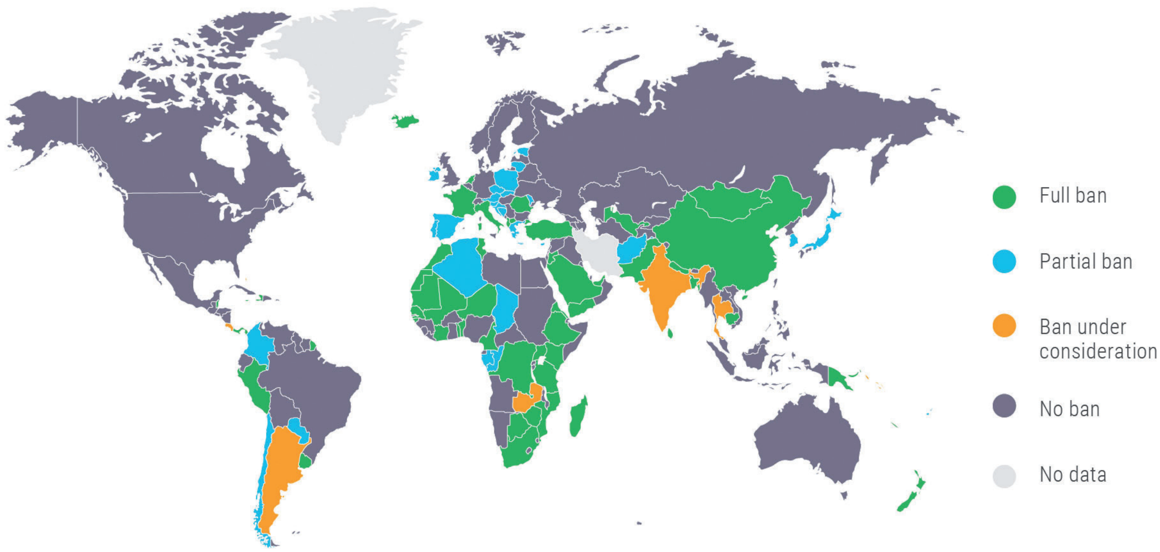
23 Ibidem.

24 Waitrose & Partners, *Food And Drink Report 2018–19*, https://waitrose.pressarea.com/pressrelease/details/78/NEWS_13/10259 (August 5th 2019).

25 United Nations Environment, op.cit.

26 The Economist, *Ever more countries are banning plastic bags*, https://www.economist.com/graphic-detail/2019/07/24/ever-more-countries-are-banning-plastic-bags (July 30th 2019)..

**Plastic-bag bans in July 2019**




Source: In-house analysis based on Google Trends data.

Not all legal regulations have brought the expected results. In some cases, the introduction of taxes or arrangements made with the private sector have forced customers to limit their use of plastic bags. There are, however, examples of poorly implemented rules that have done more harm than good or simply have not been sufficient. Since January 1st 2018, Poland has had a 'plastic bag law', which imposes a mandatory charge for plastic bags, excluding the thickest and the thinnest ones. Thus, the regulation has neither achieved the intended environmental effect nor triggered the projected budget revenue. A decision was made therefore to charge PLN 0.25 (including VAT) for each plastic bag over 15 μm (which means that the thinnest bags are exempted) starting from September 1st 2019.

## CASE 1: SUCCESS OF THE IRISH PLASTAX

In the 1990s, Ireland faced the problem of plastic bags littering its towns, countryside and the coastline. In 1998, the Department of the Environment commissioned a study to estimate the maximum price that consumers would be willing to pay for the, then free, plastic bag. The amount at which the consumption of plastic bags per person would not change was found to be EUR 0.024.

In 2002, the Irish government decided to introduce a tax on plastic bags at a rate six times higher than the estimated price the consumers were willing to pay: EUR 0.15. However, it did not apply to the smallest and thinnest bags that are necessary for hygiene purposes. At the same time, an extensive awareness campaign was carried out, and all revenues from the levy were contributed to the budget of the Ministry of Environment. As a result, within one year the use of plastic bags dropped by more than 90%, from 328 to 21 bags per person. When after four years plastic bag usage rose to 31 bags per person, the levy was raised to EUR 0.22, and in 2011 it was agreed that it could be revised once a year, to no more than EUR 0.70 per bag[27].

## CASE 2: FAILED INITIATIVES IN SOUTH AFRICA

In the 1990s, plastic bags became such a common problem in South Africa that they were mockingly referred to as 'national

27 United Nations Environment, op.cit.

Public pressure on the UK branch of McDonald's made the chain change the material of which drinking straws were made. From September 2018 to early 2019, the company completely switched from plastic to paper. However, the paper straws 'dissolved' in beverages and McDonald's had to use a thicker material. The new straws, although theoretically recyclable, have proved technically impossible to process and are therefore temporarily disposed of in mixed waste. After the problem was made public, 51,000 people signed a petition to go back to plastic straws.

In the UK, the fast-food chain uses 1.8 million straws a day.

Source: The Guardian, McDonald's to switch to paper straws in UK after customer campaign, https://www.theguardian.com/business/2018/jun/15/mcdonalds-to-switch-to-paper-straws-in-uk-after-customer-concern (August 28th 2019) and BBC, McDonald's paper straws cannot be recycled, https://www.bbc.com/news/business-49234054 (August 28th 2019).

flowers'. In 2003, the Government of South Africa introduced a ban on thin plastic bags and imposed a levy on thicker ones. The levy was ZAR 0.04, or about PLN 0.02, and applied only in the food sector. A percentage of the revenues from the levy was supposed to go to Buyisa-e-Bag, an NGO promoting waste minimisation and creating jobs in the recycling industry. After only three months, under pressures from producers, the levy was reduced to ZAR 0.03. The changes were not accompanied by any awareness campaign, and so after some time, consumers started to budget for the plastic bag charge, and the number of bags sold returned to pre-levy levels. The levy has hit the poorest, who used plastic bags to carry all goods, not just groceries, while benefitting retailers, who now charge ZAR 0.35–0.75 (PLN 0.09–0.19) per bag with the levy set at ZAR 0.08 (PLN 0.02). Buyisa-e-Bag has so far received only 13% of the proceeds, and the public is beginning to question the benefits of any changes[28].

### ORGANISATIONS, ASSOCIATIONS AND MANUFACTURERS AGAINST PLASTIC WASTE

New regulations are often created under pressure exerted on local authorities by environmental associations and NGOs. Greenpeace is the best-known international organisation tackling the problem of plastic waste. The organisation encourages people to sign a petition to the largest food producers: Nestle, Unilever, Coca-Cola, PepsiCo., Colgate, Danone, Johnson & Johnson, and Mars to stop single-use plastic packaging. It also calls for action – from turning plastic waste into a 'plastic monster' and sharing its picture on social media, to sending letters to local shops asking them to reduce the availability of plastic packaging, to running a campaign aimed at eliminating single-use plastic from local restaurants[29]. WWF, the World Wide Fund for Nature, created a petition calling on the United Nations to introduce a global regulation to prevent plastic waste leaking into the oceans by 2030. The document has already been signed by almost 1 million people[30].

Plastics and plastic packaging manufacturers are also aware of the problem. In 2017, Borealis (the second largest producer of polyolefins in Europe and eighth largest in the world) and SYSTEMIQ launched the STOP Project, aimed at partnering with cities to build economical and sustainable waste management systems[31]. Early 2019 saw the birth of the Alliance to End Plastic Waste (AEPW), bringing together big and small plastics companies such as Procter & Gamble, Lyondel-Basell, BASF, or Total. AEPW has already raised USD 1bn (out of the planned 1.5bn) to support projects such as Project STOP, partnering with organisations such as the United Nations, investments in waste collection, separation and recycling infrastructure, and clean-ups of concentrated areas of plastic waste[32]. The Plastic Pollution Coalition, comprising more than 750 organisations, businesses and leaders across 60 countries, encourages the adoption of the 4Rs: refuse (disposable plastics), reduce, reuse, recycle. In 2018, the Ellen MacArthur Foundation launched the Global Commitment, an initiative engaging more than 400 businesses and organisations, some of which account for more than 20% of global plastic packaging volumes. They include Danone, H&M, L'Oreal, Mars, PepsiCo, and The Coca-Cola Company, and the activities are supported by the WWF, World Economic Forum and The Consumer Goods Forum. The aim of the commitment is to eliminate unnecessary plastics, to innovate in the design of plastic packaging for reuse or easy recyclability, and to ensure circulation of everything that is in use by 2025[33].

## Ban petrochemicals?

Financial institutions have also joined in the fight against plastics. The World Bank announced that it would stop financing oil

28 United Nations Environment, op.cit.

29 Greenpeace, *Stop single-use plastic!*, https://www.greenpeace.org/southeastasia/act/stop-single-use-plastic/ (July 17th 2019).

30 WWF, *No more plastic in nature*, http://www.wwfca.org/en/stopplastic/ (July 17th 2019).

31 Project STOP, *Frontline action to stop marine plastic pollution*, https://www.stopoceanplastics.com/ (July 17th 2019).

32 Alliance To End Plastic Waste, *The Alliance Launches Today*, https://endplasticwaste.org/latest/the-alliance-launches-today/ (August 5th 2019).

33 Ellen MacArthur Foundation, *New Plastics Economy Global Commitment*, https://www.ellenmacarthurfoundation.org/assets/downloads/GC-Report-June19.pdf (August 5th 2019).

and gas projects after 2019[34]. The French insurance giant AXA Group and the Netherlands-based ING Group are withdrawing from industries which mostly contribute to climate change, while French BNP Paribas will no longer provide lending for oil projects which are considered harmful to the environment[35]. RBS (Royal Bank of Scotland) and HSBC have discontinued investments in oil sands and Arctic oil projects[36]. The UK-based Barclays followed suit[37]. Financing of oil and gas projects involves a certain degree of uncertainty for investors not only due to evolving environmental policies, but also due to social ostracism. Reports such as 'Banking on Climate Change' evaluate all institutions supporting fossil projects, naming the 'dirty dozen' of banks that have lent the most to fossil businesses, and creating a 'hall of shame' for the worst of the worst[38].

Considering the above, should we totally stop the use of plastics or even petrochemicals in general? It is not a black and white issue, and the elimination of petrochemicals would have far-reaching consequences that cannot be foreseen at a glance. Potential solutions are discussed in the following part of the report.

34 The Guardian, *World Bank to end financial support for oil and gas extraction*, https://www.theguardian.com/business/2017/dec/12/uk-banks-join-multinationals-pledge-come-clean-climate-change-risks-mark-carney (August 1st 2019).

35 Wall Street Journal, *Big Oil Investors Rethink Their Bets*, https://www.wsj.com/articles/big-oil-investors-rethink-their-bets-1514992061 (August 9th 2019).

36 Reuters, *RBS to stop financing new coal plants, oil sands or arctic oil projects*, https://www.reuters.com/article/us-rbs-strategy-fossil-fuels/rbs-to-stop-financing-new-coal-plants-oil-sands-or-arctic-oil-projects-idUSKCN1IU155 (August 9th 2019).

37 Global Trade Review, *Barclays to stop funding for new thermal coal, Arctic oil projects*, https://www.gtreview.com/news/sustainability/barclays-to-stop-funding-for-new-thermal-coal-arctic-oil-projects/ (August 9th 2019).

38 Banking on Climate Change, *Fossil Fuel Finance Report Card 2019*, http://priceofoil.org/content/uploads/2019/03/Banking-on-Climate-Change-2019-final.pdf (August 1st 2019).

# Part 2. Solutions

DO NOT GIVE UP ON USEFUL PRODUCTS, STOP LITTERING, USE THE WASTE

## Is there an alternative to plastics?

The plastics we use every day can be replaced by other materials. In automotive applications, metal, glass, or textiles can be used instead, and in the packaging sector, plastics can be replaced by glass, paper, and metal. In place of a plastic bag we can use a paper or textile one, instead of buying plastic toys for children, we can choose those made of metal and wood, and restaurants or cafés could serve beverages in glass and ceramic mugs, accompanied by paper, metal or natural straws. So in many situations plastics can be replaced, but this comes with consequences.

Plastic is a lightweight and durable material, so a relatively low weight is needed to satisfy consumer needs. By way of example, we show how a plastic water bottle can be replaced. The average weight of a 500 ml PET beverage bottle is 9.9 grams[39]. A glass bottle of the same volume will weigh 330 g[40], over 33 times more, and a half-litre aluminium can will weigh about twice as much[41]. If plastic packaging in the beverages and ice segment was to be replaced by alternative materials in the proportion now observed on the market, each tonne of plastic would be replaced by a mix of:

- 400 kg of metal,
- 6.5 t of glass, and
- 300 kg of paper and cardboard,

which means that 13 million tonnes of plastic beverage packaging would be replaced by nearly 94 million tonnes of other materials. The weight of the product and its packaging determines the environmental cost of its production, transport and disposal. The environmental cost per tonne of the mix of alternative packaging materials is 30% lower than that of a tonne of plastic bottles, but the quantity of materials required to satisfy the same needs increases by a factor of 7.3. This means that the final environmental cost of replacing plastic in the beverage and ice packaging segment with alternative materials will be 5.2 times higher than continued use of plastics[42].

The weight of alternative materials is not the sole factor when considering a shift away from plastics. Most of all, they are more expensive to produce than plastics. For example, the average product margin of a beverage manufacturer is currently 10.5%. Assuming that prices for the final consumer would not rise and the packaging of the product would be changed, the margin would drop to

39 PET Resin Association, *Little-Known Facts about PET Plastic*, http://www.petresin.org/news_didyouknow.asp (July 26th 2019).

40 In-house analysis based on manufacturers' catalogues (Vetropack, Brewcraft USA, BrewPac).

41 Australian Aluminium Council.

42 Trucost, op.cit.

It is estimated that replacing a single-use plastic bag with a reusable bag will only bring environmental benefits if the latter is used at least 40 times, depending on the material. In many cases, this goal is not achieved, which is counterproductive[1], and consumers forget to bring their reusable shopping bags 4 out of 10 times[2].

Independent studies by the Ministry of Environment and Food of Denmark and the UK Environment Agency show that:

- a polypropylene bag, which is the 'thicker' plastic bag sold as a reusable one, has to be used 14[3]–37[4] times,
- a paper bag has to be used 4[3]–43[4] times,
- a cotton bag has to be used 173[3]–7,100[4] times,

to make the environmental cost equal to the cost of use of disposable bags that are reused, mainly as bin liners*.

* in the study by the Ministry of the Environment and Food of Denmark, all disposable bags were reused as bin liners, while in the study by the UK Environment Agency the assumption was that the bags would be reused, of which 40.3% as bin liners.

1 S.D. Kominers, *People Make It So Hard to Ditch Plastic Straw*, https://www.bloomberg.com/opinion/articles/2019-07-15/people-make-it-so-hard-to-ditch-plastic-straws?utm_source=whatsapp&utm_medium=msg&utm_campaign=whatsap (July 17th 2019).

