



# **OCEAN WISE**

Review of Expanded  
Polystyrene (EPS) and  
Extruded Polystyrene  
(XPS) as a raw material;  
general characteristics,  
implementations, and  
suppliers

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## Executive summary

Polystyrene is a plastic which is abundantly used in manufacturing and construction. This is because it is produced in multiple forms. General Purpose polystyrene (GPPS) and high impact polystyrene (HIPS) are used in many kinds of products and their packaging. GPPS is very transparent, but brittle, while HIPS is opaquer, but far stronger due to inclusion of butadiene copolymers. Additionally, there are two kinds of polystyrene foam, expanded polystyrene (EPS) and extruded polystyrene (XPS). The main difference between these is their production method. EPS is made by fusing expanding polystyrene beads in a mould which can be any shape. XPS is made by constant extrusion as the beads expand which results in flat plates which can then be thermoformed and trimmed for different uses. Both kinds of foam consist mostly of air, making them very light weight and strong insulators. Their compressive strength also makes them very useful for packaging of fragile items and protective gear like helmets. The production process of EPS allows it to be made in any shape, making it suitable for more diverse uses such as storage and transport of food, but also protective packaging moulded to fit around appliances and personal protective equipment. As XPS is produced in flat boards, it is often used as insulation in construction, but XPS plates can also be thermoformed and trimmed into trays and other food packaging. The main structural difference between EPS and XPS is that there are still spaces between the fused EPS beads, allowing air and moisture to pass through more easily. This is not the case for XPS which gives better thermal performance and water resistance. Both EPS and XPS are used in construction as insulation or support of walls, floors and roofs, but while XPS has better thermal performance and initial water resistance, reports indicate that once moisture has gotten in, EPS dries out quicker. There is some confusion between the two types of foam with their names being mixed, seemingly unstructured online and with regard to the name Styrofoam. This name is a trademark of Dow Chemical for their XPS insulation boards, but has become common language, especially in North America, for all items made of EPS and XPS.

In addition to the base compound styrene from which polystyrene is produced, many chemicals are added to enhance the properties of the final product. Blowing and nucleating agents are needed to create the correct foam structure. Flame retardants reduce the high flammability of pure polystyrene, antioxidants give the material protection from thermo-oxidative degradation, surfactants help in production and reduce static electricity build up, plasticizers make the material more malleable, and pigments give colour, but may also enhance other factors such as thermal performance. Over the years, some compounds that have been used as flame retardants, blowing agents and plasticizers were found to be damaging to human health and the environment. These are being phased out and regulations have been put in place for use of compounds in polystyrene production, especially for use

with food since many compounds can leach from the polystyrene product. Both the EU and USA have regulations in place, especially for polystyrene in contact with food. Additionally, there are regulations on chemicals in electrical and electronic equipment to protect consumers during use as well as the environment after they have been disposed as waste.

Over recent decades, global use of plastics has increased drastically. Within Europe, polystyrene comprises 7% of plastics demand with most of it being used in packaging, automotive and construction industries. Management of plastic waste is starting to recycle a larger percentage, but most is still being landfilled or incinerated. While recycling of polystyrene foams is low, life cycle analyses can indicate their benefits. An analysis of fish box production in France, Spain and Scandinavia indicated that EPS performed better than polypropylene and cardboard in factors like energy used in production, emitted greenhouse gasses, water consumption and total waste generated<sup>70</sup>.

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## List of abbreviations

ABS	Acrylonitrile butadiene styrene
ADI	acceptable daily intake
BBP	butylbenzyl-phthalate
BHT	butylated hydroxytoluene
BPA	bisphenol A
BTBPE	1,3,5-tribromo-2-[2-(2,4,6-tribromophenoxy)ethoxy]benzene
CAS	Chemical Abstract Service Registry Number
CBA	chemical blowing agent
CEF	EFSA Panel on Food Contact Materials, Enzymes and Processing Aids
CFC	chlorofluorocarbons
CMR	carcinogenic, mutagenic or toxic to reproduction
DBDPE	decabromo diphenylether
DBP	di-butylphthalate
DBS	1,3: 2,4-dibenzylidene-D-sorbitol
DiBP	di-isobutyl phthalate
DCHP	dicyclohexyl phthalate
DEHA	di(2-ethylhexyl) adipate
DEHP	di(2-ethylhexyl) phthalate
DEP	diethyl phthalate
DMP	dimethyl phthalate
DnBP	d-n-butyl phtalate
DNP	di-n-nonyl phtalate
DnOP	di-n-octyl phthalate
ECHA	European Chemicals Agency
EEE	electrical and electronic equipment
EFSA	European Food Safety Authority
EDI	estmate daily intake
EPA	environmental protection agency
EPS	expanded polystyrene
FCM	food contact materials
FS	food simulant
FDA	U.S. Food and Drug Administration

GPPS	general purpose polystyrene
HBCD	hexabromocyclododecane
HCFC	hydrochlorofluorocarbon
HIPS	high impact polystyrene
ICCM	International Conference on Chemicals Management
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LOUS	list of undesired substances
NP	nonylphenol
OP	4-tert-octylphenol
PAH	polyaromatic hydrocarbon
PBA	physical blowing agent
PBT	persistent, bioaccumulative and toxic
PE	polyethylene
PET	polyethylene terephthalate
PP	polypropylene
PS	polystyrene
PUR	polyurethane
REACH	registration, evaluation, authorisation and restriction of chemicals
SAICM	Strategic Approach to International Chemicals Management
SDS	safety data sheet
SVHC	substance of very high concern
TBBPA	tetrabromo bisphenol A
vPvB	very persistent and very accumulative
WEEE	waste electrical and electronic equipment
XPS	extruded polystyrene

## 1) Production of polystyrene

Polystyrene (PS) was discovered in Germany in 1839 based on resin of the American sweetgum tree (*Liquidambar styraciflua*). Commercial production of polystyrene started in the 1930s by the German company BASF (I G Farben), while the Dow Chemical Company invented expanded PS in 1954 <sup>1</sup>. PS is a hard, stiff, transparent synthetic resin or thermoplast produced by the polymerization of styrene.

Taking into account the production mode and composition, there are four grades of PS: the most basic is general purpose (GPPS) or crystal polystyrene, then there are high impact polystyrene (HIPS), expanded polystyrene (EPS) and extruded polystyrene (XPS).

All PS grades have as a base of their composition the same monomer, styrene (also called phenylethylene, Figure 1). Styrene is obtained in two steps, first by combining ethylene with benzene in the presence of a catalyst (such as aluminum chloride) to yield ethylbenzene. The benzene group in this compound is then dehydrogenated at 600-650 °C by passing ethylbenzene and steam over a catalyst (e.g. iron oxide, aluminium chloride, or lately, a fixed-bed zeolite catalyst system) to get a very pure form of styrene. Nearly all ethylbenzene that is produced around the world is used for styrene manufacturing. Recent advances in styrene production have increased the ways in which it can be produced. One way in particular uses toluene and methanol instead of ethylbenzene <sup>2</sup>. For a more in depth overview of styrene production, see annex 1.

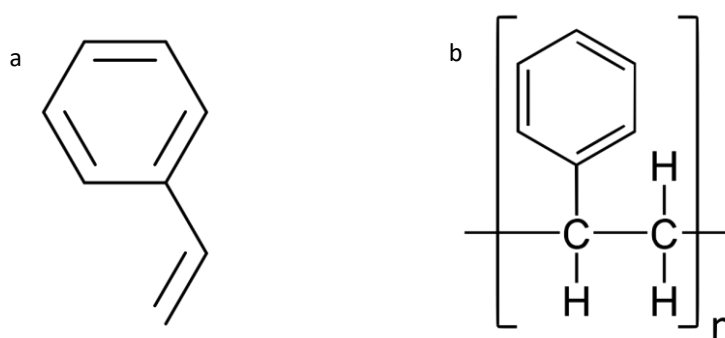


Figure 1, a) styrene molecule, b) a repeating unit of polystyrene, images under creative commons license

### a. Polymerisation

PS is formed through suspension polymerization of styrene monomers, a process in which tiny droplets of the monomer are completely surrounded by water and a mucilaginous surfactant which aids the suspension. Supporting and surrounding the styrene globules, the suspension agent produces uniform droplets of styrene and prevents them from sticking together. Numerous suspension agents

are used commercially, all similarly viscous, such as specially precipitated barium sulfate or copolymers of acrylic and methacrylic acid and their esters.

Next, a polymerization initiator (also called radical initiator or foamer, such as benzoyl peroxyde or azobisisobutyronitrile, abbreviated AIBN) is added to the droplets, which are suspended by heat radiation of about 100°C. This results in free radicals that make the droplets combine to form chains of PS (Figure 1), resulting in beads. Stopping the polymerization process is difficult. Terminators are introduced to the process to end it at the appropriate time since the chains must be of a certain length to be of use: PS with overly long chains won't melt readily, and PS with short chains will be too brittle.

After polymerization is complete, the mixture now consisting of beads made up of PS chains is cooled, washed out and dried. Uniform bead size is achieved by sorting the beads through meshes which filter out over and undersized beads <sup>2-5</sup>.

Despite its advantageous properties, PS (as a homopolymer) is brittle and flammable, it softens in boiling water and, without the addition of chemical stabilizers (antioxidants), yellows upon prolonged exposure to air. Because of this, the homopolymer is often mixed with other chemical additives (see further below).

Inorganic fillers, like carbon or silica, can be added to reinforce the plastic material <sup>1</sup>. However, more than half of all PS produced is blended with butadiene rubber to produce HIPS in order to reduce brittleness and improve impact strength of PS. HIPS is produced from GPPS by adding around 5-10% rubber or butadiene copolymer. This increases the toughness and impact strength of the polymer and results in a very stiff product ideal for packaging applications. It is a glossy and easy to process plastic that is also sturdy and durable. The end-product is hygienic and visually attractive <sup>4,5</sup>.

Expanded polystyrene (EPS) and extruded polystyrene (XPS) are both PS foams. However, the manufacturing processes are different and finished products have different performance properties. EPS is manufactured by expanding spherical beads per batch in a mould, using heat and pressure to fuse the beads together <sup>6</sup>. XPS is manufactured in an extrusion process that produces sheets of a homogeneous closed cell cross section.