2 Clemson University, *Life Cycle Assessment of Grocery Bags in Common Use in the United States*, https://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=1006&context=cudp_environment (August 1st 2019).

3 Environment Agency, *Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291023/scho0711buan-e-e.pdf (August 1st 2019).

4 Ministry of Environment and Food of Denmark, Environmental Protection Agency, Life Cycle Assessment of grocery carrier bags, https://www2.mst.dk/Udgiv/publications/2018/02/978-87-93614-73-4.pdf (August 1st 2019).

-0.2%. The absence of plastics would be even more painful for toy manufacturers. Their current margin of 4.6% would decline to -24.8%, which means that in order to maintain their current revenue levels, they would have to increase the price of toys by about one-fourth[43].

Today, about half of the environmental damage caused by plastics is due to greenhouse gas emissions, but the production process itself is not the main culprit. The energy sector, which was responsible for 38% of all $CO_2$ emissions into air in 2017, is the most emission-intensive sector.

Industry as a whole accounts for 28% of $CO_2$, and the transport sector comes third with a 24% share[44]. The meat industry is another significant source of emissions. It accounts for 14.5% of global anthropogenic emissions, or man-made greenhouse gas[45]. Plastics can help reduce emissions in these sectors.

## CASE 1: WHAT WOULD HAPPEN IF PLASTICS WERE NO LONGER USED IN THE AUTOMOTIVE INDUSTRY?

The automotive industry consumed approximately 6.5 Mt of plastic in 2015. However, 14.8 Mt of alternative materials would be needed to replace plastic parts, which is two or three times as much. If North America alone replaced all plastics with alternative materials in cars manufactured during one year, the vehicles would require an additional 336 million litres of fuel to operate over their lifetimes. However, it should be noted that North America as a whole accounts for only 16% of the automotive market[46]. A simple calculation shows that replacing plastics in car manufacturing in only one year would increase the consumption of liquid fuels by 2.1 billion litres, equivalent to all fuel consumed by the entire United States in almost 1.5 years[47].

## CASE 2: WHAT WOULD HAPPEN IF PLASTICS WERE NO LONGER USED AS FOOD PACKAGING COMPONENTS?

On average, every third food product is wasted. Most food is thrown away in

43 Trucost, op.cit.

44 BP Energy Outlook 2019, http://www.bp.com/energyoutlook (July 18th 2019).

45 Food and Agriculture Organization in the United Nations, *Key facts and findings, GHG emissions by livestock*, http://www.fao.org/news/story/en/item/197623/icode/ (August 29th 2019).

46 Trucost, op.cit.

47 EIA, *How much gasoline does the United States consume?*, https://www.eia.gov/tools/faqs/faq.php?id=23&t=10 (August 9th 2019).

developed countries. In Europe and North America, each consumer discards an average of 95 to 115 kg of food per year, while in developing countries the amounts wastedare much smaller:6 to 11 kg per person is wasted[48].

In Europe, 88 million tonnes of food are thrown away every year, and about 60% of household food waste is caused by short shelf lives[49]. However, the production of excess food comes at a cost for the environment. Greenhouse gas emissions from agriculture represent 9% and 10% of total emissions in the United States and Europe respectively[50]. Plastic packaging makes it possible to keep food fresh for a longer time. An example of a product that is sold both in and without plastic packaging is cheese. Greenhouse gas emissions from cheese packaging are 18 g $CO_2$ when purchasing 150 g of cheese at the counter and 45 g $CO_2$ when purchasing it factory-packaged in plastic. However, studies show that the average emissions from cheese wastage are 71 g $CO_2$ in the former case, and only 2 g $CO_2$ in the latter case. For cheese, the average environmental cost is lower if the cheese is 'factory-package[51].

## The cost of replacing plastics

The examples shown indicate that plastics in cars, toys, beverage and food packaging, and even the infamous bags seem to be irreplaceable for the time being. More extensive research, which considers not only individual products but also whole sectors, leads to similar conclusions. Replacement of plastics in the food, alcohol and tobacco, furniture, textile, footwear, consumer products, medical and pharmaceutical,household appliance, home electronics, cosmetics, automotive, sport, and toy sectors as well as in retail, restaurants and bars with alternative natural materials will do more harm than good. Although, on average, a tonne of alternative materials that could replace plastics in all these sectors will cause 8% less environmental damage than a tonne of plastics (environmental cost of USD 1,558 per tonne of alternative materials compared with USD 1,654 per tonne of plastics), we would need to use more of them, just like in the case of beverage packaging made of plastics and alternative materials. In global terms, this would add up to 4.1 times more, and the environmental damage would increase 3.8-fold times. The environmental cost of ditching plastics reaches as much as USD 533bn per year, compared with USD 139bn now associated with plastic.

There is no good alternative to plastics alone so far, but alternatives to the fossil fuel serving as a production feedstock are popping up.

## Is there an alternative to petrochemicals?

Instead of replacing the plastic end product, we can find a bio-alternative for the feedstock material. This means that instead of producing ethylene from naphtha and extracting naphtha from crude oil, we could obtain ethylene from bioethanol, which would be produced from biomass or from the biodegradable waste fraction. In addition, the energy needed for physicochemical processes can be derived from renewable energy sources instead of burning petroleum tar (which is a heavy residue from the crude oil refining process). In that case, the end product, such as polyethylene, would have exactly the same properties as polyethylene obtained from crude oil, but no fossil sources such as oil or natural gas would be engaged in the process.

Another possibility is to use coal as a raw material. Currently, CTC (coal to chemical) projects are becoming more and more common in China, but this production method has a greater carbon footprint than production from oil or natural gas. $CO_2$ emissions per tonne of olefins increase fivefold for coal in comparison with naphtha[52].

The production of 1 kg of beef releases 67.8 kg of greenhouse gases (in $CO_2$ equivalent)[1], which makes it one of the most environmentally expensive food products. Typical packaging for beef is made of a polystyrene tray and plastic film. Replacing them with a plastic composite can extend the shelf life by 6 to 16 days, which almost halves food waste[2].

1 Food and Agriculture Organization in the United Nations, *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment*, http://www.fao.org/3/i3461e/i3461e03.pdf (August 1st 2019).

2 Trucost, op.cit.

**Environmental costs** are costs connected with the actual or potential deterioration of natural assets due to economic activities.

Source: OECD, Glossary, https://stats.oecd.org/glossary/detail.asp?ID=819 (August 28th 2019).

48 Food and Agriculture Organization in the United Nations, op.cit.

49 European Commission, Periodic Reporting for period 1 - Fresh Solutions (Fresh Solutions -'A fresh approach to food packaging'), https://cordis.europa.eu/project/rcn/210402/ reporting/fr (August 1st 2019).

50 United States Environmental Protection Agency, Sources of Greenhouse Gas Emissions, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (August 1st 2019) and Eurostat, Agri-environmental indicator – greenhouse gas emissions, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_greenhouse_gas_emissions (August 1st 2019)

51 B. Wohner, E. Pauer, V. Heinrich, M. Tacker, Packaging-Related Food Losses and Waste: An Overview of Drivers and Issues, https://www.mdpi.com/2071-1050/11/1/264/pdf (August 1st 2019).

52 Q. Zhang, S. Hu, D. Chen, A comparison between coal-to-olefins and oil-based ethylene in China: An economic and environmental prospective, https://www.columbiariverkeeper.org/sites/default/files/2018-12/Exh.%205%20Qun%20et.%20al.%202017%20%281%29.pdf (August 7th 2019).

**What are bioplastics?**

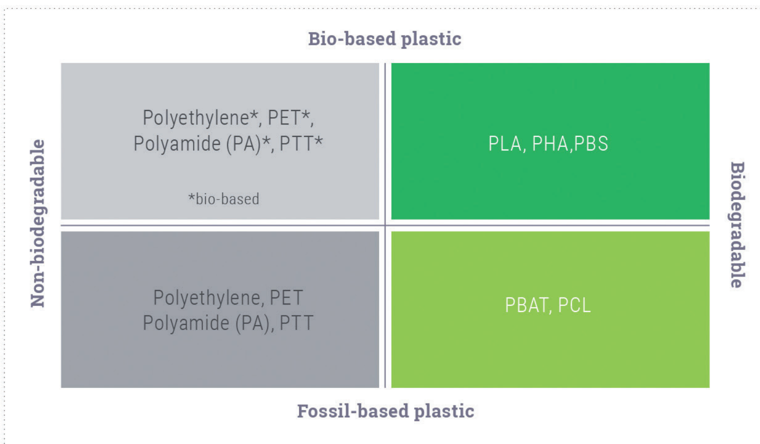
**Bio-based plastic** – plastic made using plant-based or other biological feedstocks, usually from starch, cellulose, or lignin; it is often referred to as bioplastic, the term 'bio' refers only to the origin of the feedstock, which will not necessarily be reflected in a smaller environmental footprint

**Biodegradable plastic** – plastic that decomposes in a defined period of time; biodegradable plastics can be either bio-based or fossil-based

**Compostable plastic** – plastic that degrades under industrial composting conditions and conforms to EN13432 (or other comparable standards), which stipulates that compostable plastic has 12 weeks to decompose under appropriate conditions; not all biodegradable plastic is compostable, but all compostable plastic is biodegradable

Not every plastic of biological origin is biodegradable and not every biodegradable plastic is of biological origin.

**Examples of plastics by source and biodegradability**




Source: WRAP, Understanding plastic packaging and the language we use to describe it, http://www.wrap.org.uk/sites/files/wrap/Understanding%20plastic%20packaging%20FINAL.pdf (August 6th 2019).

## Bioplastics

If replacing plastics with alternative materials does not produce the expected outcomes, the petrochemical feedstock for plastics could be replaced with bio-based feedstock. This is how we obtain bioplastics.

A life cycle assessment of bio-based plastics shows that in most cases they represent a lower or even negative global warming potential. As a rule, the production of bioplastics also releases less summertime smog and requires less fossil resources[53]. The production of PHA plastics (polyhydroxyalkanoates) from corn straw, i.e. bio-based biodegradable polymers with properties similar to polypropylene, is particularly climate-friendly. PHA can be produced with a negative carbon footprint, which means absorbing greenhouse gases from the environment rather than releasing it. However, the LCA study shows that obtaining PHA from corn grain instead of straw will, on average, produce more $CO_2$ than oil-based

53 M.D. Tabone, J.J. Cregg, E.J. Beckman, A.E. Landis, Sustainability Metrics: Life Cycle Assessment and Green Design in Polymers, http://www.news.pitt.edu/sites/default/files/documents/TaboneLandis_etal.pdf (July 6th 2019).

polypropylene. So it cannot be claimed that PHA is 'better' or 'worse' than polypropylene, because everything depends on the production process.

Furthermore, it appears that bio-based plastics can be more damaging to the environment than their conventional counterparts obtained from fossil hydrocarbons, and not only in terms of emissions. Firstly, their production requires an increased farmland use and more fertilisers. Additional fertilisation results in increased eutrophication of soil and water (undesirable enrichment with nutrients) and may contribute to environmental acidification[54]. Today, the farmland needed for the production of biopolymers amounts to 0.01% of the global agricultural area, and the replacement of all plastics with those of biological origin would require an increase in that area from 0.6% to 4.4%. In 2020, this would additionally take up about 8% to 61% of the available arable land. The production of bio-based plastics requires more water than fossil-based plastics. In 2016, the water consumption (calculated as water footprint) due to bioplastics was 7.72 billion $m^3$, i.e. less than 0.1% of the annual global water consumption. A total shift to bio-based plastics would result in an increase in water consumption of 307 billion to 1,652 billion $m^3$ per year, leading to a global increase of 3% to 18%[55]. In other words, adverse climate and environmental effects are not eliminated but emerge elsewhere. This is illustrated by the following examples.

## CASE 1: POLYETHYLENE FILM

The study involved comparing two 30 g polyethylene film packagings using the life cycle assessment method. One was produced from fossil-based naphtha in Germany, the other from sugar cane in Brazil. Both materials were transported to Germany and used there. A note was made where the transport from Brazil to Germany had a bearing on the results.

The study showed that:

- the climate change potential of bio-polyethylene is ten times less than that of the conventional polymer;
- the consumption of fossil resources for the bio-based material is negative (which means that fossil resources are created in the production process), while the traditional method of polyethylene production requires almost 0.03 kg of crude oil per square metre of plastic film;
- the conventional material generates over four times more summer smog

On the other hand:

- the biopolymer is a stronger contributor to environmental acidification (including acidification of oceans), even if transport of the polymer from Brazil to Germany is not factored in;
- polyethylene obtained from sugar cane has a three times stronger effect on soil eutrophication than the conventional polymer (or more than 2.5 times stronger when the effect of polymer transport is not factored in);
- while the traditional polyethylene does not contribute to aquatic eutrophication, each square metre of bio-PE film results in a release of about 0.075 g of phosphates causing soil overfertilisation;
- emissions of the harmful PM10 particles (particulate matter suspended in the air with a diameter not exceeding 10 μm) is six times higher for the biopolymer than for the conventional material;
- approximately 0.085 m2 of farmland is used for sugar cane production to obtain 1 m2 of plastic film, while the production of polyethylene from naphtha does not take up any agricultural areas;
- energy consumption is more than four times higher for the biopolymer;

**Life cycle assessment** (LCA) is the process of evaluating the environmental effects a product exerts throughout its life cycle by improving resource efficiency and reducing environmental liabilities. It may cover both the product itself and its function. LCA is treated as a 'cradle-to-grave' analysis.

Source: UNEP.

- water consumption is almost 30 times higher for the sugar cane-based process

**Conclusion: bio-PE cannot be considered to be better or worse in environmental terms than its conventional counterpart**[56].

## CASE 2: PLASTIC BOWL

In this study, two 15 g bowls with lids were compared using the life cycle assessment method. One of them was produced from oil-based polystyrene, and the other from PLA. PLA stands for polylactic acid, derived from lactic acid, which in turn is obtained from agricultural products, mainly corn and sugar beet.

Efforts are under way to launch lactic acid production on a commercial scale from bio-based inputs that are not a potential source of food. The study covered production from both sugar beet and inedible lignocellulose. Furthermore, account has been taken of potential improvements in the lactic acid production process in 'future' scenarios.

It appears that:

- polystyrene has a higher climate change potential than PLA in all scenarios – the difference ranges between 20% and 50%;
- a polystyrene bowl consumes up to four times more fossil resources than its PLA counterpart;

54 Ibidem.

55 R.E. Putri, *The water and land footprint of bioplastics*, https://www.utwente.nl/en/et/wem/education/msc-thesis/2018/putri.pdf (August 6th 2019).

56 Umweltbundesamt, *Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics*, https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4446.pdf (August 6th 2019).

- polystyrene packaging generates 5 to 10 times more summer smog than a PLA bowl;
- the production of a polystyrene bowl consumes more energy compared to the 'future' PLA production technology, while for the current technologies there is only a minor difference.

On the other hand:

- the PLA bowl obtained using today's technology will acidify the environment at least twice as much as a bowl made of polystyrene; the future technology and the use of lignocellulose may help reduce acidification by some 10%;
- both terrestrial and aquatic eutrophication is always greater for biopolymers; soil enrichment with nutrients can be even twice higher for the PLA bowl than it is for its polystyrene counterpart; water fertilisation is negligible for polystyrene, low for lignocellulose and high (approx. 45 g phosphates per 1,000 bowls) for sugar beet-based PLA;
- PM10 emissions are the highest when the bowl is obtained from PLA using today's methods and the lowest when using future methods; this means that currently the polystyrene bowl releases less PM10, but the hierarchy is likely to reverse in the future;
- farmland is used only for the production of sugar beet-based bowls: 15 to 16 $m^2$ of land is required for 1,000 bowls;
- currently the use of a polystyrene bowl requires over five times more water than in the case of a PLA bowl; polystyrene will continue to be the most advantageous material in the future, but the gap will shrink.

**Conclusion: currently the polystyrene bowl is neither worse nor better than the PLA bowl. In the future, if the assumptions regarding lactic acid production technology are met, the production of PLA bowls will have a lower environmental footprint**[57].

## (Non)artificial fertilisers

As the population grows, so will the demand for food. In addition to population growth, the amount of crops needed in the future will be influenced by increased biofuel and biomaterial production volumes and higher average meat consumption, mainly in developing countries. In 1970, meat consumption per person was 26 kg per year. In 2000, it was already 37 kg, while in 2050 it is likely to increase to 44 kg[58]. At the same time, one in nine people worldwide are undernourished and the number of people without adequate access to food has started to grow for the first time in decades. Moreover, another 1.3bn people do not have regular access to sufficient and nutrient-rich food[59]. To ensure food security, supply of a wide range of agricultural products will be required, including in particular three cereal grains: rice, wheat and corn. Today, they account for 58% of the total agricultural area and provide half of the total calorific value consumed, and their production on such a large scale would not be possible without fertilisation. Studies have shown that the application of nitrogen fertilizers improves corn yields by nearly 70%, rice yields by 38%, and wheat yields by 19%. Without adequate fertilisation, the world's output of the key agricultural produce would be smaller by half[60].

### CASE 1: TOMATO

The study was carried out to investigate the environmental impact of fertilisation of tomatoes using home compost, industrial compost and mineral fertilisers during a year. Where mineral fertilisers were used, tomato yield was 37.6 tonnes per hectare – 5% higher than in the case of application of industrial compost and 1/3 higher than after fertilisation with home compost. Home compost turned out to be the best for the environment in the analysed year: it proved to be better than industrial compost or mineral fertilisers in all categories except from soil acidification. Mineral fertiliser had a greater impact on climate change, water eutrophication and consumption of fossil resources, while the use of industrial compost required more energy and made a 25% higher contribution to the depletion of the ozone layer[61]. The study did not consider how the environmental impact of each type of fertilisers would increase if it was counted per one tonne of tomatoes rather than per one year. It can be estimated that in such a case, in terms of energy consumption, impact on the ozone layer and eutrophication of freshwater as well as consumption of fossil resources, the results for mineral fertilisers would be comparable even to those for home compost. Two categories in which a mineral fertiliser is always worse are the contribution to climate change and the eutrophication of saline water.

**Conclusion: from the environmental point of view, home compost is the best fertiliser for tomatoes, but given its small production volumes it cannot replace artificial fertilisers.**

### CASE 2: CAULIFLOWER

The study was carried out to investigate the environmental impact of fertilisation of cauliflowers using home compost, industrial compost and mineral fertilisers during a year. Where mineral fertilisers were used, cauliflower yield was 8.6 tonnes per hectare, 25% higher than in the case of application of industrial compost and

57 Ibidem.

58 W.M. Stewart, T.L. Roberts, *Food Security and the Role of Fertilizer in supporting it*, https://core.ac.uk/download/pdf/82098360.pdf (August 7th 2019).

59 Food and Agriculture Organization in the United Nations, *State of Food Security Nutrition*, http://www.fao.org/state-of-food-security-nutrition/en/ (August 8th 2019).

60 W.M. Stewart, T.L. Roberts, op.cit.

61 R. Quiros, G. Villalba, X. Gabarrell , P. Munoz, *Life cycle assessment of organic and mineral fertilizers in a crop sequence of cauliflower and tomato*, http://www.bioline.org.br/pdf?st15310 (August 9th 2019).

nearly twice higher than after fertilisation with home compost. As in the case of tomatoes, home compost proved to be the best for the environment in all categories except eutrophication of soils.

Mineral fertiliser:

- contributes to climate change more than organic fertilisers while compost, in some cases may have a negative impact on the progress of the global warming;
- always has a weaker effect on soil acidification;
- has a negligible effect on the eutrophication of seas and oceans, while organic fertilisers help reduce the amount of nitrogen in saline water;
- consumes less energy than compost per one tonne of crops;
- has a smaller contribution to depletion of the ozone layer than industrial compost, but greater than domestic compost;
- it has a similar impact on the eutrophication of freshwater as compost in the case of a per-year assessment, and lower impact in the case of a per-tonne-of-produce assessment;
- requires the use of a greater amount of fossil resources than industrial compost in the case of a per-year assessment and a similar amount in the case of a per-tonne-of-produce assessment[62].

**Conclusion: from the environmental point of view, home compost is the best fertiliser for cauliflowers, but given its small production volumes it cannot replace artificial fertilizers.**

The available technologies for large-scale production of biocomponents, bioplastics and biofertilisers are not better than conventional methods in terms of environmental impact. Replacing fossil resources with other materials as feedstocks in the production of petrochemicals does not reduce the adverse environmental impact, but transfers the impact from climate to soil and water. The biggest problem with fossil-based petrochemical production is the high emission rates, i.e. the impact on the climate. However, these elevated emission rates can be reduced using existing techniques.

## Is sustainable development of petrochemical production better than replacing petrochemicals?

The environmental impact of petrochemical production can be reduced at every stage of a product's life cycle, starting from extraction of crude oil or natural gas, through manufacturing of the final product, to end with product use and disposal

### PRODUCTION OF CRUDE OIL AND NATURAL GAS

The environmental impact of petrochemical production begins with exploration for oil and gas. Once the most prospective area has been chosen and a site visit has been made, seismic surveys begin. If the identified geological structures appear promising, exploratory drilling starts and if the initial boreholes are positive, more wells are drilled in order to determine the size of the petroleum field. Once the size of the field has been established, even hundreds of larger wells may be drilled. Initially hydrocarbons flow to the surface driven by the pressure differential. Once on the surface, flows are directed to the separator, which splits oil from gas and water . As a well matures, pressure in the reservoir must be increased artificially in order to drive the hydrocarbons to the surface. Various media are used to this end, mainly water and chemicals. However, the carbon sequestration process has been increasingly used for the purpose of increasing reservoir pressure in wells characterised by a rapidly falling production curve. In the process, $CO_2$ is injected deep underground and not only does it improve the well production rates and the financial parameters of an upstream operation, but also remains trapped underground (carbon capture and storage). However, this technology can only be used at sites with specific geological characteristics, which is a major limitation. After 20 to 40 years, a depleted reservoir is abandoned, which entails decommissioning of the buildings and structures and restoring appropriate natural environment for the flora and fauna, as well as incurring certain environmental and social costs (such as resettlements, noise, change of landcscape)[63]. Studies carried out in 2015, covering approximately 98% of the global oil production, have shown that on average, production of 1 barrel of oil and condensate emits 61.8 kg of $CO_2$.These emissions were the highest in Algeria, Venezuela and Cameroon, while Denmark, Saudi Arabia and Bahrain had the lowest emission rates. The studies have also demonstrated the existence of a link between flaring (burning unmarketable gases in flares) and venting (direct release of gas, mainly methane, into the environment) and GHG emission rates. It is estimated that 22% of the total greenhouse gas emissions from oil and gas production come from flaring. Also, higher emission rates are reported for extraction of heavy crudes and production of hydrocarbons from reservoirs which are close to depletion, due to higher energy consumption. Research indicates that the introduction of limits on venting (equal to the average emissions recorded at Norwegian petroleum fields in 2015) and flaring (no routine flaring,

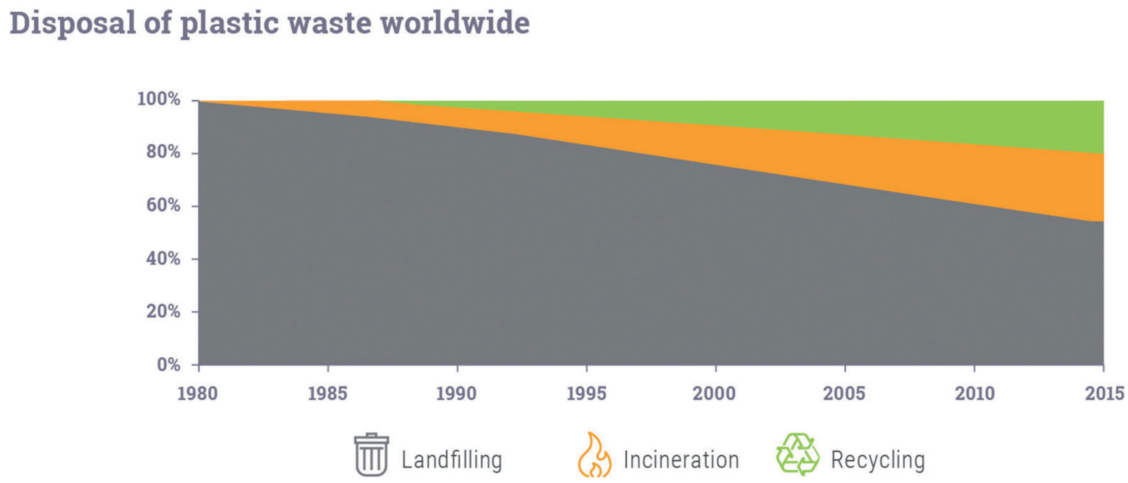
**And what about water?**

An average of 635 litres of water is used to produce one barrel of oil. A similar amount is needed to produce  coffee for as few as three cups*.

* Most of the water is used to grow coffee beans. Source: CNBC & Total, Five barrels of water for one barrel of oil, https:// www.cnbc.com/advertorial/2017/11/13/five-barrels-of-water-for-one -barrel-of-oil.html (July 18th 2019).

62 Ibidem.

63 E&P Forum and UNEP, *Environmental management in oil and gas exploration and production*, https://wedocs.unep.org/bitstream/handle/20.500.11822/8275/-Environmental%20Management%20in%20Oil%20&%20Gas%20Exploration%20&%20Production-19972123.pdf?sequence=2&isAllowed=y (July 7th 2019).




Source: In-house analysis based on R. Geyer, J.R. Jambeck, K.L. Law, op.cit.

flaring allowed only in the case of emergencies) would make it possible to cut average emissions by 30% to 43%. Emissions of another 5 kg of greenhouse gases per one barrel of oil produced could be eliminated if the equipment at production sites was powered with renewable energy instead of electricity generated using fossil fuels. Such a solution has already been implemented in Oman and in California[64]. Technologies that already exist could reduce emissions from oil and gas production even by more than 50%.

## PRODUCTION

Reducing emissions from oil and gas production is not the only way to reduce the environmental impact of petrochemical processing The simplest solution is to use low-carbon energy in the production processes. Nearly half of the greenhouse gas emissions, 12% of the environmental cost of water and land pollution, and 86% of the environmental cost of air pollution related to plastic production are due to the consumption of electricity generated mainly by burning fossil fuels. It is estimated that if plastic producers doubled the share of low-carbon energy in their total energy consumption, the full environmental cost of plastics (from hydrocarbon extraction to disposal of plastic items) would drop by 5%. In a hypothetical scenario of full transition to low-carbon sources, the harmful effects of plastics would be reduced by a quarter[65].

Additional ways to bring down the plastic-related emission rates, and consequently the impact of plastics on climate change, are $CO_2$ capture technologies. These include carbon capture and storage (CCS) and carbon capture and utilisation (CCU). Carbon dioxide combined with hydrogen can be used in the production of hydrocarbons, and in the future – on a large scale – also in the production of petrochemicals. By capturing $CO_2$ we can eliminate emissions of this compound into the atmosphere, and by using energy from renewable sources – start to produce low-emission petrochemical products. Currently, there are 18 ongoing $CO_2$ capture projects worldwide, which are expected to eliminate 40m tonnes of $CO_2$ per year[66].

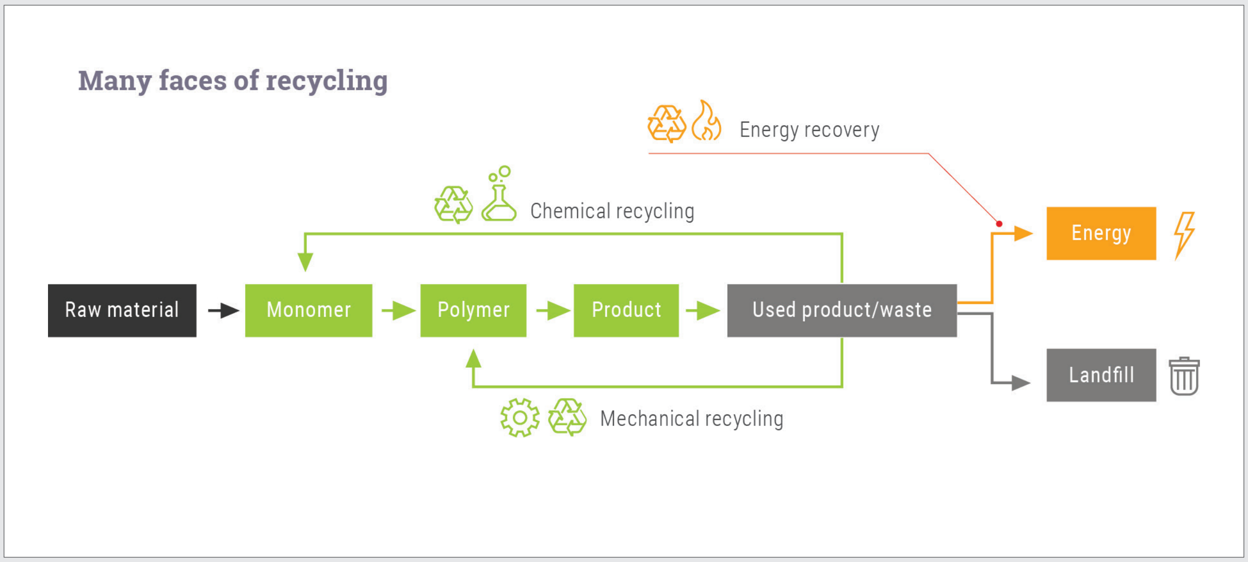
In addition to remodelling the production process, manufacturers could also modify the final product as such. Changes in the design of packaging may affect its weight, translating into a lower environmental cost of product manufacturing and transporting. In addition, packaging may be designed in such a way as to facilitate its subsequent reuse or waste treatment. Changing the design to make containers weigh less is by all means possible. For example, in 2012 the Coca-Cola Company reduced the weight of its 600 ml PET bottles by 25%. Studies indicate that a similar 30% reduction in the weight of packaging used in the food sector in Europe and North America would cut the environmental cost of all plastics in the sector by 5%[67].