## b. EPS

EPS goes through a series of changes that take it from a small pre-expanded PS bead which is about 1mm in width to an expanded bead forty times that diameter (Figure 2). The process of pre-expansion involves very precise measurements of timing, pressure variables and high temperature steam in the pre-expander, as well as the use of a blowing agent. Substituting the ozone depleting chlorofluorocarbons (CFCs) used in the past, the main blowing agents used nowadays are pentane, as well as carbon dioxide, hydrochlorofluorocarbons (HCFCs, still some ozone depletion as well as a very strong greenhouse gas emissions, being phased out) and, recently approved, isobutane <sup>7</sup>.

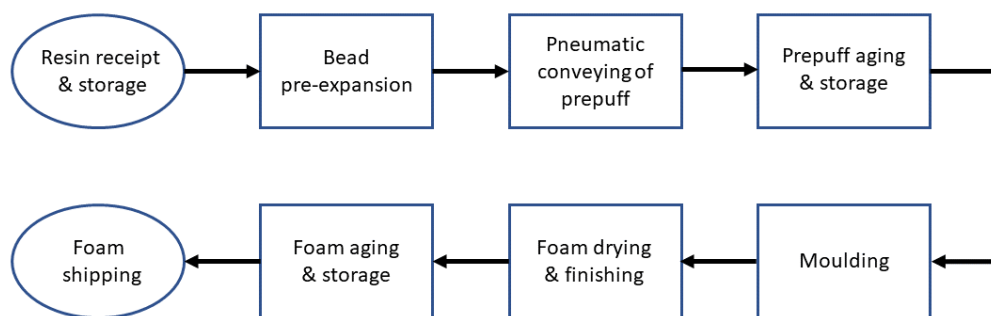


Figure 2 Steps in the production of EPS (based on <sup>8</sup>).

First, the PS beads must be expanded to achieve the proper density. This process is known as pre-expansion and involves heating the PS either with steam (the most common method) or hot air (for high density foam, such as that used for a coffee cup); the heating is carried out in a vessel holding anywhere from 189 to 1,892 liters. During pre-expansion, the blowing agent inside the bead changes to a gas due to the high temperature. This process happens under agitation to keep the beads from fusing together. The settings and parameters in the pre-expander are critical for the properties of the end-product dictated by the application for which it is being produced. If the pre-expansion lasts too long, the beads may even collapse.

After the expanded EPS beads are at the designated size, they are sucked out of the pre-expander into large storage silos. The pre-expanded beads are usually "aged" for at least 24 – 72 hours. This allows air to diffuse into the beads, cooling them and making them harder.

After aging, the beads are fed into a mould of the desired shape. High temperature steam and high pressure are then applied into and between the beads, expanding them once more and fusing them together. The mould is then cooled, either by setting it vertically to dissipate the remaining blowing

agent and heat, or cooled with water by circulating it through the mould or by spraying it on the outside.

EPS can be bonded with adhesives that do not destroy it, like water-based adhesives (such as phenolics, epoxies, resorcinols and ureas). Pure EPS is not resistant to weathering or sunlight, and it is flammable, so generally coatings such as epoxy, different kinds of paint and nonflammable substances can be applied to the surface, see below for an overview of additives <sup>2,3,5</sup>.

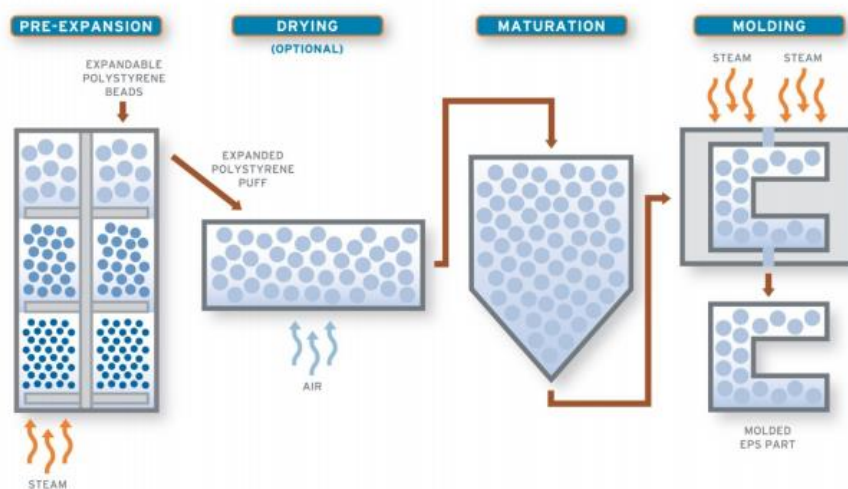


Figure 3 : EPS - Manufacturing Process<sup>82</sup>

### c. XPS

XPS is produced by combining the crystal PS beads and the blowing agents directly in an extruder under pressure (Figure 5). The polymer/gas mixture is forced downstream to an area with lower pressure and temperature causing the beads to expand and extrude from the machine in large plates which can then be thermoformed if a different shape is needed (e.g. for food packaging). The plates, or moulded forms are then cut or trimmed to size. To ensure stable dimensions upon delivery, plates are aged after cutting <sup>9</sup>.



Figure 4 : XPS foam board extrusion line <sup>10</sup>

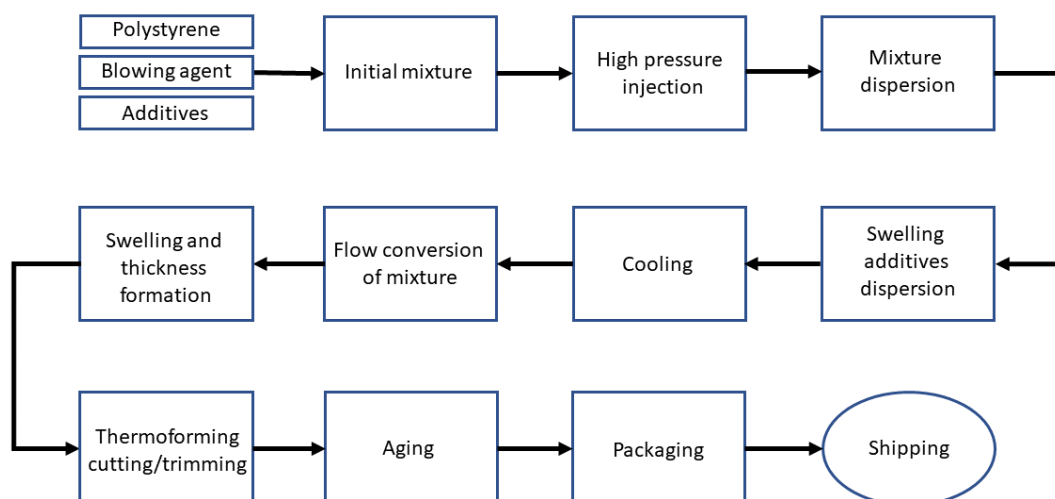


Figure 5 Steps in the production of XPS (based on <sup>11</sup>)

## 2) Properties and uses of polystyrene

### a. GPPS

General purpose polystyrene (GPPS) is often injection moulded to create highly transparent products. Examples of uses are old-style CD cases (Figure 6), petri dishes, cookie trays, bakery cake domes and other display packaging <sup>12</sup>. However, GPPS is very brittle, making its use cases limited.

### b. HIPS

High impact polystyrene (HIPS) is widely used in the food packaging industry because of its properties with regard to strength, hygiene, visual appearance and ability to retain heat, while also not deforming because of general warm water application. However, its lack of clarity makes GPPS more useful in certain cases. While the moisture vapor transmission numbers are not as good as with other polymers, HIPS has inherent moisture barrier properties that make this material suitable for short shelf life products. In addition, improvements to particular grades of HIPS have resulted in good environmental stress crack resistance, making this material suitable for the packaging of fatty foods such as butter. This material can be used in low-heat food packaging applications, but it is not recommended for applications where the packaging will undergo heat higher than approximately 85°C. The rigid nature of this material makes it ideal for food packaging applications such as cookie and bakery trays or clamshells. Plastic cutlery, salad bowls, yogurt and milk/cream containers, cold drink cups (

Figure 6), lids, stirrers, condiment containers and reusable plates are amongst the products made from HIPS. But there are also other uses not compatible with food contact. Due to its durable nature, HIPS is used in packaging applications for a wide range of applications in medical, consumer goods, cosmetics, industrial and horticultural markets among others <sup>4</sup>.



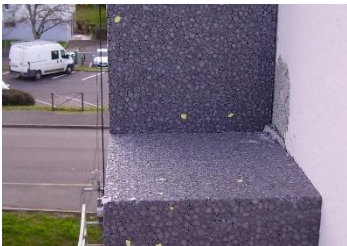







Figure 6 a) CD case with GPPS front and HIPS CD tray b) bottom of a HIPS cup with resin code 6 for PS, images under creative commons license

### c. EPS

EPS foam is perhaps the most commonly used plastic foam in everyday life. Its most remarkable property is that it consists of 98% air. This means that it has a very low density and very good insulation properties due to the many small air pockets. Additionally, it can be moulded into any needed shape and it is shock absorbing and compression resistant. These properties mean that it is used in a wide range of applications (Table 1, <sup>6,12,14</sup>)

Table 1 Uses of expanded polystyrene (EPS) and extruded polystyrene (XPS), , images under creative commons license

EPS		
		
Insulation	Flotation	Construction fill in
		
Recreation	Transport of fragile goods	Transport of food



Serving of food



Personal protective equipment



Agriculture

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#### XPS

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Insulation



Serving of food

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However, the production process of fusing beads together leaves spaces between the fused beads in the final product. This means that the foam performs less well than XPS with regard to water resistance and insulation since water, air and therefore warmth can travel through these spaces.

#### d. XPS

XPS has the same chemical composition as EPS, but the different production process causes a closed structure with smaller, more uniform, air pockets. This stronger structure makes XPS ideal for construction purposes due to its higher compressive strength and superior thermal performance. Those properties together with a strong resistance to water, make XPS the preferred choice for architects and builders <sup>6</sup>. However, the resistance also means that XPS dries out slower than EPS when moisture has gotten in which would impact its thermal performance. Besides being used as insulation material in construction, XPS can be thermoformed and trimmed into various products. Food trays, fastfood clamshell packaging, and for example ice cream boxes are all formed from XPS (Table 1).