64 M.S. Masnadi i in., *Global carbon intensity of crude oil production*, https://www.researchgate.net/publication/327328315_Global_carbon_intensity_of_crude_oil_production (August 7th 2019).

65 Trucost, op.cit.

66 Komisja Europejska, *The Potential For CCS And CCU In Europe Report To The Thirty Second Meeting Of The European Gas Regulatory Forum 5–6 June 2019*, https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf (August 16th 2019).

67 Trucost, op.cit.




There are three main types of recycling: mechanical recycling, chemical recycling, and energy recovery.

**Mechanical recycling** (material recycling) consists of shredding post-use products. The mechanical recycling process begins in a sorting plant, where waste comprising various polymers is sorted and separated from the composite material, that is material made of a few different components. If the sorting plant is not located on the site of a processing plant, waste consisting of one type of polymer is pressed into bales and transported or otherwise goes straight onto the washing line, where impurities, mostly organic, are removed. The washed waste is sent to a mill, where it is shredded into flakes. These can be used directly to manufacture a new product or to make granules, which are easier to further process than flakes[1]. The final product of the mechanical recycling process often has worse mechanical properties than the original product, and its quality heavily depends on the quality of the sorting and washing processes. Thermoplastics are particularly suitable for mechanical recycling because they do not lose their properties during the melting and hardening processes, so they can be converted with no major loss to quality[2].

**Chemical recycling** (feedstock recycling) consists of converting plastic waste into chemicals that can be used as feedstock by the chemical industry. The technologies used to obtain monomers, oligomers and higher hydrocarbons from plastic waste include mainly pyrolysis, gasification, chemical depolymerisation, catalytic cracking, reforming, and hydrogenation. The chemical recycling product has the same properties as the primary product, and the plastic waste does not need to be sorted. There is no single generally accepted definition of chemical recycling. Sources mention energy recovery or only selected energy recovery methods as belonging to this category[3]. For the purposes of this report, chemical recycling and energy recovery are defined as separate waste treatment methods.

**Energy recovery** is the processing of post-use plastics to generate electricity and heat, mainly through incineration. By replacing fossil fuels in the energy industry with high-calorific plastic waste, the energy contained in fossil fuel can be used twice: first to produce the plastic and then to generate energy.

1 K. Ragaert, L. Delva, K. Van Geem, *Mechanical and chemical recycling of solid plastic waste*, https://www.researchgate.net/publication/319189954_Mechanical_and_chemical_recycling_of_solid_plastic_waste (August 8th 2019).

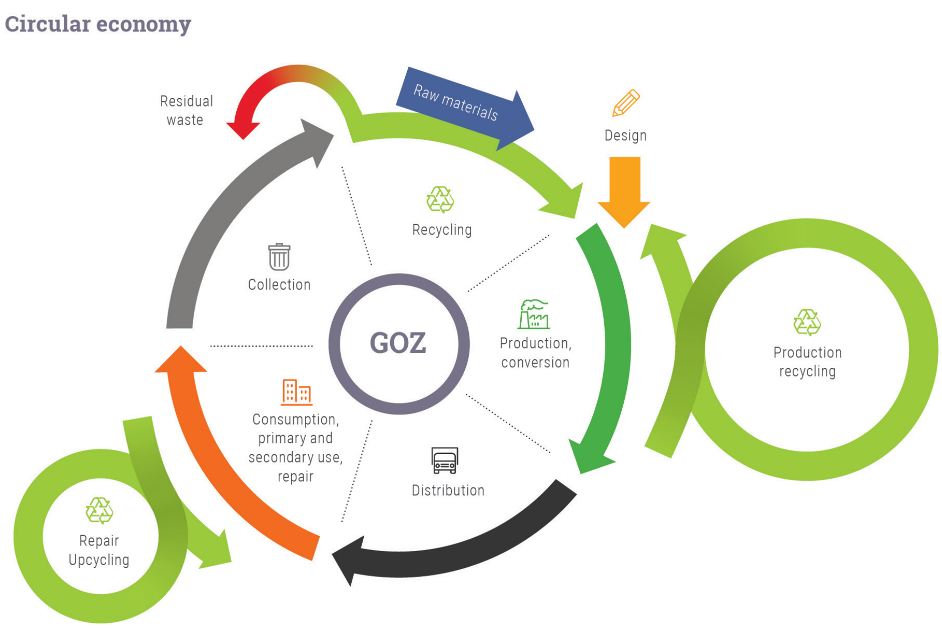
2 Plastics Europe, *Recycling and Energy Recovery*, https://www.plasticseurope.org/en/focus-areas/circular-economy/zero-plastics-landfill/recycling-and-energy-recovery (August 8th 2019).

3 Plastics Recyclers Europe, *Chemical Recycling*, https://www.plasticsrecyclers.eu/chemical-recycling (August 8th 2019).

**What is circular economy?**

**Circular economy** is a concept aiming at rational use of resources and mitigation of adverse environmental impacts of manufactured goods, which – in common with materials and raw materials – should remain in the economy as long as possible, with waste reduced to a minimum[1]. In circular economy:

- raw materials are used efficiently;
- products are designed to be made of the smallest possible amount of the raw material and to be reused;
- products are distributed using low-carbon means of transport;
- new products are bought only when necessary, then used repeatedly, repaired and disposed of only when they are no longer useful;
- waste is collected and sorted, and used as input for further production.




1. Ministerstwo Środowiska (MInistry of the Environment), Gospodarka o obiegu zamkniętym [Circular Economy], https://www.gov.pl/web/srodowisko/goz (August 26th 2019).

## DISPOSAL

A vast majority of plastic waste is stored – in 2015, 55% of waste produced globally was legally landfilled or illegally dumped. However, incineration and recycling are gaining prominence as waste management methods. Since 2000, the share of incinerated and recycled plastic waste has grown at an annual rate of 3.6% and 5.3%, respectively[68].

Most of the plastics manufactured today are suitable for mechanical recycling, which could translate into an almost tenfold reduction in carbon emissions compared with plastics obtained from the virgin polymer. Any non-mechanically-recyclable plastics could be treated chemically, saving up to 75% of greenhouse gas emissions compared with plastics derived from fossil resources[69].

68 R. Geyer, J.R. Jambeck, K.L. Law, op.cit.

69 Material Economics, *The Circular Economy a Powerful Force for Climate Mitigation. Transformative innovation for prosperous and low-carbon industry*, https://europeanclimate.org/wp-content/uploads/2018/06/FINAL-MATERIAL-ECONOMICS-CIRCULAR-ECONOMY-SUMMARY.pdf (August 6th 2019).

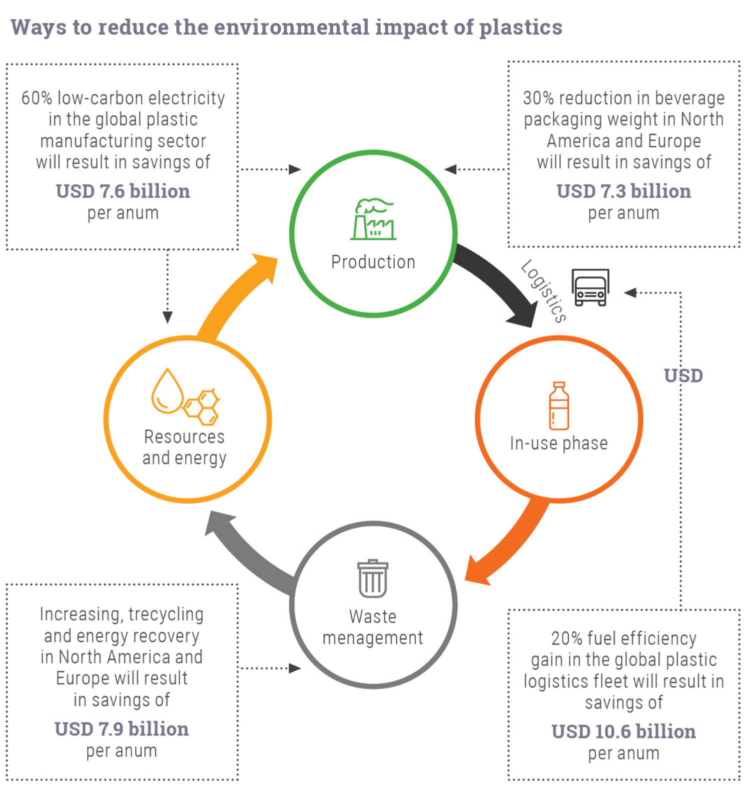
By properly designing products to extend their life cycle and making them recyclable, we can transition from linear economy, where goods are produced, used and thrown away, to circular[70], or closed-loop, economy.

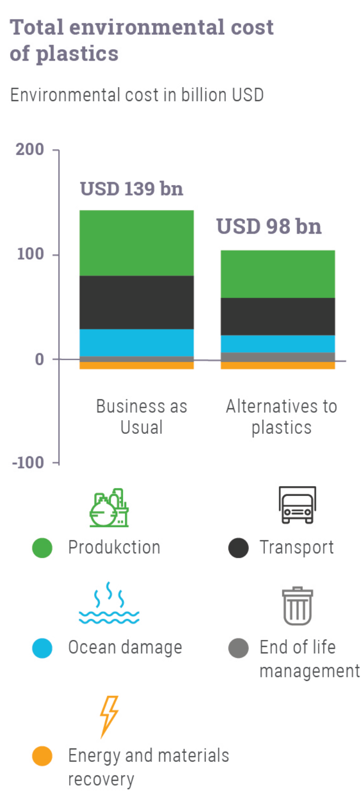
## So, what is the verdict??

A petrochemical production process that has been responsibly designed and implemented brings benefits to the environment and society alike. Research indicates that a few changes to the plastic manufacturing process could reduce the cost to the environment from USD 139bn to USD 98bn, that is by almost a third. However, the changes would have to cover the entire life cycle of products[71].

Reducing the environmental cost of plastics by a third would entail shifting to low-carbon energy in petrochemical production. Based on research findings, a 60% share of low-carbon sources (nuclear and renewable) in the energy mix used in petrochemical production would cut the environmental cost by over 5%. The product design stage should also be modified – achieving a 30% reduction in the weight of packaging used by the food sector in Europe and North America alone would curtail the adverse impact of plastics by a further 5%. Such changes could be implemented around the globe in the long term. Increasing the fuel efficiency of vehicles used for carrying plastic goods would generate the biggest savings, as cutting fuel consumption by a fifth would translate into a roughly 8% reduction in environmental costs. Recycling in developed countries would in turn bring further environmental benefits[72].

In addition to the changes that have already been measured in terms of their environmental impact, there is potential for implementing other environmentally-beneficial solutions in the petrochemical sector. The industry can reduce flare combustion and capture $CO_2$ from stacks and flares and then use it as a feedstock for petrochemical production. Petrochemical companies do not have to be polluters, and responsible production and use of petrochemicals can bring many positive effects to the public and the environment.




Source: In-house analysis based on Trucost, op.cit.

70 For more information, see the report *Pillars of Business Sustainability. Vision, raw material resources, talent.*

71 Trucost, op.cit.

72 Ibidem.

# Part 3. The future

THE AVAILABILITY OF CRUDE OIL AND NATURAL GAS, THE PROPERTIES OF PETROCHEMICAL MATERIALS AND THEIR LOWER ENVIRONMENTAL FOOTPRINT OVER THE PRODUCT LIFE CYCLE COMPARED WITH ALTERNATIVES, FUEL THE GROWTH OF THE PETROCHEMICAL INDUSTRY.

## Demand for petrochemical products is set to grow

Despite their environmental impacts, demand for petrochemical products is set to grow. At today's rates, demand for basic chemicals is going to increase by 50% by 2030, double by 2050, and rise fourfold by the end of this century[73]. This means that in 30 years' time the annual chemical output will amount to roughly one billion tonnes. Even if the chemical industry is forced to reduce its emissions by 60% by 2050 (in the alternative scenario), petrochemical production will not drop, as consumption of basic chemicals is forecast to increase by 30% in 2030 and by 40% in 2050[74].

### GROWING AND INCREASINGLY WEALTHY POPULATION

The world population will grow by 13% and almost 30%[75] by 2030 and 2050, respectively, which means that even in the alternative scenario petrochemical consumption per person is bound to rise.

Plastic consumption per capita will also increase, with the largest growth expected in the coming years in China, at an average annual rate of 4.6%[76]. Plastic consumption per capita rises as society becomes more affluent, and the countries with the most rapid population growth rates (Nigeria, Pakistan, Egypt) will soon be among the nations with the fastest growing wealth[77]. The consumption of plastic per capita is also on the rise

**Basic chemicals** are those that have no direct applications, but are used to make other chemicals. A case in point is ethylene, used mainly in the production of polyethylene, a polymer used to make plastic bags. Basic chemicals include ethylene, propylene, benzene, toluene, xylene, methanol, and ammonia.

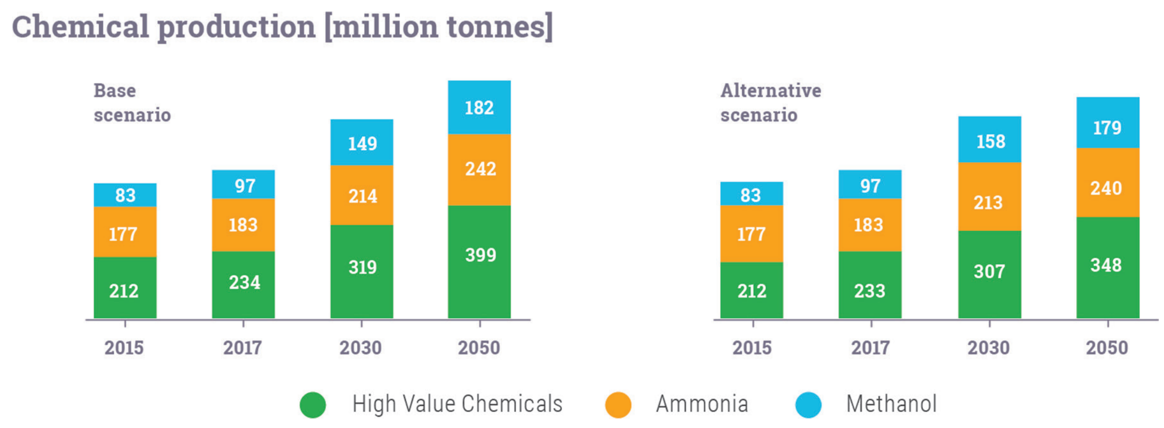
73 Material Economics, op.cit.

74 International Energy Agency, op.cit.

75 United Nations, *World Population Prospects 2019*, https://population.un.org/wpp/ (July 18th 2019).

76 Euromap, op.cit.

77 PwC, *The Long View How will the global economic order change by 2050?*, https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf (July 19th 2019).



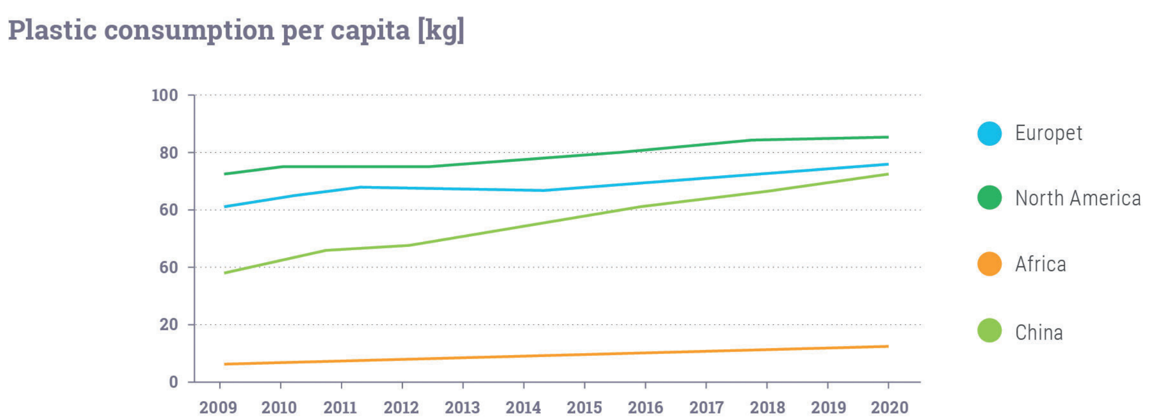

Source: In-house analysis based on International Energy Agency, op.cit.

in developed countries, although the rate of this growth is more than twofold lower than in developing countries[78].

## URBANISATION

The growing population is not the sole factor contributing to the rise in petrochemical consumption. Urbanisation is another one. The share of population living in urban areas will increase in the near future, with the fastest growth expected in developing countries. About 9% of the global population is predicted to be living in 41 megacities (with populations exceeding 10 million people) by 2030, 29 of which will be in Asia. However, the continent urbanising at the fastest rate will be Africa, with the population of Kinshasa, the capital of the Democratic Republic of Congo, to rise 100-fold, from 200,000 in 1950 to 20 million in 2030. In the same year, the population of Lagos in Nigeria will be 24 million[79].

As cities expand, so will the number of roads, bridges, tunnels and buildings, with skyscraper numbers growing even faster. There will be 6,800 skyscrapers

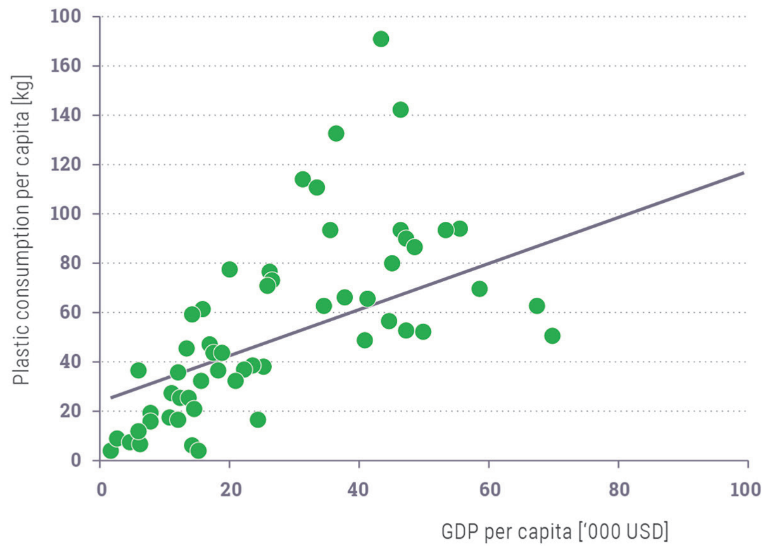



Source: In-house analysis based on Euromap, Plastics Resin Production and Consumption in 63 Countries Worldwide, http://www.pagder.org/images/files/euromappreview.pdf (July 18th 2019).

78 Euromap, op.cit.

79 The Economist, *Bright lights, big cities*, https://www.economist.com/node/21642053 (25.07.2019).

**Correlation between plastic consumption and GDP in 2015**




Source: ibidem.

**Geofoam,** made from expanded polystyrene, is a material used for filling and levelling the surface for constructing buildings. It is approximately 100 times lighter than soil and 10 times lighter than other fill alternatives, making it a convenient and durable material used for applications where other materials fail. For instance, it is used in road and railway pavements where the soil is too loose, as well as for slope stabilisation.

If added to cement, polystyrene reduces its viscosity, allowing it to be easily pumped to the top floors of skyscrapers under construction. The technology was used to build the world's tallest building, the Burj Khalifa Hotel in Dubai.

Source: D. Wisne, High Performing Buildings, Nine Ways Chemistry Contributes to High Performing Buildings, http://www.hpbmagazine.org/Nine-Ways-Chemistry-Contributes-to-High-Performing-Buildings/ (July 22nd 2019).

per one billion people in 2050 compared with 800 skyscrapers in 2018. Buildings will also be taller. Today, the tallest building is 828m high, but 2020 is expected to see the first building rising 1 km above ground. In 2050, the tallest building will be 1,134m high, although there is a 9% chance it will surpass one mile, or approximately 1,600m, in height[80]. The construction of better roads, stronger bridges, and more and taller buildings requires the use of specialty chemicals

There is also a correlation between the urbanisation level and plastic consumption.

More urbanised countries tend to use more plastic than their less urbanised counterparts, which is due to the use of plastic resins in urban construction but also to the wider application of plastic packaging by the food and restaurant industry, and the availability of household appliances and electronics[81].

## ENERGY-EFFICIENT BUILDINGS

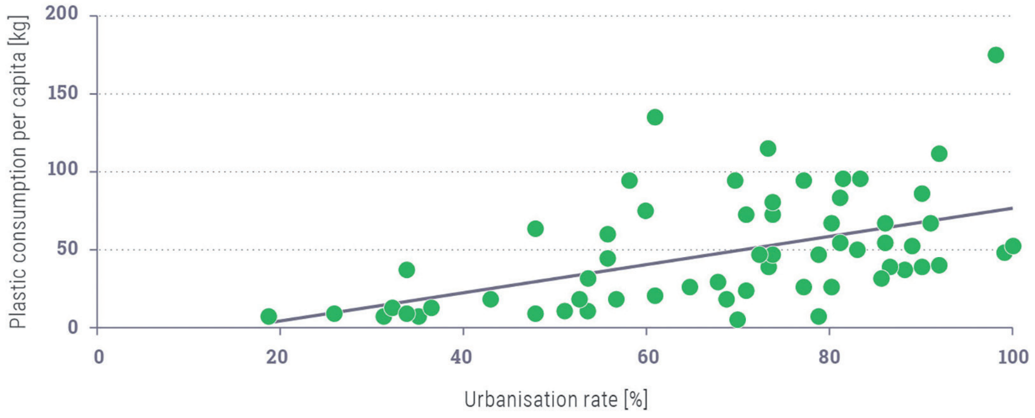
Energy use in buildings has increased by approximately 40% since 1995, and today buildings are the direct source of one-tenth of global $CO_2$ emissions. Adding indirect emissions from generation of the electricity used to power the buildings, the figure is nearly 30%, exceeding transport emissions[82]. Europe had 160 million buildings in 2010,

80 MIT Technology Review, *Get ready for more and taller skyscrapers*, https://www.technologyreview.com/s/611878/get-ready-for-more-and-taller-skyscrapers/ (July 19th 2019)).

81 United Nations, op.cit. oraz Euromap, op.cit.

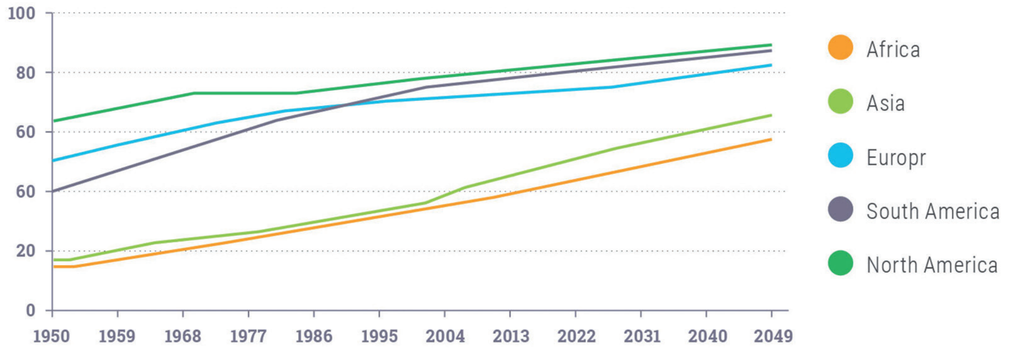
82 BP Energy Outlook 2019, op.cit.

## Correlation between plastic consumption and the urbanisation rate in 2015




Source: ibidem.

## Urbanisation rate [%]




Source: In-house analysis based on United Nations, World Urbanization Prospects: The 2018 Revision, https://data.worldbank.org/indicator/sp.urb.totl.in.zs?end- =2015&start=1960 (July 19th 2019).

In 2012, direct emissions from buildings in the UK accounted for 37% of national greenhouse gas emissions, or 91 million tonnes of $CO_2$. Insulation of the existing buildings would reduce emissions by 5.2 million tonnes of $CO_2$, or about 6%.

Source: Committee on Climate Change, Fourth Carbon Budget Review - technical report, https://www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Chap3_1.pdf (July 25th 2019).

most of them built before 1990 and half of them built before 1960. With new buildings accounting for a mere 1% of the total, renovating the old ones makes more environmental sense than focusing only on new projects. According to estimates, major retrofitting of buildings could reduce their carbon footprint by 36% by 2030[83].

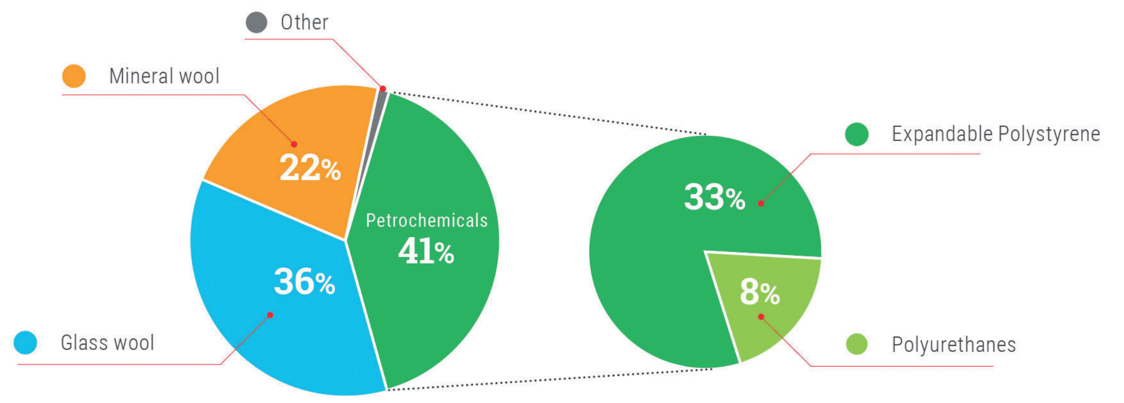
Thermal insulation is used to alleviate emissions from buildings. In addition to reducing heat losses and increasing thermal comfort, it prevents damaging accumulation of moisture, increases the durability of buildings and reduces their operating costs[84]. The insulation materials most commonly used in Europe are glass wool, expanded and extruded polystyrene, mineral wool, and polyurethanes. The consumption of thermal insulation of petrochemical origin is expected to rise the fastest, with its share reaching 46% in 2025[85].

## ELECTROMOBILITY AND VEHICLE WEIGHT REDUCTION

The average vehicle weight rose with the growing customer expectations as to performance, comfort, safety, and technological advancement. A car in 2005 weighed on average 10% more than a car in the 1990s[86]. Research shows that emissions from a vehicle increase with its weight, and growing environmental awareness has forced manufacturers to search for methods to lightweight vehicles while maintaining the quality expected by consumers. The use of petrochemicals by the automotive industry helps to improve the appearance and safety of vehicles and to reduce $CO_2$ emissions. With plastic, the weight of vehicles can be cut down by 200–300 kg, and a 50 kg reduction in weight translates into a 5–8.5 g/km decrease in carbon emissions[87].

Most major car manufacturers have reduced the weight of new vehicles compared with older models. For instance, the 2016 Ford F-150 weighs 288 kg less than the 2014 model, and Chevrolet Camaro shed 10% from its weight in one year[88].

### Thermal insulation sales in Europe in 2015




Source: In-house analysis based on the European Commission, JRC Technical Reports. Competitive landscape of the EU's insulation materials industry for energy-efficient buildings, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108692/kj1a28816enn.pdf (July 25th 2019).

83 European Commission, op.cit.

84 KEA Climate Protection and Energy Agency of Baden-Württemberg GmbH, *The significance of thermal insulation*, http://www.buildup.eu/sites/default/files/content/the_significance_of_thermal_insulation.pdf (July 25th 2019).

85 European Commission, op.cit.

86 International Council On Clean Transportation, *Lightweighting Technology Developments*, https://theicct.org/sites/default/files/publications/PV-Lightweighting_Tech-Briefing_ICCT_07032017.pdf (July 25th 2019).

87 DuPont, *Wehicle Weight Reduction for Optimal Performance*, https://www.dupont.com/industries/automotive/articles/lightweighting.html (12.07.2019) oraz Bax & Willems, op.cit.

88 International Council On Clean Transportation, *Lightweighting Technology Developments*, https://theicct.org/sites/default/files/publications/PV-Lightweighting_Tech-Briefing_ICCT_07032017.pdf (July 25th 2019).