#### e. Confusion between foam names

There is some confusion on the naming of different types of PS foams. Product descriptions online appear to mix EPS and XPS without clear understanding of the production processes. Additionally, the name Styrofoam, trademarked by Dow Chemical, is a brand of XPS used in building insulation.

However, especially in North America, this name is commonly used for EPS and other XPS products. Similarly to how the brand names Xerox and Velcro have become synonymous with the product they are linked to, this has happened to Styrofoam. However, here the name has also become linked in the public mind with other PS foams.

### 3) Chemicals found in PS foams

Overall, the analysis of additives in plastics and their transfer in the environment represent today a challenge for environmental chemists. Like other plastics, additives composition of EPS/XPS is complex, as a large diversity of additives can be used depending on the final application of the material. In this context, it appears difficult to obtain an overview of chemical composition of each material as it requires the analysis of a large number of molecules using different analytical methods (Bridson et al., 2021). In addition, the chemical structure of these additives is not always known nor included in databases used to identify molecules during chemical analysis. As a consequence, they appear difficult to identify in non-targeted analysis applied to screen a wide number of suspect and/or unknown chemicals. The availability of analytical standards is also limited, making difficult the development of targeted analytical methods and the obtention of quantitative data. Recently, Bridson et al. (2021) have reviewed the analytical approaches for the extraction and leaching study of additives from plastic to inform from environmental risk.

A summary of the chemicals reported in different PS materials is compiled in the tables in Annex 2: Table A for PS and GPPS, Table B for HIPS and Table C for EPS and XPS.

#### **a. Precursor compounds**

Styrene monomers are the main component of polystyrene. Although the final polystyrene products consist of polymers, traces of free monomers are still present in the final product, including in PS used for food packaging. Another precursor of PS found in food packing is ethylbenzene. It has been included in some safety data sheets (SDS), sometimes as a degradation product, but there are studies looking at the migration of ethylbenzene from food packaging<sup>15,88</sup>.

#### **b. Nucleating agents**

The goal in manufacturing EPS is to create cells which are homogeneously distributed and of similar size. Dispersing a nucleating agent throughout the polymer allows for better control of the number of cell formation sites and thus, leads to a homogeneous structure.

There are passive and active nucleating agents. Passive nucleating agents such as talc or silica can lead to larger cells in the centre of the foam. To prevent this, active nucleating agents are also used. The most widely used nucleating agent in the EPS industry is (1,3: 2,4) dibenzylidene sorbitol (DBS) <sup>23</sup>.

### c. Blowing agents

The blowing agent creates the particular cellular structure of EPS by expanding the beads to 40 times their initial size. This process consists of three steps: nucleation by which the gas cells in the polymer are formed, cell growth which is the actual expansion of the gas within the polymer and cell stabilisation in which the polymer solidifies and traps the gas permanently in the cells.

Fluorocarbon agents such as CFCs and HCFCs were used as blowing agents for many years which led to severe environmental damage due to ozone depletion and greenhouse gas effects. Use of CFCs has been restricted whilst HCFCs are currently being phased out. Today there are two types of blowing agents on the market, physical blowing agents and chemical blowing agents.

*Physical Blowing Agents (PBA):* PBAs include, for example, fluorocarbons (e.g. CFCs, HCFCs), hydrocarbons (e.g. pentane, iso-butane ) liquid carbon dioxide, etc.. The formation of EPS with a physical blowing agent is an endothermic and irreversible process. During cooling, the blowing agent will condense, making it impossible to return to the initial state <sup>20</sup>.

*Chemical Blowing Agents (CBA):* For thermoplastic foams such as EPS, pentane-based, nitrogen-based or CO<sub>2</sub>-based materials are used as CBAs in powder or bead form. Since expansion produces low molecular weight compounds, additional exothermic heat will be released. The use of such an agent in solid form is advantageous since it can be used in conventional extrusion and injection processes.

The choice of blowing agent for expansion of the EPS depends on the use of the material produced. Since the restriction of fluorocarbon agents, pentane and butane have become the most used agents due to their far lower impact on both ozone depletion and global warming <sup>21</sup>. Of the pentane added during manufacturing, 24%/10-44% is lost during pre-expansion, 19%/5-37% during puff aging/maturing, 14%/4-31% during moulding, 15%/5-30% remains in the final moulded part (immediate), from which 13%/3-23% is lost during initial storage (2-3 days) while the remaining pentane will continue to diffuse slowly over prolonged periods <sup>22</sup>. Some companies warn in the SDS about solvent accumulation during transport in ships and lorries, which indicates that complete loss of the blowing agent can take a very long time.

Since 2005, other agents have been studied. Gases such as nitrogen and carbon dioxide are now making their way into the EPS market due to their lower environmental impact <sup>21</sup>. These inert gases are not flammable which was a big disadvantage of pentane and butane. They are also more economic, non-toxic and leave no residue in the foamed material.

#### d. Flame retardants

Plastics can be highly flammable, making them a potential hazard when used in construction. To mitigate this risk, flame retardants are added. A technical mixture of hexabromocyclododecane diastereoisomers (HBCD) was used as a flame retardant for many years. HBCD is persistent in the environment and bioaccumulates in living tissues, causing long-term health problems. Because of this, the use of HBCD in plastics has been regulated in 2016 in Europe by the Commission regulation EU 2016/293 <sup>16</sup> (which amends the regulation 850/2004 <sup>17</sup>). Regulation 2016/293 allows the use of 100 mg/kg of HBCD (0.01 % by weight), and allows its use in EPS and XPS articles, which should be labelled. However, many older buildings already have this compound in their construction at higher levels. Additionally, HBCD is a flame-retardant of the additive type, which means that it is physically combined with the material being treated rather than chemically combined (as in reactive flame-retardants) and are more likely to diffuse out of the products. When the foam is damaged through for example demolition, leaching or dispersal of HBCD as part of the dust could be a clear health hazard <sup>18</sup>. Some alternative compounds have been suggested to replace the use of HBCD in EPS and XPS, such as butadiene styrene brominated copolymer (1195978-93-8) by BASF or IC RK-972 (1,1'-(isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene]) by Into Chemicals <sup>19</sup>. A list of flame retardants has been approved for various applications (Annex 1). Flame retardants have been found in buoys, where they are not required because of their use, however likely to be made from re-used or recycled materials, where it would not be possible to eliminate the flame retardant from the material before its use.

#### e. Antioxidants

Antioxidants are used to protect the material from thermo-oxidative degradation. They reduce the appearance of yellowing, cracking or more general surface degradation. This process is exacerbated by prolonged exposure close to a heat source <sup>24</sup>. Two types of antioxidants are used: phenolic antioxidants (primary antioxidant) and sulfur containing antioxidants <sup>25</sup>. Examples of phenolic antioxidants are Hostanox® 03 from Clariant, a glycol ester, and Irganox® 1076 from BASF which is a sterically hindered antioxidant. It is odorless and light stable, has good compatibility with most



substrates, low volatility and high resistance to extraction. An example of a sulphur based antioxidant is Hostanox® SE 10 from Clariant which is a very effective co-stabilizer based on thioether with excellent compatibility with polyolefins.

#### f. Surfactants

There are multiple uses of surfactants in EPS production. One is during the suspension polymerization by decreasing the surface tension. Another use is as a surface treatment to strengthen the outer coating, while a third use is to eliminate the accumulation of static electricity on the surface. This minimises dust deposition on the surface which could reduce product performance.

The most used antistatic compounds are Hostastat® from Clariant. In particular Hostastat® FA 14 and Hostastat® FA 38 <sup>25</sup>.

- Hostastate FA 14 is (N, N-BIS- (2-hydroxyethyl) coco-alkyl-amine) and is in the form of a liquid.
- Hostastat 38 is in powder form and is a mixture of N, N-bis- (2-hydroxyethyl) -alkyl- (C14-C18) -amine (56%) and calcium stearate (44%) ).

#### g. Plasticizers

Plasticizers make the plastic more flexible via a lowering of the glass transition temperature. The plasticizer is inserted between the macromolecular chains and replaces certain polymer-polymer interactions by plasticizer-polymer interactions. The majority of plasticizers used for plastics are phthalates. Some of which have been banned from use in food or toys.

Phthalate esters are plasticizers commonly applied commercially for PS. Examples are dimethyl, diethyl, dipropyl, dibutyl, diheptyl, dioctyl, diisodecyl and benzylbutyl phthalates<sup>79</sup>. Di-isobutyl phthalate (DIBP) has been added since 2017 to the European Chemicals Agency (ECHA) list of endocrine disruptors and has been classified as a Substance of Very High Concern (SVHC) for monitoring <sup>26</sup>. Adipate and glutarate esters have been used as plasticizers for EPS, and the liquid paraffin and zinc stearate as an internal plasticizers. As an alternative to the toxic phthalates, more eco-friendly plasticizers such as epoxidized vegetable oils, biodiesel oils, hydrogenated Castrol oil, citrate esters, poly(ethylene glycol of low molecular weight or core-hydrogenated phthalates have been investigated<sup>79</sup>.

#### h. Pigments

Carbon black is used in a number of polymer and coatings applications, including as an infrared opacifier in EPS foams. The good infrared absorption characteristics of such black EPS foams provide improved thermal performance compared to white EPS.

Some chemical blowing agents are coloured. Using such agents, e.g. yellow EXPANCEL® from Akzo Nobel, will provide their colour to the final product to, for example, be used in food packaging.

As an example for other types of PS, BASF recommends Sicostyren as additive for the coloration of articles made of GPPS or HIPS, produced by injection moulding or extrusion <sup>27</sup>. Sicostyren Red (or Sudan IV, 85-83-6) is 2-naphthalenol, 1-[[2-methyl-4-[(2-methylphenyl)azo]phenyl]azo]-, a compound that may cause cancer <sup>28</sup>.