The battery installed in an average electric car can weigh over 500 kg, representing up to 25% of the total vehicle weight[89]. Lighter batteries further reduce the weight of a vehicle, leading to a secondary range extension, and enable the use of an even smaller battery with other properties remaining intact

## European petrochemicals have a future

Europe understands the good and bad sides of petrochemicals. The European plastics market is mature. Having recovered from a decline triggered by the 2008 financial crisis, it is growing steadily at a rate of around 1% per year. The European Union alone currently consumes 49 million tonnes of plastic per year, which is over 100 kg of plastic per person. The ongoing shift towards lightweight packaging materials and vehicles and the growing use of thermal insulation will drive a further increase in plastic consumption, to 62 million tonnes by 2050. The plastics industry in Europe provides over 1.5 million jobs across 60,000 companies and a further three-fold that in neighbouring sectors. In 2017, the European plastics industry contributed EUR 32.5bn (i.e. nearly PLN 140bn) to public finances in

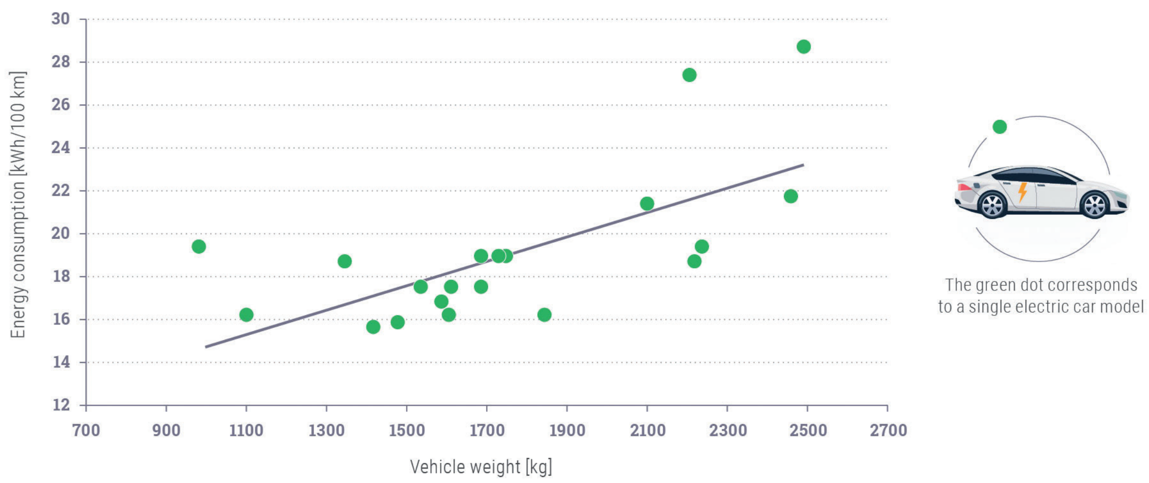
There are around 600,000 cars on the streets of Barcelona that emit about half of the total carbon dioxide emissions generated by the city. A 100 kg reduction in their weight would help to cut annual $CO_2$ emissions by 30,000 tonnes and the city's total emissions by 1%.

Source: Bax & Willems, Lightweighting automotive past, present and future collaborative R&D&i, https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/sites/default/files/report/The%20Role%20of%20Lightweight%20in%20Today%E2%80%99s%20an%20Tomorrow%E2%80%99s%20Car%20Manufacturing.pdf (25.07.2019) and Ajuntament deBarcelona, Barcelona's Commitment to the Climate, http://eldigital.barcelona.cat/wp-content/uploads/2016/10/Barce-lona-Commitement-to-Climate-1.pdf (August 9th 2019).

Replacing 100,000 traditional combustion-engine vehicles moving on the streets of Barcelona with electric cars would help reduce $CO_2$ emissions by another 90,000 tonnes per year. Thus, the environmental costs borne by the city each year would drop by EUR 28m.

Source: Bax & Willems, op.cit.

### Corellation between vehicle weight and consumption of energy needed to drive 100 km




Source: in-house analysis based on Fuel Economy, Office of Energy Efficiency & Renewable Energy, https://www.fueleconomy.gov/ (July 16th 2019); Electric Vehicle Database, Compare hybrid and electric vehicles, https://ev-database.org (July 26th 2019); OPEL product catalogue, https://www.opel.pl/ (July 26th 2019); Renault product catalogue, https://www.renault. co.uk/vehicles/new-vehicles/zoe.html (July 26th 2019) and Citroen product catalogue, https://www.citroen.com/en/ (July 26th 2019).

89 D. Berjoza, *Influence of Batteries Weight on Electric Automobile Performance*, http://www.tf.llu.lv/conference/proceedings2017/Papers/N316.pdf (July 25th 2019).

90 Material Economics, op.cit.

**Economies of scale** – a long-term reduction of the average per-unit total production costs of a given product as the level of output increases.

the form of taxes and charges, and ranked 7th in Europe in industrial value added contribution [91].

## IS PETROCHEMICAL PRODUCTION PROFITABLE IN EUROPE TODAY?

The European petrochemical industry is in transitional period. It has always been recognised globally and renowned for its premium quality. What gives Europe a competitive edge over other regions is still the same factors, i.e. qualified workforce, expertise, experience, highly integrated production, strong infrastructure, and a plethora of suppliers and service providers. The integration of petrochemical production also affects its profitability.

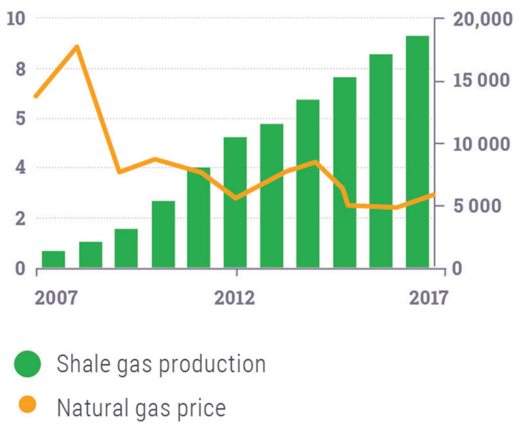
However, the position of the European petrochemical industry is now under threat. In other regions operators have access to cheaper raw materials (including natural gas, which is less expensive than oil), regional authorities subsidise industry, and the customer base is expanding at a faster pace, if only due to population growth. Economies of scale bring tangible benefits, too[92].

## THE US SHALE GAS REVOLUTION

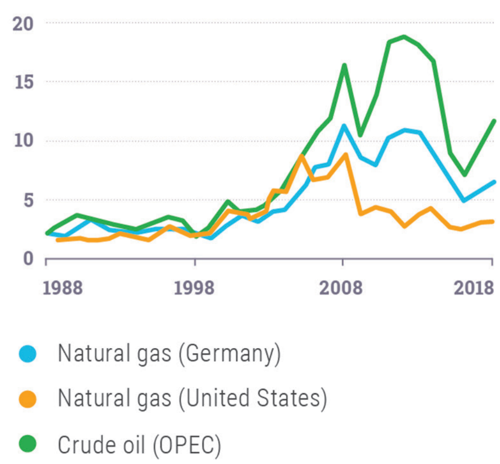
The unconventional gas boom, which began in the United States in 2005, started the shale gas revolution. In 2015, shale gas accounted for 45% of total gas output in the United States, while in Canada shale gas production grew threefold in 2010–2015. Improved technology helped reduce the cost of shale gas production by 25%–30%[93] in just three years (2012–2015). The prospects of low production costs and high availability, coupled with low initial capital requirements, led to a fast growth in production volumes and price declines.

Although it is widely believed that the cost of shale gas production is below

**Impact of shale gas production volumes on gas prices in the United States**




**Oil and gas prices (USD/MMBtu)**



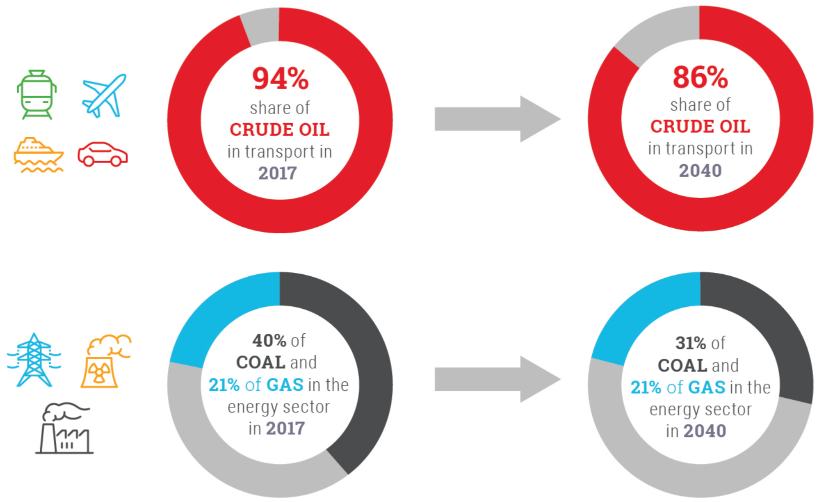

Source: in-house analysis based on EIA, Henry Hub Natural Gas Spot Price, https://www.eia.gov/dnav/ng/hist/rngwhhda.htm (August 9th 2019); EIA, Shale Gas Production, https:// www.eia.gov/dnav/ng/ng_prod_shalegas_s1_ a.htm (August 9th 2019); BP Statistical Review of World Energy 2019 - Crude Oil, https://www.bp.com/content/dam/bp/business-sites/en/glo- bal/corporate/pdfs/energy- economics/statistical-review/bp -stats-review-2019 -oil.pdf (August 7th 2019); BP Statistical Review of World Energy 2019 - Natural Gas, https://www.bp.com/ content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-natural-gas.pdf (August 7th 2019).

91 Plastics Europe, *Plastics – the Facts 2018. An analysis of European plastics production, demand and waste data*, https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf (July 15th 2019).

92 The European Petrochemical Association, *The Role of Clusters in the Chemical Industry*, https://newsroom.epca.eu/wp-content/uploads/2017/02/946705.pdf (August 9th 2019).

93 M. Mistré, *Shale gas production costs: historical developments and outlook*, http://www.insightenergy.org/system/publication_files/files/000/000/067/original/RREB_Shale_Gas_final_20170315_published.pdf?1494419889 (August 9th 2019).

**Energy mix evolution**




Source: in-house analysis based on BP Energy Outlook 2019, op.cit.

USD 3/MMBtu, the producers' annual reports show otherwise. Cabot, Range and Antero, shale gas producers operating in the eastern part of the United States, spent USD 1.43 for every dollar they earned in 2016, which means that the costs they incurred at that time exceeded their revenues. In the case od Chesapeake, another producer, the size of losses it reported for a year made it unable to cover operating expenses. According to Forbes, the minimum price at which shale gas production is profitable is USD 4/MMBtu, i.e. one third more[94].

## LARGE PETROCHEMICAL PLANTS IN CHINA

China is the largest and the fastest growing market for petrochemical products. It is estimated that in the next ten years China will account for half of all global growth in demand for petrochemicals[95], and in the next five years its production capacities will increase by 60%[96], with nearly a third of that relying on coal as feedstock.

## THE FUTURE OF EUROPEAN PETROCHEMICALS

The European petrochemical sector uses mainly crude oil distillation fractions as feedstock, while the very dependence on oil is seen as a soft spot of the sector. The preferred solutions include replacing it with cheap natural gas and coal.

## WILL NATURAL GAS BE CHEAPER THAN CRUDE OIL IN THE FUTURE?

Not necessarily. Crude oil is mainly used in transport, but its importance to this sector is going to fade in the future. A similar scenario is expected in the case of coal: its share in the energy sector will decrease from 40% in 2017 to 31% in 2040[97]. Natural gas will be preferred as an energy carrier both in the automotive and the power sector because of the lower emission levels it generates. In the wake of changes in the energy mix, crude oil and coal prices may decline relative to gas prices in the long term, and the US producers will gradually lose their competitive advantage over their European peers.

## WHAT ABOUT CHINA?

On the other hand, Europe is threatened by China and Asian investments in mega production plants. The new production capacities will primarily cover the internal demand, but this will result in a reduced demand for imports. China currently imports approximately 38 million tonnes of base petrochemicals, mainly from the United States and the Middle East[98]. Therefore, the volumes produced

94 A. Berman, *Shale Gas Is Not A Revolution*, https://www.forbes.com/sites/arthurberman/2017/07/05/shale-gas-is-not-a-revolution/#986c1a831b57 (August 9th 2019).

95 Wood Mackenzie, *Is the outlook for China's petrochemicals market hanging in the balance?*, https://www.woodmac.com/news/opinion/outlook-china-petrochemical-market-balance/ (August 9th 2019).

96 In-house estimates.

97 BP Energy Outlook 2019, op.cit.

98 In-house estimates.

in these two regions will need to be placed on other markets.

## WILL THE EUROPEAN MARKET BE FLOODED WITH PETROCHEMICALS PRODUCED IN THE US?

Not necessarily. Ten largest producers in the US also have a two-thirds share of the European market. If they were to enter Europe, this would result in a decline in average product prices and thus the 'cannibalisation' of their profits. Things are altogether different in Asia. At present, the companies with a joint 90% share in the US petrochemical production have only a 7% share in the Eastern market.

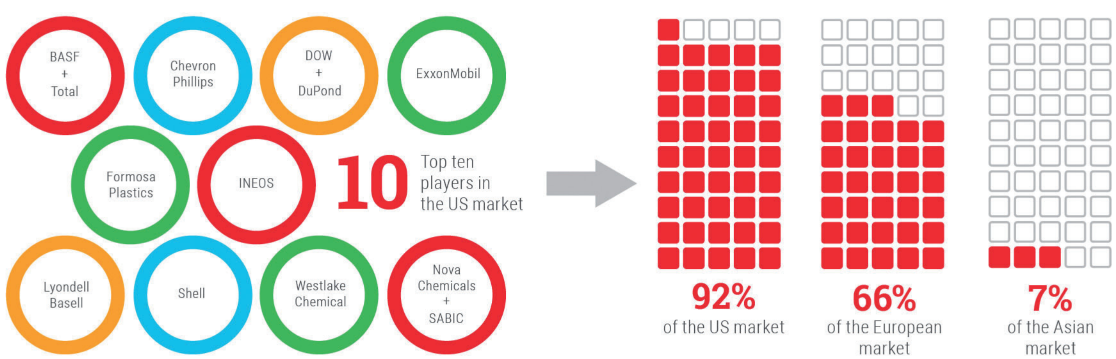
## WHAT ABOUT ECONOMIES OF SCALE?

In the United States, average annual production capacity of a cracker, i.e. a unit producing olefins, is 700,000 tonnes of ethylene. In Europe, it is 30% lower. Europe also has fewer (only 4% vs 34% in the US) mega-plants, i.e. crackers producing over 1m tonnes of ethylene per annum, while some projects currently under construction include units with annual capacities in excess of as much as 2m tonnes. Thus Europe faces rationalisation of its older and smaller petrochemical plants, which may involve the construction of larger plants to expand the production scale.