The FDA allows the use of pigments and lists exemption chemicals allowed under certain requirements for the use in PS with food contact<sup>46</sup>: Solvent Yellow 72 (CAS 4645-07-2), Disperse Orange 47 (CAS 5718-26-3), Solvent Orange 60 (CAS 6925-69-5), Solvent Red 26 (CAS 4477-79-6), Solvent Red 24 (CAS 85-83-6), C.I. Solvent Red 23 (CAS 85-86-9), C.I. Solvent Blue 36 (CAS 14233-37-5), Solvent Yellow 72 (2,4-dihydro-4-((2-methoxyphenyl)azo)-5-methyl-2-phenyl-3H-pyrazol-3-one (CAS 4645-07-2), colorant 2,4-dihydro-4-((2-methoxyphenyl)azo)-5-methyl-2-phenyl-3H-pyrazol-3-one (CAS 4645-07-2), solvent violet 13 (1-hydroxy-4-((4-methylphenyl)amino)-9,10-anthracenedione (CAS 81-48-1) for use in foamed polystyrene articles used in contact with all types of food.

Other organic pigments included in a draft for the use in PS for commodities or in contact with food are<sup>81</sup>: Solvent Yellow 130 (CAS 26846-41-3) Dibenzo (a,h)-phenazinediol-1,8, Pigment Orange 72 (CAS 78245-94-0) 2-[(3,3'-dichloro[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis[N-(2,3-dihydro-2-oxo-1Hbenzimidazol-5-yl)-3-oxobutanamide, Solvent Red 111 (CAS 82-38-2) methylamino-1-anthracenedione-9,10, Disperse Violet 26 or 31 (CAS 6408-72-6) diamino-1,4 diphenoxy-2,3 anthracenedione-9,10 and Solvent Violet 36 (CAS 82-16-6) bis (methyl-4-phenylamino)-1,8anthracenedione-9,10.

#### 4) Polystyrene composition from major global suppliers

Different companies use different formulations, sometimes with proprietary chemicals. Key vendors include BASF, SABIC, DOW chemicals, NOVA Chemicals, TOTAL SA, Versalis S.P.A., Unipol Holland BV, Ravago group, Alpek S.A.B. De Cv, Styrochem, Brodr Sunde group, Synthos SA, Sunpor Kunststoff GMBH, Kaneka Corporation, and ACH foam technologies. However, the market is highly fragmented on account of a vast number of companies engaged in the manufacturing of polystyrene, and regional

players seem to attain a larger section of opportunity than multi-national players on account of supplying the product forms at low prices <sup>47</sup>.

The safety datasheets (SDS) from different companies shed light on some of the components and additives used for the different grades of polystyrene. However, the degree of detail on the composition depends on what the company wants to declare and also on the date of preparation of the SDS and the regulations of the country (different countries have different demands on details for the SDS which also get stricter with time). Therefore, although the information given by SDS is reliable, it most likely is incomplete. Degradation products for the material are also described in some of the SDS. Some SDS for products are the following:

#### HIPS:

- LG polymers India <sup>48</sup>: styrene monomer (CAS 100-42-5) 83-88%, butadiene rubber (CAS 9003-17-2) 6-8%, others 6-9%.
- Primex <sup>49</sup>: polystyrene (CAS 9003-53-6), modified polystyrene (CAS 9003-53-8)
- REprapper <sup>50</sup>: polystyrene (>95%), antioxidant <3%, pigment <2%.
- Styrolux <sup>51</sup>: > 80 – 100% Polystyrene with 1,3-butadiene polymer (CAS 9003-55-8), it is flammable (so a solvent is also present)
- Tehcnology supplies <sup>52</sup>: Styrene butadiene copolymer (CAS 9003-55-8), mineral oil (CAS 008042-47-5)
- Total HIPS <sup>53</sup>: polystyrene (impact) (CAS 9003-55-8) ~100%
- Velleman <sup>54</sup>: Butadiene-styrene copolymer (CAS 9003-55-8) 99.9%, additives 0.1%;

#### XPS:

- Foamular (Owens Corning) <sup>55</sup>: polystyrene (CAS 9003-53-6) 80-90%, HCFC-142b (CAS 75-68-3) (7-12%), HBCD (CAS 3194-55-6) 0.5-1.5 %, Talc 0-2 % (CAS 14807-96-6)
- Izoacam <sup>56</sup>: ethylbenzene homopolymer (CAS 9003-53-6) max 90%, blowing agent (DME, CO<sub>2</sub>, HFCs) > 10 %, HBCD (CAS 14807-96-6).
- Neopor F 5300 Plus (5000 series) (BASF) <sup>57-59</sup> (insulation): pentane 3.84-4.48% (CAS 109-66-0), 2-methylbutane (CAS 78-78-4) 0.96-1.12%, butadiene styrene brominated copolymer (CAS 1195978-93-8)
- Neopor F Pro (5000 series) (BASF) <sup>57-59</sup> (insulation): PolyFR, graphite, pentane ~4.5% (CAS 109-66-0), butadiene styrene brominated copolymer (CAS 1195978-93-8)
- Styrodur (BASF) <sup>60</sup>: dyes, polystyrene, polymeric flame-proofing agent (CAS 1195978-93-8)



- Styrofoam (Dow chm.) <sup>61</sup>: 1-chloro-1,1-difluoroethane (CAS 75-68-3) <10%, chlorodifluoromethane (HCFC-22) (CAS 75-45-6) < 5%. Decomposition products can include and are not limited to: Aromatic compounds. Aldehydes. Ethylbenzene. Polymer fragments. Styrene. Decomposition products can include trace amounts of: Hydrogen bromide. Hydrogen chloride. Hydrogen fluoride. Under high heat, non-flaming conditions, small amounts of aromatic hydrocarbons such as styrene and ethylbenzene are generated

EPS and PS foam:

- Cordek <sup>62</sup>: pentane (CAS 109-66-0) <1% , HBCD (CAS 25637-99-4) >0.1%. STEL for styrene monomer and hydrogen bromide
- Dyplast <sup>63</sup>: polystyrene foam (CAS 9003-53-6) 92-97%, pentane isomers (CAS 109-66-0; 78-78-4; 287-92-3) 2-<7%, additives <3%, styrene (CAS 100-42-5 ) <0.2%;
- Knauf insulation <sup>64</sup>: EPS (CAS 9003-53-6), HBCD (CAS 3194-55-6) > 0.1%. Products from combustion will include carbon monoxide, carbon dioxide and hydrogen bromide. Trace amounts of styrene can also be released.
- NovaChemicals <sup>8</sup>: food contact PS: 1-8% n-pentane, 0-<3% isopentane, max of combined 8%; ethenyl benzene, ethyl benzene; insulation PS: pentane (1-8%), cyclopentane (0-3%), isopentane (0-3%); brominated or other flame retardants < 1%.
- Neopolen (BASF) <sup>65</sup>: 1-Propene, polymer with ethene (9010-79-1)
- Neopor F 2000 series (BASF) <sup>57,59</sup> (insulation): PolyFR, graphite, pentane ~4.5%, butadiene styrene brominated copolymer (CAS 1195978-93-8) (with graphite)
- SIG <sup>66</sup>: pentane (CAS 109-66-0) <1%, HBCD (CAS 25637-99-4 or CAS 3194-55-6) >0.1%; STEL for styrene monomer and hydrogen
- Styropor P 326 (BASF)(food contact) <sup>58,67</sup>: polystyrene (CAS 9003-53-6), pentane 4.64 – 5.04%, isopentane (CAS 78-78-4) 1.16-1.24%
- Styropor F 315 E (BASF) (insulation) <sup>58,68</sup>: polystyrene, propellant, butadiene styrene brominated copolymer (1195978-93-8)

## 5) Leaching of chemicals from polystyrene products

The number of works studying the migration and leaching of chemicals from PS products to the environment or organisms has increased in the recent years, but they are still limited. A worse case scenario could be considered the migration to foods, since the PS material utilised has been produced more recently (therefore, potentially more susceptible of releasing production chemicals) and many

additives are easily transferred to fats/oils or food simulants. Therefore, studies reporting migration of chemicals from PS to food have been included. Several institutions and projects have studied the release and migration of the precursor styrene, especially to food. There are reviews on the methodologies used to analyse food packaging materials <sup>28</sup> and regulations on how to undertake migration studies for food contact plastics <sup>30,31</sup>. Most studies target specific compounds, and a few try to see a more general picture of what compounds can leach from plastics.

It must be kept in mind that PS weathering (degradation), interaction with organisms and reactions with the environment can change the rate and type of compounds released from PS into the environment or organisms<sup>83,96</sup>. In addition, weathering induce the degradation of polystyrene into carbon dioxide and dissolved organic carbon<sup>96,100</sup>, potentially releasing plastic additives into the environment.

### a. Styrene

Styrene and styrene oligomers are the most studied leaching chemicals from PS products. Examples of studies analysing styrene into food are the works by Ehret-Henry et al. (1994) <sup>15</sup>, Lickly et al. (1995) <sup>32</sup>, Tawfik & Huyghebaert (1999) <sup>33</sup>, Choi et al. (2005) <sup>34</sup>, Khaksar & Ghazi-Khansari (2009) <sup>35</sup>, the Plastics Food Service Packaging Group for the FDA (2015) <sup>12</sup> and Hahladakis et al. (2018) <sup>36</sup>.

Examples of levels of total styrene found in cups are: GPPS: 0.61 – 8.30 µg/L, IPS: 0.48 – 7.78 µg/L (c11), 51 µg/kg food <sup>37</sup> 0.025% of total styrene in cups <sup>33</sup>. The Plastics Food Service Packaging Group calculated migration levels for different polystyrene plastic materials through food contact, with levels of 0.81 – 30.2 ppb for GPPS, 0.41- 91.6 ppb for HIPS, and 1.10 – 42.1ppb for EPS foam <sup>12</sup>.

Summing all the individual exposure contributions for the different food packaging, this yields 2.20 ppb of styrene in the diet. Assuming that an individual consumes a daily diet of 3.0 kilograms of food (all solids and liquids), this results in an estimated daily intake (EDI) of styrene of 6.6 µg/person/day (0.0066 mg/person/day). The “Toxicological Review of Styrene (CAS 100-42-5)” submitted to the U.S. Food and Drug Administration (FDA) by the Styrene Information and Research Center in 2002 states that the acceptable daily intake (ADI) for styrene is considered to be 90,000 µg/person/day. This value is calculated as a four-orders-of-magnitude safety factor from the estimated daily intake, in this case 9 µg/person/day in the U.S. <sup>12</sup> This limit is much higher than the 6.6 µg/person/day estimated by Plastics Food Service Packaging Group. The limit set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) is of 0.04 mg/kg body weight per day <sup>37</sup>.