## WHAT ABOUT COMPETITION FROM BIO-BASED PRODUCTS AND ENVIRONMENTAL PROTECTION?

Chinese products, especially those based on coal, pollute the environment more than their European counterparts, which are produced using crude oil and meet the most stringent environmental requirements. This will also be the case with all products reaching European consumers from overseas, as the environmental cost of transport may outweigh the economic advantage of feedstock costs. With the introduction of a carbon footprint tax or other environmental charges, European products will prevail on local markets even under adverse macroeconomic conditions. In Europe, there is room not only for conventional petrochemical operations, but also for bio-based products. The key is spending on research and development (R&D). Leading petrochemical companies invest in research into both petroleum and bio-based chemicals. Correlation has also been observed between the amount of R&D expenditure and financial performance. Each Polish złoty spent on R&D activities translates into a PLN 2.3 increase in EBITDA (earnings before interest, taxes, depreciation and amortisation)[99]. Some companies in the sector boast an even higher return on their R&D investments. ExxonMobil expects to earn more than USD 5 on each US dollar invested[100].

**Share of the global petrochemical market covered by top 10 US players**

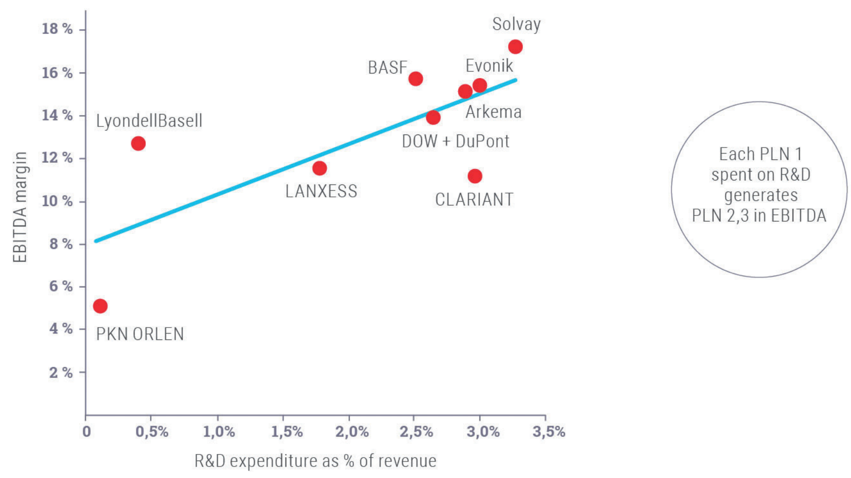



Source: In-house analysis based on IHS.

99 In-house study based on Arkema, BASF, Clariant, DOW DuPont, Evonik, Lanxess, LyondellBasell and Solvay reports.

100 ExxonMobil, *Raport roczny 2017.*

**Effect of R&D expenditure on the financial performance of a petrochemical company**




Source: In-house study based on Arkema, BASF, Clariant, DOW DuPont, Evonik, Lanxess, LyondellBasell and Solvay reports.

## Polish petrochemicals have a future

The petrochemical sector is the backbone of economy in any country. It develops innovative products, which are becoming more and more useful and common thanks to new materials with sophisticated characteristics, or cheap plastics that allow the general public to enjoy civilisational achievements, such as computers, smartphones, cars, household appliances, exercise equipment, etc.

Polish petrochemical industry is also a major employer on a nationwide scale. Its development contributes to the general welfare of the state and society. In 2017, 302 thousand people were employed in 11,000 enterprises operating in the Polish chemical sector. Every single job in the chemical industry generates another two to eight jobs in other sectors. In 2017, companies from the chemical industry made investments worth over PLN 11bn, of which 27% was invested in R&D, and the value of production sold was in excess of PLN 240bn. The largest share of the total sales was represented by petroleum products (about 30%) and fertilisers (about 20%)[101].

The Polish petrochemical industry is keeping pace with the global megatrends thanks to, among others, PKN ORLEN's efforts. With increasing consumption of petrochemical products, including plastics, the chemicals production capacities in Poland are growing. The Petrochemical Segment Development Program announced in June 2018 by PKN ORLEN S.A., with a budget of over PLN 8bn until 2023, is the largest investment project pursued in the sector. It assumes the implementation of three key sub-projects: construction of an Aromatic Derivatives complex, extension of the Olefins complex, and expansion of the Phenol production capacities. Implementation of The Petrochemical Segment Development Program, and in particular extension of the Olefins complex, will improve the availability of base chemicals to the ORLEN Group as well as to other chemical operators in the region, boosting industrial production and driving the growth of the entire economy. The project will be supported by a parallel development of the Group's R&D base and construction of the Research and Development Centre in Płock. Research and development activities are of fundamental importance to production of specialty chemicals, which are essential to the process of urbanisation and meeting the population's growing housing needs. Currently, every 4 out of 10 people in Poland live in overcrowded homes, which means that in order to catch up with the European average

101 Statistics Poland data.

by 2030, we would need to build 200,000 new dwelling units per year. It is precisely investments in R&D that are going to drive growth of the Polish chemicals sector, including in particular its construction chemicals segment, building insulation materials segment, and the segment of materials for the production of pipes and cables.

In Poland, we also see the need to close up the linear model of production so that plastics are used and disposed of according to the circular economy model. Production of good quality products based on recycled materials requires investments in research, and the Research and Development Centre in Płock may be the right platform to engage in such activities. Other Polish companies produce bio-based materials and use biological feedstocks as well. ORLEN Południe has signed a contract for the construction of Poland's first unit to produce eco-friendly propylene glycol. The new unit will have an annual production capacity of 30,000 tonnes of propylene glycol, covering as much as 75% of Poland's total demand for the product. Propylene glycol is a safe and environmentally-friendly product, with applications in medicine, cosmetics and the food industry.

In common with the rest of the world, Poland is moving towards electromobility. With this in mind, PKN ORLEN is increasing the number of its electric car charging points. By the end of 2019, approximately 50 fast charging points will be made available to motorists, followed by another 100 in the next few years. Electromobility is not only about the charging infrastructure, another important area being the production of batteries. By investing in The Petrochemical Segment Development Program, the Group will obtain capacities to produce the base chemicals needed to manufacture electrolytes for automotive batteries. The Program also addresses the issue of electromobility by redirecting the stream of gasolines currently used to make liquid fuels to the production of petrochemicals. This will extend the life of the Group's refining assets and enhance their profitability relative to the competition.

# Conclusions

In recent decades, crude oil and natural gas have become the most important raw materials used in the production of consumer and industrial goods, and petrochemicals have displaced some traditional materials such as metals, glass and wood. They owe their success to three main characteristics: wide availability and easy and inexpensive processing. Moreover, manufacturing of goods based on crude oil and natural gas is less energy-intensive compared with other materials, making petrochemical production less harmful in terms of emission rates. Oil and gas are too valuable and efficient raw materials to be abandoned, at least until the technological advancement brings better alternatives. Demand for petrochemicals will therefore continue to grow, which bodes well for the entire industry, although much has yet to change.

The petrochemical sector is currently undergoing a necessary transition. With growing public awareness in developed countries, there has been increasing pressure to reduce the use of plastics. Combined with tightening regulation, this public awareness has forced structural changes in the petrochemical industry. However, this should not be viewed as a threat, but rather as a long-term opportunity for the petrochemical industry to survive and reinforce its dominant role in today's world. The shift has been manifested in the growing share of recycling in the management of waste of petrochemical origin. There are a number of limitations, so the plastic recovery processes will ultimately reach the appropriate scale but this will require time and a lot of commitment at every stage of the product life cycle. The solution to the problem of emissions as well as the alarming build-up of waste is not just recycling, but closed-loop, or circular economy, covering not only plastics and petrochemicals but all the products and materials. Commitment to circularity should start with the producers of petrochemicals (who should use low-carbon technologies) and manufacturers of plastic end products (appropriate labelling of polymers), involve the general public (proper sorting of waste, reuse of products), and end with appropriate waste segregation and recycling infrastructure.

Increasingly frequent signs that the petrochemical industry companies are ready to take responsibility for their products exist side by side with the search for natural alternatives to petrochemicals. It should be remembered, however, that paper straws or bags, which are made using chemicals (e.g. caustic soda), are only a temporary solution. The same is true of bioplastics, whose production competes for farmland with the production of food and is therefore unlikely to reach an appropriate scale. The use of bio-components only causes one social problem, air pollution, to be substituted with a much more serious problem of malnutrition or hunger, while pollution of water and the environment continues. An ideal solution for the petrochemical industry in the transition period, i.e. until RES, the fourth energy resource besides oil, gas and coal, are adopted for the production of petrochemicals, is manufacturing of second-generation bioplastics based on agricultural waste. However, again in this case there are limitations related to the scale and availability of the feedstock of repeatable quality and properties.

Ultimately, therefore, the global petrochemical industry, people and producers of consumer goods should be given an opportunity and time to learn how to manage their waste wisely and be rational consumers. Sustainable development combined with closed-loop economy is the most cost-effective solution and offers the best effects for the public. The petrochemical sector also has a great opportunity ahead of it in the form of cheap or free renewable energy sources (RES), which will allow the industry to become a part of sustainable development that benefits everyone.

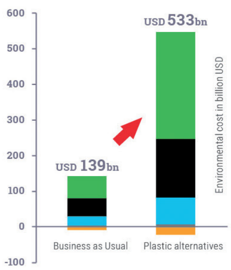
# How can the problem of plastic and petrochemical emissions be solved?

The growing pollution of the environment with plastic waste and the problem of industrial emissions require urgent action.

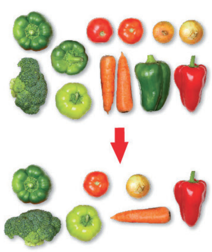
**There are two possibilities – to look for alternative solutions or improve what we have today.**

### Giving up plastic is not beneficial for the environment or the climate

For abandonment of plastic bags to have a positive environmental effect, bags made of other materials would have to be used **40 times** on average!




At the global economy level, a complete shift away from plastics would increase the environmental cost 3.8 times.



### Doing away with petrochemicals is not a solution, either

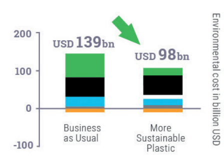
Artificial fertilisers help to grow more food.Inadequate fertilisation would cause crop yields to decrease by half.


Current technologies for the manufacture of bio-based plastics are no better for the environment than their fossil counterparts, causing environmental damage through soil and water pollution instead of emissions.

### Sustainable development is based on petrochemical products

Petrochemicals bring a range of benefits to the economy and the environment. For instance, they facilitate the development of electromobility and help reduce food wastage and transport emissions.


**The solution is to close the loop on products and materials** while extending the product life cycle and changing the consumption model.




Changes to production, transport and waste management processes would reduce environmental costs by 30%.

The technologies helping to reduce emissions from oil and gas extraction and processing are well-known. **When they are combined with green energy, zero-emission petrochemicals will emerge.**

## Petrochemicals have a future

# Bibliography


- Ajuntament de Barcelona, *Barcelona's Commitment to the Climate*, http://eldigital.barcelona.cat/wp-content/uploads/2016/10/ Barcelona-Commitement-to-Climate-1.pdf (August 9th 2019).
- Alliance To End Plastic Waste, *The Alliance Launches Today*, https://endplasticwaste.org/latest/the-alliance-launches-today/ (August 5th 2019).
- American Fuel & Petrochemical Manufacturers, *How Much Oil is in an Electric Vehicle?*, https://www.visualcapitalist.com/how-much-oil-electric-vehicle/ (July 17th 2019).
- Banking on Climate Change, *Fossil Fuel Finance Report Card 2019*, http://priceofoil.org/content/uploads/2019/03/Banking-on-Climate-Change-2019-final.pdf (August 1st 2019).
- Bax & Willems, *Lightweighting automotive past, present and future collaborative R&D&i*, https://ec.europa.eu/growth/tools-databases/ regional-innovation-monitor/sites/default/files/report/The%20Role%20of%20Lightweight%20in%20Today%E2%80%99s%20an%20 Tomorrow%E2%80%99s%20Car%20Manufacturing.pdf (July 25th 2019).
- BBC, *McDonald's paper straws cannot be recycled*, https://www.bbc.com/news/business-49234054 (August 28th 2019).
- Berjoza D., *Influence Of Batteries Weight On Electric Automobile Performance*, http://www.tf.llu.lv/conference/proceedings2017/ Papers/N316. pdf (July 25th 2019).
- Berman A., *Shale Gas Is Not A Revolution*, https://www.forbes.com/sites/arthurberman/2017/07/05/shale-gas-is-not-a-revolution/#986c1a831b57 (August 9th 2019).
- BP Energy Outlook 2019, http://www.bp.com/energyoutlook (July 18th 2019).
- BP Statistical Review of World Energy 2019 - Crude Oil, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/ pdfs/ energy-economics/statistical-review/bp-stats-review-2019-oil.pdf (August 7th 2019).
- BP Statistical Review of World Energy 2019 - Natural Gas, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/ pdfs/ energy-economics/statistical-review/bp-stats-review-2019-natural-gas.pdf (August 7th 2019).
- Business Insider, *In some countries, people face jail time for using plastic bags. Here are all the places that have banned plastic bags and straws so far*, https://www.businessinsider.com/plastic-bans-around-the-world-2019-4?IR=T (August 5th 2019).
- Center for International Environmental Law, *Facts & Figures of the European chemical industry 2018*, https://cefic.org/app/ uploads/2018/12/ Cefic_FactsAnd_Figures_2018_Industrial_BROCHURE_TRADE.pdf (July 12th 2019).
- Center for International Environmental Law, *Plastic & Climate The Hidden Costs of a Plastic Planet*, https://www.ciel.org/wp-content/ uploads/2019/05/Plastic-and-Climate-FINAL-2019.pdf (July 15th 2019).
- Clemson University, *Life Cycle Assessment of Grocery Bags in Common Use in the United States*, https://tigerprints.clemson.edu/cgi/ viewcontent.cgi?article=1006&context=cudp_environment (August 1st 2019).
- CNBC & Total, *Five barrels of water for one barrel of oil*, https://www.cnbc.com/advertorial/2017/11/13/five-barrels-of-water-for-one- barrel-of-oil.html (July 18th 2019).
- Committee on Climate Change, *Fourth Carbon Budget Review - technical report*, https://www.theccc.org.uk/wp-content/ uploads/2013/12/1785b-CCC_TechRep_Singles_Chap3_1.pdf (July 25th 2019).
- DuPont, *Vehicle Weight Reduction for Optimal Performance*, https://www.dupont.com/industries/automotive/articles/lightweighting. html (July 12th 2019).
- E&P Forum and UNEP, *Environmental management in oil and gas exploration and production*, https://wedocs.unep.org/bitstream/ handle/20.500.11822/8275/-Environmental%20Management%20in%20Oil%20&%20Gas%20Exploration%20&%20Production-19972123. pdf?sequence=2&isAllowed=y (July 7th 2019).