Styrene oligomers are produced during the polymerization of polystyrene and during its degradation<sup>83</sup>. They have been reported to have endocrine disrupting effects and affect of

development<sup>80</sup>. They have been found to leach from PS into water, favoured by turbulence<sup>93</sup>. De-la-Torre et al. (2020)<sup>80</sup> reviewed the distribution of styrene oligomers in the marine environment and found that they have become ubiquitous but highly variable in the marine environment. They found that concentrations are usually much higher in sediments than in water and usually much higher in industrialized, urban or aquaculture locations. Recently, Amamiya et al. (2019)<sup>78</sup> found evidence that styrene oligomers can be transported from land to the ocean, suggesting transport and redistribution from remote sources into the marine environment. Some styrene oligomers seem to be indicative of freshly leached EPS (2,4,6-triphenyl-hexene (ST-1)), while 2,4-diphenyl-1-butene (SD-2) and styrene trimers seem to reflect older particles or diluted leachate<sup>83</sup>.

### b. Other chemicals

Besides the precursor styrene, many other chemicals have been found migrating from PS. Some studies have tried to identify relevant components of PS by studying their leachability from food related plastics or undertaking migration studies into food/food simulants. While other studies attempt to evaluate the environmentally relevant chemicals in PS by undertaking migration studies in water or by degrading plastics by reproducing digestion in the stomach of organisms.

Arvanitoyannis & Bosnea (2004)<sup>39</sup> and Bhunia et al. (2013)<sup>40</sup> have reviewed studies for the migration of substances from food packaging materials to foods. Most studies usually target known specific compounds. These studies provide some additional information about chemicals found in the final polystyrene products, which could originate from the chemicals used during manufacturing or from the degradation of polystyrene material. Some of them confirm the data in reviews about leaching in non-PS plastics<sup>36,39-42</sup>. Examples include the work by Fasano et al. (2012)<sup>43</sup>, who analysed the migration of chemicals from several types of plastics for food packaging. They studied two polystyrene products (an EPS tray and a yogurt pot) and found that the EPS tray contained high concentrations of plasticisers, such as di(2-ethylhexyl) phthalate (DEHP), and nonylphenol (NP) (between 129 – 1239 ng/L food simulant (fs)). They also found dimethyl phthalate (DMP), 4-tert-octylphenol (OP) and di(2-ethylhexyl) adipate (DEHA) in lower concentrations (15-48 ng/L fs). They did not find di-butylphthalate (DBP), butylbenzyl-phthalate (BBP) or bisphenol A (BPA). Yogurt packaging contained only DMP and DEHA, DMP in low levels (15-26 ng/L fs) but DEHA in much higher levels (1876-2902 ng/L fs). Li et al. (2017)<sup>44</sup> studied the content of polycyclic aromatic hydrocarbons (PAHs) in 21 polystyrene food contact materials. They found low-ring PAHs in concentrations between  $18.9 \pm 5.16$  and  $476 \pm 52.0$  ng/g (in a fork and in a foam container, respectively). The concentrations were lower in the colourless materials than in the coloured ones, and also lower in extruded than in expanded PS. Their migration studies concluded that the maximum migration was below the 10 ng/g stated by the EU<sup>30</sup>. The main

PAHs found were phenantrene and naphthalene. But they also found in less abundance anthracene, fluorene, fluoranthene, pyrene, acenaphthene and acenaphthylene. They suggest PAHs are generated during production and adsorbed during the use of the material.

Plasticisers are commonly found in migration, extraction and digestion studies. Several studies have detected nonylphenol (NP)<sup>43,108</sup>, 4-tert-octylphenol (OP)<sup>43,90</sup>, dimethyl phthalate (DMP)<sup>43,99,108</sup>, diisobutyl phthalate (DiBP)<sup>25,96,99</sup>, Di-n-butyl phthalate (DnBP)<sup>25,99</sup>, di-(2-ethylhexyl) phthalate (DEHP)<sup>43,90,93</sup>, acetophenone<sup>96,101,105,106</sup> and tributyl acetate<sup>94,106</sup>. Zhang et al. (2018)<sup>99</sup>, found several plasticizers (mainly DMP, diethyl phthalate (DEP), diisobutyl phthalate (DiBP), DiBP, di-n-butyl phthalate (DnBP), and di-(2-ethylhexyl) phthalate (DEHP)) in microplastic PS found in beaches in China. Wang et al. (2020)<sup>96</sup> found DBP and DiBP in PS leachate after radiation experiments. On the other hand, DEHP and OP were the only compounds detected by Coffin et al. (2019)<sup>90</sup> in polystyrene particles degraded simulating invertebrate and vertebrate digestive conditions. The DEHP levels in invertebrate digestions were higher than in vertebrate, suggesting a higher accessibility of this compound to invertebrates.

Flame retardants have also been found to be leaching from PS materials. Jang et al (2017)<sup>86</sup> found HBCDs in EPS debris and microplastics collected from the Asia-Pacific coast. A study by Rani et al. (2014)<sup>45</sup> shows that most of the EPS products from South Korea analysed had very high concentrations of HBCD (106 - 960000 ng/g), while XPS had also presence of HBCD but in lower levels (24 – 164000 ng/g). Interestingly, they found some of the EPS and XPS materials had also tetrabromo bisphenol A (TBBPA), although in lower concentrations (3.83 – 545 ng/g). Some XPS materials had also other flame retardants, such as BTBPE (1,3,5-tribromo-2-[2-(2,4,6-tribromophenoxy)ethoxy]benzene) (44 – 216 ng/g) and all of them had decabromo diphenylether (DBDPE) (215 – 4200 ng/g). They warn, though, that although most food contact materials had low concentrations (24.3 – 199 ng/g), some of the products with high concentrations of HBCD were ice boxes, aquaculture buoys and disposable trays used in the fish market. This supported the hypothesis of unregulated use of flame retardants in consumer products<sup>45</sup>. Ionas et al. (2014) found PBDEs and DBDPE in foam toys, suggesting the use of recycled plastics<sup>95</sup>. While Abdallah et al. (2018)<sup>84</sup> found HBCD at levels above the EU's regulatory 0.01% in PS used for packaging as a result of uncontrolled recycling activities. Recycling of PS materials is a concern since these materials have been found to be sources of HBCD into the environment<sup>84,86</sup>. HBCD has been found to leach (4.9%) from EPS microparticles into soil<sup>103</sup>. As for styrene, HBCD is found in much higher concentrations in sediments than in water, although at levels not considered to be a

threat for marine biota<sup>80</sup>. HBCD has been found in mussels growing in marine EPS debris<sup>87</sup>, that probably due leaching rather than digestion of particles<sup>87</sup>. However, studies of accumulation of HBCD in earthworm from microparticles of EPS showed that most of their exposure came from digested plastic<sup>103</sup>.

There are other works which look at a broader range of compounds the plastic contain or can leach. Lahimer et al. (2017)<sup>25</sup> did a characterization study of plastic packaging additives. They found that polystyrene boxes, trays and yogurt pots contained also methylpalmitate, polysiloxane, phthalic acid, sebacic acid (2-methoxyethyl tetradecyl ester, CAS 111-20-6), methadone N-oxide (CAS 33100-61-7), benzene 1,1'-(1,2-cyclobutanediyl) bis-cis, octadecanoic acid, methyl ester and benzene 1,10-(1,2-cyclobutanediyl) bis-trans, benzyl benzoate (or ascabin or ascabiol CAS 120-51-4), Irganox 1076 (CAS 2082-79-3), butyl ester of propanoic acid (or CAS 590-01-2). While the analysis of EPS material contained benzyl benzoate (or ascabin or ascabiol CAS No. 120-51-4), Irganox 1076 (CAS 2082-79-3), DIBP (Phthalic acid), diisobutyl ester, diisooctyl phthalate (CAS 27554-26-3), methadone N-oxide (CAS No. 33100-61-7), benzoic acid, methyl ester (niobe oil CAS 93-58-3), dibutyl phthalate (CAS 84-74-2), decanedioic acid, Polycizer DBS (or dibutyl sebacate, CAS 109-43-3). Wang et al.<sup>96</sup> found acetophenone, benzaldehyde and benzoic acid in PS leachate in degradation studies of PS exposed to UV radiation. This leachate showed toxicity in fish<sup>96</sup>. The study of Barua et al. (2021)<sup>97</sup> showed higher toxicity of micro-EPS leachate than of micro-PS leachate in seastar, suggesting the presence of more toxic compounds in EPS<sup>88, 96</sup>, although their study did not identify chemicals. Kuhn et al. (2020)<sup>101</sup> extracted PS and identified acetophenone, 1,1'-(1,3-propanediyl)bis benzene, phenyl ester benzoic acid (phenyl benzoate) and 1,2,3,5-triphenyl cyclohexane. The digestion of the PS in stomach oil to simulate leaching in a fulmar stomach observed high leaching of acetophenone and phenyl benzoate, although the later seem to largely disappear with time<sup>101</sup>.

The FDA records chemicals exempted (due to meeting their requirements) from the regulations for food contact substances, and therefore allowed for this use (more detail about the exemptions in Chapter 7. Regulations). Exemption chemicals allowed under certain requirements for the use in PS with food contact are <sup>46</sup>:

- glycerol monooleate complying with 21 CFR 184.1323, polyamide 6/66 and polyamide 6/12 in PS tray lids.

- in PS foam trays with a coating that can contain tetrakis[methylene(3,5-di-tert-butyl-4-hydroxyhydrocinnamate)methane] (6683-19-8), octadecyl 3,5-di-tert-butyl-4-hydroxyhydrocinnamate (2082-79-3), di-tert-butylphenyl phosphonite condensation product with biphenyl (119345-01-6), tri(mixed mono- and di-nonylphenyl) phosphate (26523-78-4), tris(2,4-di-tert-butylphenyl)phosphite (31570-04-4), cyclic neopentanetetrayl bis(octadecyl phosphite) (3806-34-6), butylated hydroxytoluene (BHT), diatomaceous silica. Also allowed at the minimum levels a blend of a styrene-butadiene thermoplastic elastomer and a styrene-butadiene copolymer, both complying with §177.1640 and an ethylene vinyl alcohol copolymer, complying with §177.1360, as components of the non-food contact layers of the laminate.
- Solvent yellow 72 (4645-07-2), disperse orange 47 (5718-26-3), solvent orange 60 (6925-69-5), solvent red 26 (4477-79-6), solvent red 24 (85-83-6), C.I. solvent red 23 (85-86-9), C.I. solvent blue 36 (14233-37-5), solvent yellow 72 (2,4-dihydro-4-((2-methoxyphenyl)azo)-5-methyl-2-phenyl-3H-pyrazol-3-one 4645-07-2), colorant 2,4-dihydro-4-((2-methoxyphenyl)azo)-5-methyl-2-phenyl-3H-pyrazol-3-one (4645-07-2), solvent violet 13 (1-hydroxy-4-((4-methylphenyl)amino)-9,10-anthracenedione (81-48-1) for use in foamed polystyrene articles used in contact with all types of food.