- EIA, *Henry Hub Natural Gas Spot Price*, https://www.eia.gov/dnav/ng/hist/rngwhhda.htm (August 9th 2019).
- EIA, *How much gasoline does the United States consume?*, https://www.eia.gov/tools/faqs/faq.php?id=23&t=10 (August 9th 2019).
- EIA, *Shale Gas Production*, https://www.eia.gov/dnav/ng/ng_prod_shalegas_s1_a.htm (August 9th 2019).
- Electric Vehicle Database, *Compare hybrid and electric vehicles*, https://ev-database.org (July 26th 2019).
- Ellen MacArthur Foundation, *New Plastics Economy Global Commitment*, https://www.ellenmacarthurfoundation.org/assets/ downloads/GC-Report-June19.pdf (August 5th 2019).
- Encyclopaedia Britannica, *Petrochemical*, https://www.britannica.com/science/petrochemical (July 15th 2019).
- Encyclopaedia Britannica, *Plastic*, https://www.britannica.com/science/plastic (July 15th 2019).
- Environment Agency, *Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006*, https://assets. publishing. service.gov.uk/government/uploads/system/uploads/attachment_data/file/291023/scho0711buan-e-e.pdf (August 1st 2019).
- EPS Industry Alliance, *Expanded Polystyrene (EPS) Geofoam Applications & Technical Data*, https://my.civil.utah.edu/~bartlett/ Geofoam/ EPS%20Geofoam%20Applications%20&%20Technical%20Data.pdf (July 22nd 2019).
- Euromap, *Plastics Resin Production and Consumption in 63 Countries Worldwide*, http://www.pagder.org/images/files/ euromappreview.pdf (July 18th 2019).
- European Commission, *JRC Technical Reports. Competitive landscape of the EU's insulation materials industry for energy-efficient buildings*, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108692/kj1a28816enn.pdf (July 25th 2019).
- Eurostat, *Agri-environmental indicator - greenhouse gas emissions*, https://ec.europa.eu/eurostat/statistics-explained/index. php?title=Agri-environmental_indicator_-_greenhouse_gas_emissions (August 1st 2019).
- Food and Agriculture Organization in the United Nations, *Greenhouse gas emissions from ruminant supply chains - A global life cycle assessment*, http://www.fao.org/3/i3461 e/i3461 e03.pdf (August 1st 2019).
- Food and Agriculture Organization in the United Nations, *Key facts and findings, GHG emissions by livestock*, http://www.fao.org/news/ story/en/item/197623/icode/ (August 29th 2019).
- Food and Agriculture Organization in the United Nations, *Key facts on food loss and waste you should know!*, http://www.fao.org/save- food/resources/keyfindings/en/ (August 1st 2019).
- Food and Agriculture Organization in the United Nations, *State of Food Security Nutrition*, http://www.fao.org/state-of-food-security-nutrition/en/ (August 9th 2019).
- Fuel Economy, *Office of Energy Efficiency & Renewable Energy*, https://www.fueleconomy.gov/ (July 16th 2019).
- Geyer R., Jambeck J.R., Law K.L., *Production, use, and fate of all plastics*, https://advances.sciencemag.org/content/3/7/e1700782 (July 15th 2019).
- Global Trade Review, *Barclays to stop funding for new thermal coal, Arctic oil projects*, https://www.gtreview.com/news/sustainability/ barclays-to-stop-funding-for-new-thermal-coal-arctic-oil-projects/ (August 9th 2019).
- Google Trends, https://trends.google.com/trends/explore?date=2004-01-01%202019-07-31&q=plastic%20ocean,plastic%20 waste,plastic%20pollution,zero%20waste (August 5th 2019).
- Greenpeace, *Stop single-use plastic!*, https://www.greenpeace.org/southeastasia/act/stop-single-use-plastic/ (July 17th 2019).
- International Council On Clean Transportation, *Lightweighting Technology Developments*, https://theicct.org/sites/default/files/ publications/ PV-Lightweighting_Tech-Briefing_ICCT_07032017.pdf (July 25th 2019).
- International Energy Agency, *The Future of Petrochemicals: Towards more sustainable plastics and fertilisers*, https://webstore.iea.org/ Content/Images/uploaded/The_Future_of_Petrochemicals_Methodological_Annex.pdf (July 18th 2019).
- *Citroen product catalogue*, https://www.citroen.com/en/ (July 26th 2019).
- *OPEL product catalogue*, https://www.opel.pl/ (July 26th 2019).
- *Renault product catalogue*, https://www.renault.co.uk/vehicles/new-vehicles/zoe.html (July 26th 2019).

- KEA Climate Protection and Energy Agency of Baden-Württemberg GmbH, *The significance of thermal insulation*, http://www.buildup. eu/ sites/default/files/content/the_significance_of_thermal_insulation.pdf (July 25th 2019).
- Kominers S.D., *People Make It So Hard to Ditch Plastic Straw*, https://www.bloomberg.com/opinion/articles/2019-07-15/people-make- it-so-hard-to-ditch-plastic-straws?utm_source=whatsapp&utm_medium=msg&utm_campaign=whatsap (July 17th 2019).
- European Commission, *Periodic Reporting for period 1 - Fresh Solutions (Fresh Solutions - 'A fresh approach to food packaging')*, https:// cordis. europa.eu/project/rcn/210402/reporting/fr (August 1st 2019).
- European Commission, *The Potential For CCS And CCU In Europe Report To The Thirty Second Meeting Of The European Gas Regulatory Forum 5-6 June 2019*, https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf (August 16th 2019).
- Masnadi M.S. et al., *Global carbon intensity of crude oil production*, https://www.researchgate.net/publication/327328315_Global_ carbon_ intensity_of_crude_oil_production (August 7th 2019).
- Material Economics, *The Circular Economy a Powerful Force for Climate Mitigation. Transformative innovation for prosperous and low- carbon industry*, https://europeanclimate.org/wp-content/uploads/2018/06/FINAL-MATERIAL-ECONOMICS-CIRCULAR-ECONOMY- SUMMARY.pdf (August 6th 2019).
- Polish Ministry of Environment, *Circular economy*, https://www.gov.pl/web/srodowisko/goz (August 26th 2019).
- Ministry of Environment and Food of Denmark, *Environmental Protection Agency, Life Cycle Assessment of grocery carrier bags*, https://www2. mst.dk/Udgiv/publications/2018/02/978-87-93614-73-4.pdf (August 1st 2019).
- Mistre M., *Shale gas production costs: historical developments and outlook*, http://www.insightenergy.org/system/publication_files/ files/000/000/067/original/RREB_Shale_Gas_final_20170315_published.pdf?1494419889 (August 9th 2019).
- MIT Technology Review, *Get ready for more and taller skyscrapers*, https://www.technologyreview.com/s/611878/get-ready-for-more- and-taller-skyscrapers/ (July 19th 2019).
- OECD, *Glossary*, https://stats.oecd.org/glossary/detail.asp?ID=819 (August 28th 2019).
- PKN ORLEN, *Pillars of sustainable development of enterprises. Vision, raw materials, talents*, volume 11, https://napedzamyprzyszlosc.pl/files/ Raport/ Raport/PKN_ORLEN_Filary_trwaego_rozwoju_przedsibiorstw_-_Wizja_surowce_talenty.pdf (August 28th 2019).
- PET Resin Association, *Little-Known Facts about PET Plastic*, http://www.petresin.org/news_didyouknow.asp (July 26th 2019).
- Petroleum Service Company, *What's in a Barrel of Oil? The 42-Gallon Breakdown*, https://petroleumservicecompany.com/blog/oil- barrel-42-gallon-breakdown/ (July 18th 2019).
- Plastics Europe, *Plastics - the Facts 2018. An analysis of European plastics production, demand and waste data*, https://www. plasticseurope. org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf (July 15th 2019).
- Plastics Europe, *Recycling and Energy Recovery*, https://www.plasticseurope.org/en/focus-areas/circular-economy/zero-plastics- landfill/ recycling-and-energy-recovery (August 8th 2019).
- Plastics Industry Association, *Plastics Market Watch. Transportation. A Series On Economic - Demographic Consumer & Technology Trends In Specific Plastics End Market*, https://www.plasticsindustry.org/sites/default/files/2019-TransportationMarketWatch.pdf (July 25th 2019).
- Plastics Recyclers Europe, *Chemical recycling*, https://www.plasticsrecyclers.eu/chemical-recycling (August 8th 2019).
- Polish Zero Waste Association, *What is zero waste?*, http://zero-waste.pl/czym-jest-zero-waste/ (August 5th 2019).
- The STOP Project, *Frontline action to stop marine plastic pollution*, https://www.stopoceanplastics.com/ (July 17th 2019).
- Putri R.E., *The water and land footprint of bioplastics*, https://www.utwente.nl/en/et/wem/education/msc-thesis/2018/putri.pdf (August 6th 2019).
- PwC, *The Long View, How will the global economic order change by 2050?*, https://www.pwc.com/gx/en/world-2050/assets/pwc-the- world-in-2050-full-report-feb-2017.pdf (July 19th 2019).
- Quiros R., Villalba G., Gabarrell X., Munoz P., *Life cycle assessment of organic and mineral fertilizers in a crop sequence of cauliflower and tomato*, http://www.bioline.org.br/pdf?st15310 (August 9th 2019).
- Ragaert K., Delva L., Van Geem K., *Mechanical and chemical recycling of solid plastic waste*, https://www.researchgate.net/ publication/319189954_Mechanical_and_chemical_recycling_of_solid_plastic_waste (August 8th 2019).

- Reuters, *RBS to stop financing new coal plants, oil sands or arctic oil projects*, https://www.reuters.com/article/us-rbs-strategy-fossil- fuels/rbs-to-stop-financing-new-coal-plants-oil-sands-or-arctic-oil-projects-idUSKCN1IU155 (August 9th 2019).
- Stewart W.M., Roberts T.L., *Food Security and the Role of Fertilizer in supporting it*, https://core.ac.uk/download/pdf/82098360.pdf (August 7th 2019).
- Tabone M.D., Cregg J.J., Beckman E.J., Landis A.E., *Sustainability Metrics: Life Cycle Assessment and Green Design in Polymers*, http:// www.news.pitt.edu/sites/default/files/documents/TaboneLandis_etal.pdf (July 6th 2019).
- The Economist, *Bright lights, big cities*, https://www.economist.com/node/21642053 (July 25th 2019).
- The Economist, *Ever more countries are banning plastic bags*, https://www.economist.com/graphic-detail/2019/07/24/ever-more- countries-are-banning-plastic-bags (July 30th 2019).
- The European Petrochemical Association, *The Role of Clusters in the Chemical Industry*, https://newsroom.epca.eu/wp-content/uploads/2017/02/946705.pdf (August 9th 2019).
- The Guardian, *McDonald's to switch to paper straws in UK after customer campaign*, https://www.theguardian.com/business/2018/ jun/15/mcdonalds-to-switch-to-paper-straws-in-uk-after-customer-concern (August 28th 2019).
- The Guardian, *The plastic backlash: what's behind our sudden rage - and will it make a difference?*, https://www.theguardian.com/environment/2018/nov/13/the-plastic-backlash-whats-behind-our-sudden-rage-and-will-it-make-a-difference (August 5th 2019).
- The Guardian, *World Bank to end financial support for oil and gas extraction*, https://www.theguardian.com/business/2017/dec/12/uk- banks-join-multinationals-pledge-come-clean-climate-change-risks-mark-carney (August 1st 2019).
- Trucost, *Plastics and Sustainability: A Valuation of Environmental Benefits, Costs and Opportunities for Continuous Improvement*, https://plastics.americanchemistry.com/Plastics-and-Sustainability.pdf (July 8th 2019).
- Umweltbundesamt, *Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics*, https://www. umweltbundesamt.de/sites/default/files/medien/461/publikationen/4446.pdf (August 6th 2019).
- United Nations, *World Urbanization Prospects: The 2018 Revision*, https://data.worldbank.org/indicator/sp.urb.totl. in.zs?end=2015&start=1960 (July 19th 2019).
- United Nations, *World Population Prospects 2019*, https://population.un.org/wpp/ (July 18th 2019).
- United Nations Environment, *Single-Use Plastics, A Roadmap for Sustainability*, https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustainability.pdf?isAllowed=y&sequence=1 (July 15th 2019).
- United Nations Environment & Beat Plastic Pollution, *Our planet is drowning in plastic pollution*, https://www.unenvironment.org/ interactive/beat-plastic-pollution/ (July 15th 2019).
- United Nations Environmental Protection, *Microplastics: Trouble in the Food Chain*, https://uneplive.unep.org/media/docs/early_ warning/microplastics.pdf (July 15th 2019).
- United States Environmental Protection Agency, *Sources of Greenhouse Gas Emissions*, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (August 1st 2019).
- Visual Capitalist, *What Can be Made from One Barrel of Oil*, https://www.visualcapitalist.com/can-made-one-barrel-oil/ (July 17th 2019).
- -Waitrose & Partners, *Food And Drink Report 2018-19*, https://waitrose.pressarea.com/pressrelease/details/78/NEWS_13/10259 (August 5th 2019).
- Wall Street Journal, *Big Oil Investors Rethink Their Bets*, https://www.wsj.com/articles/big-oil-investors-rethink-their-bets-1514992061 (August 9th 2019).
- Wisne D., *High Performing Buildings, Nine Ways Chemistry Contributes to High Performing Buildings*, http://www.hpbmagazine.org/ Nine-Ways-Chemistry-Contributes-to-High-Performing-Buildings/ (July 22nd 2019).
- Wohner B., Pauer E., Heinrich V., Tacker M., *Packaging-Related Food Losses and Waste: An Overview of Drivers and Issues*, https://www. mdpi.com/2071-1050/11/1/264/pdf (August 1st 2019).
- Wood Mackenzie, *Is the outlook for China's petrochemicals market hanging in the balance?*, https://www.woodmac.com/news/opinion/outlook-china-petrochemical-market-balance/ (August 9th 2019).

- World Petroleum Council Guide, *World Petroleum Council Guide: Petrochemicals and Refining*, http://www.world-petroleum.org/docs/ docs/ publications/petrochemicals/wpc-guide2_layout_lo-res.pdf (July 12th 2019).
- WRAP, *Understanding plastic packaging and the language we use to describe it,* http://www.wrap.org.uk/sites/files/wrap/ Understanding%20 plastic%20packaging%20FINAL.pdf (August 6th 2019).
- WWF, *The lifecycle of plastics*, https://www.wwf.org.au/news/blogs/the-lifecycle-of-plastics (July 16th 2019).
- WWF, *No more plastic in nature*, http://www.wwfca.org/en/stopplastic/ (July 17th 2019).
- Zhang Q, Hu S., Chen D., *A comparison between coal-to-olefins and oil-based ethylene in China: An economic and environmental prospective*, https://www.columbiariverkeeper.org/sites/default/files/2018-12/Exh.%205%20Qun%20et.%20al.%202017%20%281%29. pdf (August 7th 2019).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