Hahladakis et al. (2018)<sup>36</sup> have reviewed the chemical additives present in general plastics. Similarly, the report by the Danish Environmental Protection Agency (2014)<sup>41</sup> (updated later in the Nordic Council of Ministers (2017)<sup>42</sup>) aims to be a list on hazardous substances in plastics, to assess their migration and evaluate their fate during recycling. The range considered in the Danish report project covers substances included in the following lists of hazardous substances: the Danish EPA's list of undesired substances (LOUS), the SVHC (substances of Very High Concern) Candidate List under EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulations, the Norwegian list of priority substances, ECHA's Registry of Intentions, CMR-substances likely to be present in plastic toys (as assessed by the Danish Technological Institute), and recognized alternatives to problematic phthalates and brominated flame retardants<sup>41,42</sup>. All these substances are summarized in the tables in Annex 1.

### c. Adsorbed chemicals

The last years have found plastics and microplastics as ubiquitous contaminants in most environments around the world. Specifically, the Asian-Pacific coast seems to have a predominance of EPS debris<sup>87, 98</sup>. Due to their relative large surface area, the presence of microplastics has raised concerns as potential vectors for hydrophobic organic chemicals (HOC) in the environment, especially into

animals<sup>91,92</sup>. A critical review by Koelmans et al. (2016)<sup>91</sup> saw that, although HOC were sorbed by microplastics, the total amount was small compared to amounts present in other media in the ocean. They concluded that the overall flux of hydrophobic organic chemicals to marine animals was much higher from natural prey than from ingested microplastics for most habitats.

On the other hand, the study of compounds migrated from plastic rubbish collected on the Mediterranean coast<sup>94</sup> showed PS plastics releasing high concentrations of plastic additives (tributyl-2-acetyl citrate and tris(2-chloropropyl)phosphate)) and personal care products. In much lower levels they also released PAHs, triazines and organophosphorous pesticides. This seems to confirm that many HOCs in the environment can be accumulated in plastics and transferred to seawater once they reach the marine environment<sup>94</sup>. Some of the more hydrophobic compounds (e.g PAHs and some pesticides) showed slower desorption rates, meaning they can be transported from coastal waters to the marine environment<sup>94</sup>. Similar results were found by Liu et al. (2018)<sup>102</sup>, who found polar chemicals leaching more easily from polystyrene nano-plastics, while more apolar compounds (i.e. the flame retardant BDE47) seemed to have got physically trapped in the PS structure.

## 6) Use and disposal of plastics and polystyrene

Plastics are a family of hundreds of different materials with a wide variety of properties. They are organic materials that can be either fossil fuel base or bio based. Both types of plastic materials are recyclable and it is possible to produce bio-degradable plastics with both types of feedstocks. Currently, most plastics materials are derived from fossil feedstocks such as natural gas, oil or coal, although only 4-6% of all and gas used in Europe is employed in the production of plastic materials<sup>69</sup>. There are two categories of plastics (Figure 7): thermoplastics, and thermosets. Thermoplastics can be melted when heated and hardened when cooled. They include polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyethylene (PE), Acrylonitrile butadiene styrene (ABS), etc. Thermosets undergo a chemical change when heated, so they cannot be re-melted and reformed, such as polyurethane (PUR), epoxy resins, acrylic resins, etc.<sup>69</sup>. In the recycling market, PS products are identified by the resin ID code '6'.



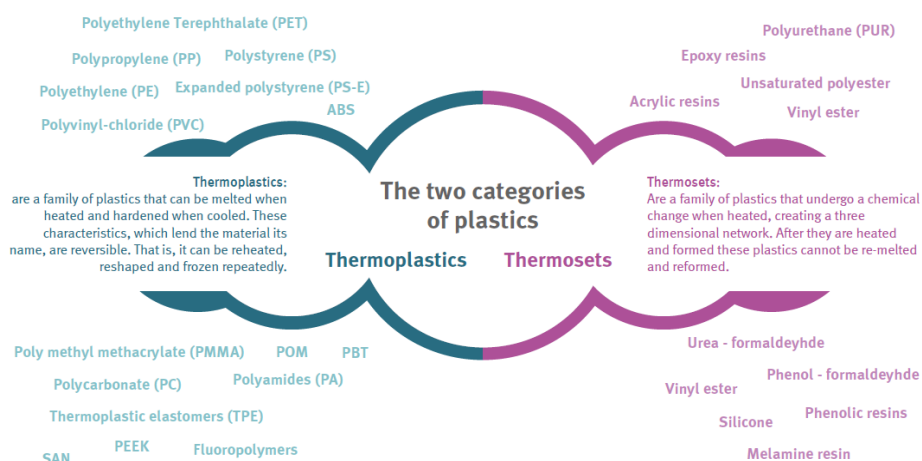


Figure 7 Categories of plastics <sup>69</sup>

The production of thermoplastics and thermosets worldwide, (with 280 million tonnes in 2016) is dominated by Asia (mainly by China), with a 50% of the world production, followed by Europe and NAFTA (Figure 8). The plastics trade reported a positive balance for the trade in Europe of 15 billion euros in 2016 <sup>69</sup>.

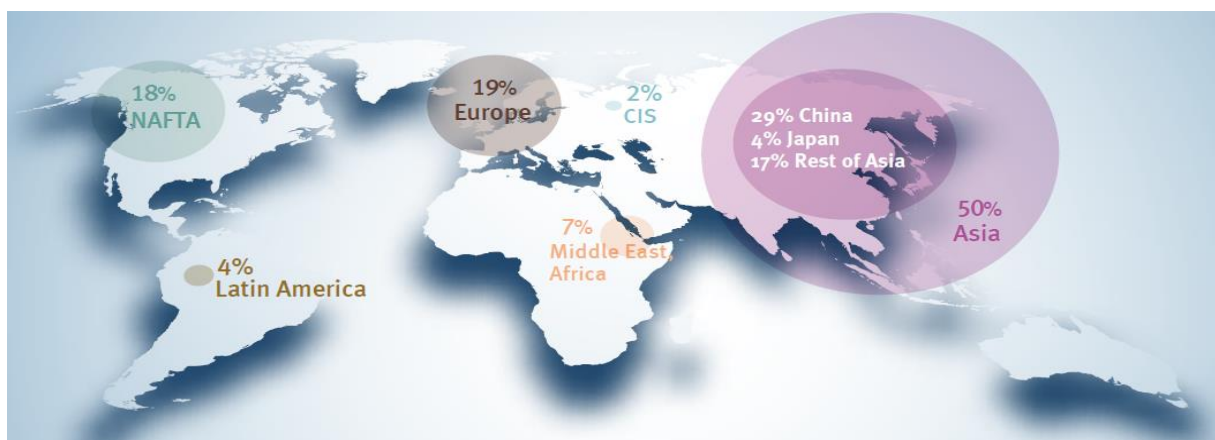


Figure 8 Worldwide production of plastic materials (only thermoplastics and polyurethanes) <sup>69</sup>

The demand for plastics in Europe (not including fibres) is dominated by the six larger European countries: Germany, Italy, France, Spain, UK and Poland. The demand from these six plus the Benelux covers almost 80% of the European demand of 49.9 mt in 2016 (Figure 9), consisting of different demands for different plastic types (

Figure 10). From these, PS (including GPPS, HIPS and foams) accounts for a 6.7% of the total demand. The main use for plastics in Europe is the packaging industry, with 39.9% in 2016 (Figure 11) <sup>69</sup>.



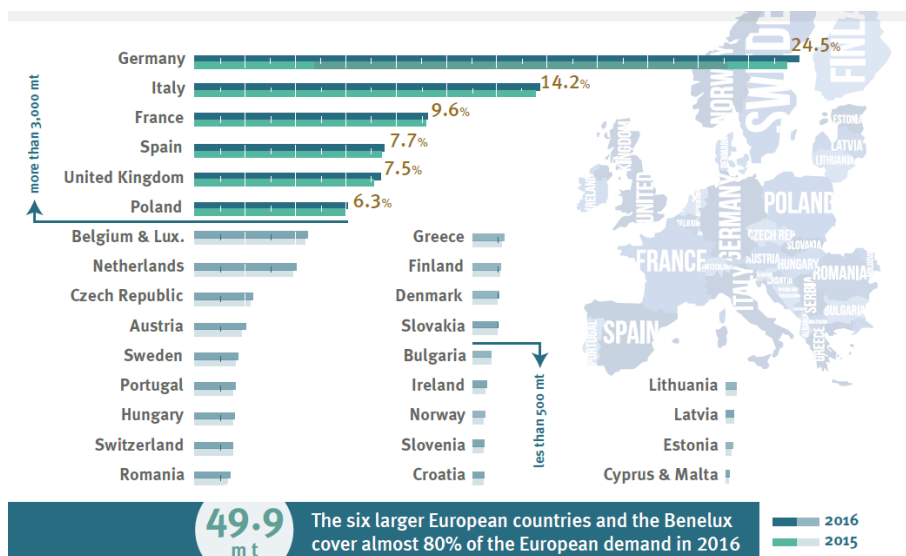


Figure 9 European demand of plastics <sup>69</sup>

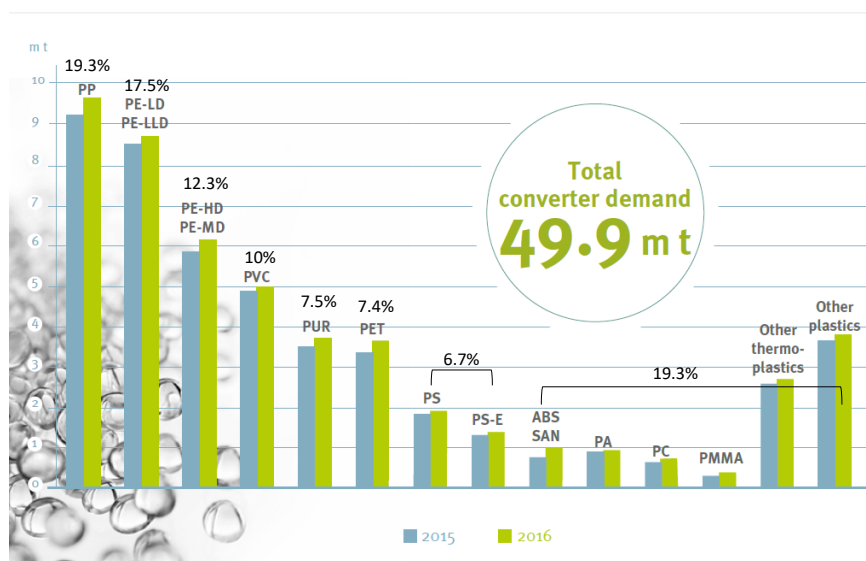


Figure 10 European (EU28+NO / CH) demand of plastics by type in 2016 <sup>69</sup>

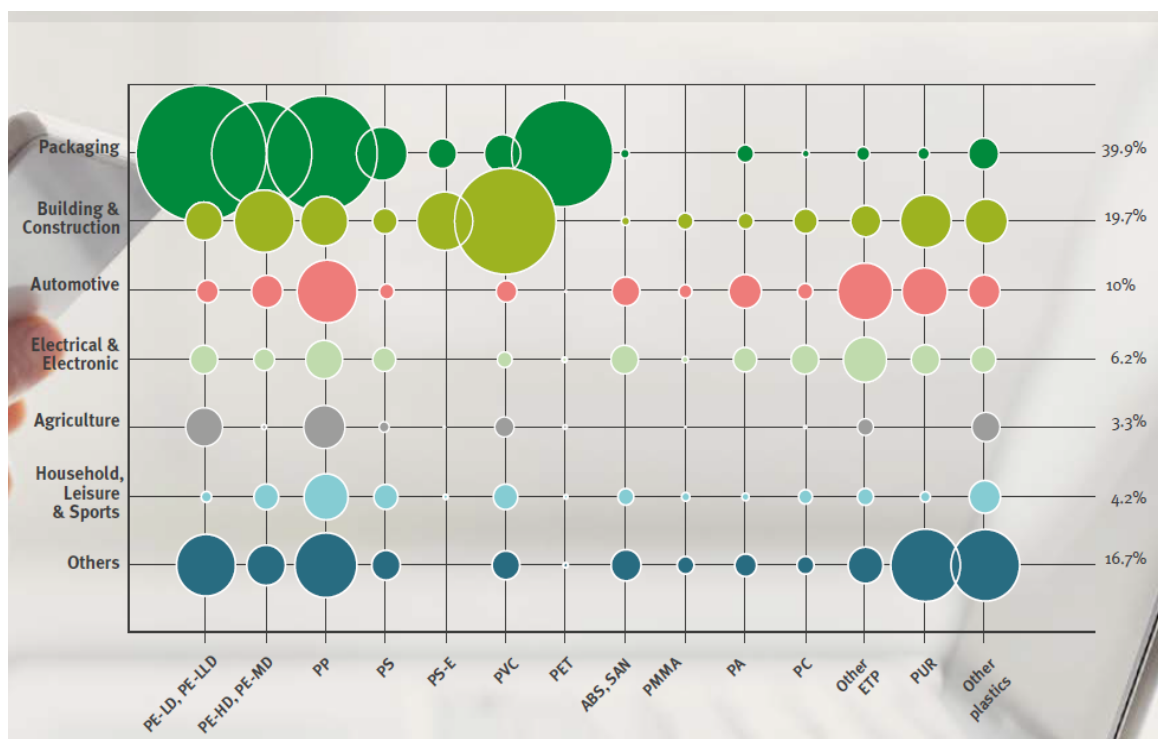


Figure 11 European plastics converted demand by segment and plastic type in 2016 <sup>69</sup>

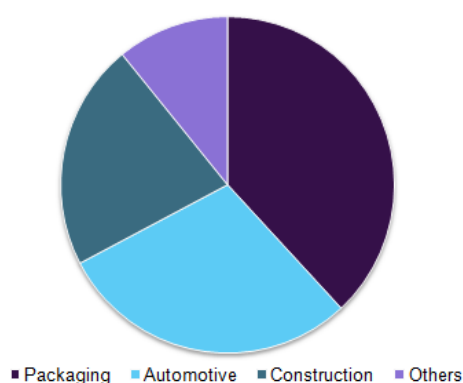


Figure 12 Global EPS market in % in 2016 <sup>47</sup>

A forecast study about the market of EPS <sup>47</sup> shows that most of the EPS in the global market is dedicated to packaging and automotive (

Figure 12). According to the study, the demand is expected to increase in 2025 to ~32.8% for the automotive industry, while construction is expected to account for 21.4% of the global volume.

Most of the plastic waste from the production industry is recycled in the same production unit. From the plastic collected in post-consumer waste, around 27.1 mt, 31.1% is recycled, 41.6% is used for energy recovery and 27.3% is deposited in landfills (

Figure 13, <sup>69</sup>).

Although recycling overtook landfill disposal in Europe in 2016 <sup>69</sup>, landfilling and incineration are still common for plastic packaging waste and a large amount also ends up in the environment and oceans <sup>70</sup>. Countries with landfill restrictions of recyclable and recoverable waste generally have higher recycling rates of post-consumer plastic waste (Figure 14).

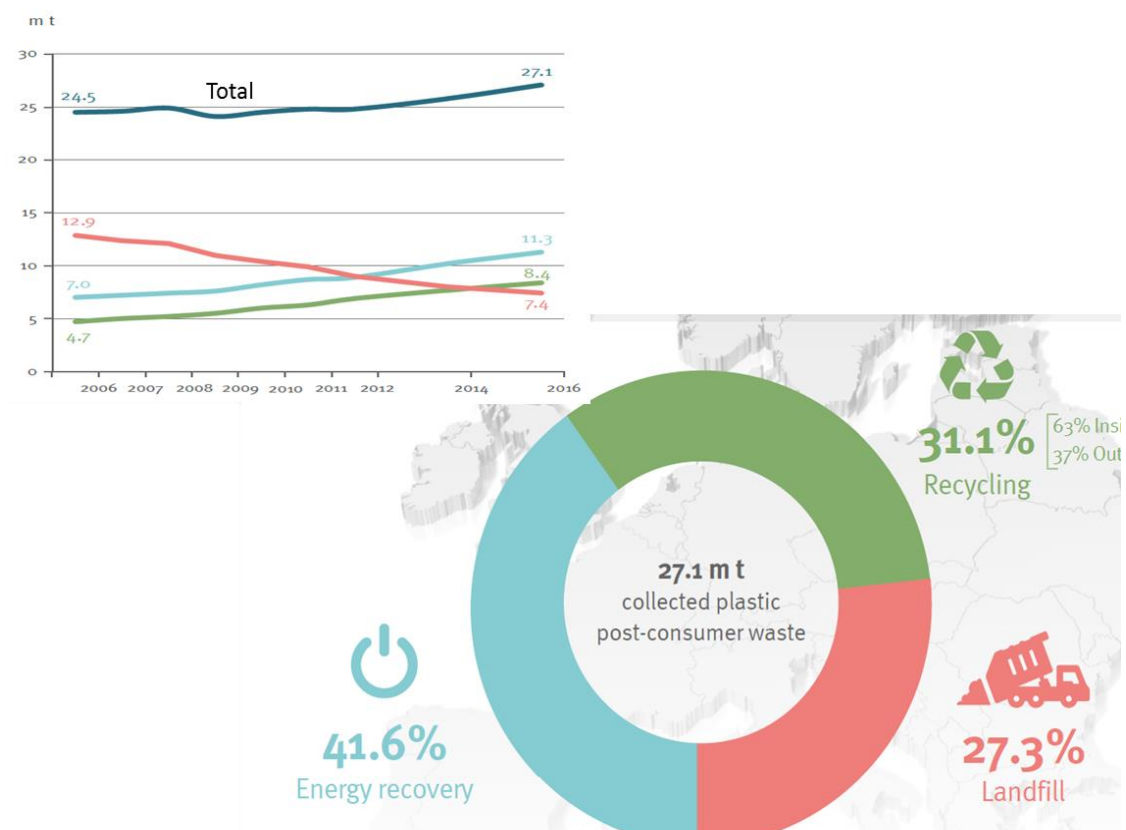
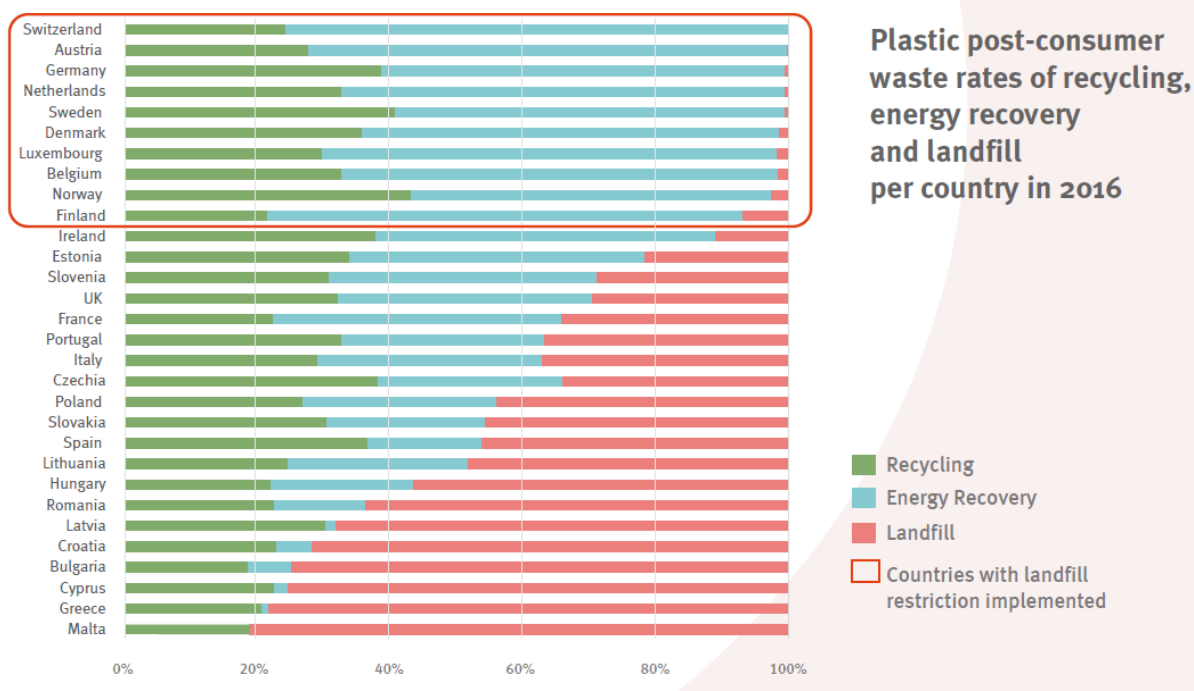
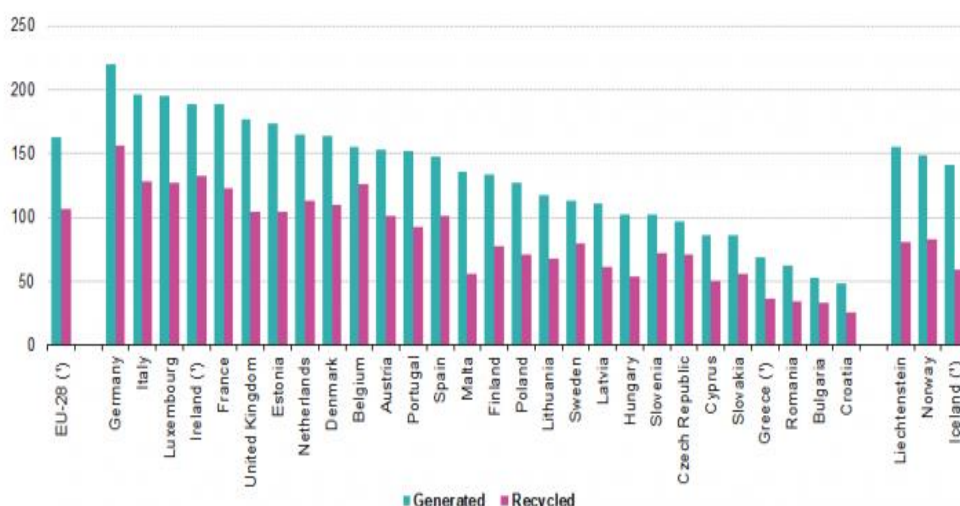


Figure 13 Post-consumer plastic waste in Europe in 2016 <sup>69</sup>



**Figure 14 Plastic waste rates of recycling in 2016** <sup>69</sup>

Although the generated waste of plastics in Europe is very high (Figure 15), and although recycling of materials like EPS is very low, some studies show that EPS seems to still be the best solution for certain packaging requirements. One of these studies was carried out by the European Manufacturers of Expanded Polystyrene <sup>71</sup> for fish boxes in the French, Spanish and Scandinavian fish markets. This study based on the life cycle assessment, seems to give better final results for the EPS compared to PP or cardboard alternatives (Table 2). Although results are market dependent, since results in the Scandinavian market showed much better results for PP and cardboard than in the other markets <sup>71</sup>. There is no evidence in the report that this is better for the marine environment if it ends up there, something often lacking from life cycle assessments.



Note: ranked on 'Waste generated'.  
 (\*) Estimate: Iceland (2012 data); Ireland, Greece (2013 data)

Figure 15 Volume of overall packaging waste generated (in kg per inhabitant) and recycled per inhabitant in 2014 <sup>72</sup>

## 7) Amounts of EPS/XPS waste generated

Recent European data from 2016/2017 estimate the total European EPS/XPS waste generation from construction and packaging at 527,000 tonnes (Conversio 2018a). The recycling rate for EPS waste in Europe in 2017 was 27% in total; for EPS packaging waste 34%, and for EPS construction waste 8%. This is slightly lower than the overall recycling rate for plastics in general in Europe, which in 2016 was 31.2%.

Table 2 Comparative results of the three packaging solutions in an average European situation. The results of the EPS packaging are taken as the reference <sup>71</sup>

Indicator		EPS	PP	Cardboard
		6 kg	6 kg	6 kg
		Europe	Europe	Europe
Non renewable primary energy	MJ	1	1.3	1
Depletion of Non Renewable Resources	kg eq. Sb	1	1.3	1.0
Emission of Greenhouse gases	kg CO2 eq., 100 years	1	1	1.3
Air acidification	g SO2 eq.	1	1.2	1.9
Photochemical Oxidants formation	g eq. ethylene	1	0.3	0.2
Water consumption	m3	1	0.8	3.5
Water Eutrophication	in g eq. PO43-	1	1.2	5.1
Total waste production	kg	1	2.3	5.2

## 8) Regulations

The EU regulation REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) Regulation No 1907/2006 came into force in 2007. The aim of this regulation is to ensure that all substances are manufactured and used safely (REACH covers the use of substances in products manufactured in EU or imported to EU). According to REACH, manufacturers and importers of chemical substances of at least one tonne per year must register the chemical substances to ECHA (European Chemicals Agency). Unregistered chemical substances cannot be marketed on the EU market. Substances are identified as substances of very high concern (SVHCs) if they are carcinogenic, toxic for reproduction or mutagenic (CMR); persistent, bioaccumulative and toxic (PBT); or very persistent and very accumulative (vPvB) according to REACH Annex XIII. Restricted substances can be found in Annex XVII. However, the majority of substances in REACH are not covered by restrictions. A Member State or ECHA can propose a substance to be identified as an SVHC at the request of the European Commission. Listing of a substance as an SVHC on the so-called Candidate list by ECHA is the first step in the procedure for authorisation of use of a chemical. Substances on the candidate list can be used in mixtures and articles, but there is obligation to provide information about use in articles to ECHA and to users. Substances on the authorisation list as per January 11th 2016 concerning plastics are listed in Table 3, although some have restrictions of use, like the phthalates in toys <sup>42</sup>.

**Table 3 Substances in plastics on the authorization lists <sup>42</sup>**

Substance	Function
Bis (2-ethylhexyl) phthalate (DEHP)	Plasticiser
Dibutyl phthalate (DBP)	Plasticiser
Benzyl butyl phthalate (BBP)	Plasticiser
Diisobutyl phthalate (DIBP)	Plasticiser
Acrylamide (monomer)	Intermedia – Co-monomer
Hexabromocyclododecane (HBCDD)	Flame retardant
Lead chromate	Pigment
Lead chromate molybdate sulfate red	Pigment
Lead sulfochromate yellow	Pigment

The European Directive 2011/65/EC on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic equipment (EEE) (the RoHS directive) became effective in 2006, with the purpose of limiting the use of hazardous substances in electrical and electronic equipment, and to contribute to the protection of human health and the environmentally sound recovery and sound disposal of WEEE (waste EEE). The substances restricted in EEE under RoHS directive are listed in Table 4 <sup>42</sup>.

Table 4 Substance restricted under RoHS <sup>42</sup>

Substance	Maximum concentrations
Lead (Pb)	0.1%
Mercury (Hg)	0.1%
Cadmium (Cd)	0.01%
Hexavalent Chromium (Cr VI)	0.1%
Polybrominated Biphenyls (PBB)	0.1%
Polybrominated Diphenyl Ethers (PBDE)	0.1%
*Bis(2-Ethylhexyl) phthalate (DEHP)	0.1%
*Benzyl butyl phthalate (BBP)	0.1%
*Dibutyl phthalate (DBP)	0.1%
*Diisobutyl phthalate (DIBP)	0.1%

Note: \*From 2019.

The European Commission regulates the substances that can be used in materials and products intended to come into contact with food in the EU regulation (EC) No 1935/2004 (updated with the regulation EC) No 450/2009). This regulation provides a harmonized legal EU framework. It sets the general principles of safety and inertness for all Food Contact Materials (FCMs). Regulation (EC) No 2023/2006 also ensures that the manufacturing process is well controlled so that the specifications for FCMs remain in conformity with the legislation <sup>31</sup>. The basic rules for the manufacture of plastic materials and articles intended to come into contact with food and lists of the monomers and additives used in plastic materials and products can be found in European Commission regulation (EC) 10/2011 <sup>30</sup> (which modifies the basic regulation 2002/72/EC <sup>73</sup>. Regulation 10/2011 also lists the group restriction of substances. This regulation is regularly amended, such as the Regulation (EU) 2016/1416, (that will enforce limits for metals and specific food groups from September 2018), Regulation (EU) 2017/752, or Regulation (EU) 2018/79 <sup>31</sup>. The European Food Safety Authority (EFSA) regularly publishes substances studied for use in food contact materials as Scientific Opinions of the Panel on food contact materials, enzymes, flavourings and processing aids (CEF). In general, regulation 2002/72/EC sets some limits: plastic materials and articles shall not transfer their constituents to foodstuffs in quantities exceeding 10 milligrams per square decimetre of surface area of material or article, as an overall migration limit set as a generic limit for the inertness of a plastic material <sup>30</sup>. However, this changes to 60 milligrams of the constituents released per kilogram of foodstuff (mg/kg) if the containers can be filled between 500 mL and 10 L, if it is impracticable to estimate the surface area in contact with foodstuffs or for sealing devices (caps, gaskets, stoppers, etc). For solvents, regulation 10/2011 states that solvents used in the manufacture of plastics to create a suitable reaction environment are expected to be removed in the manufacturing process as they are usually volatile. As for plastic colorants, no rules have yet been set out at EU level for the risk assessment and

use of solvents in the manufacture of plastics and therefore their use should remain subject to national law <sup>31</sup>. Flame retardant use, as mentioned before, has been regulated by the Commission regulation (EU) 850/2004 <sup>17</sup> and amended in the (EU) 2016/293 <sup>16</sup>. The EU Marine Strategy Framework, EU water Framework and associated priority substances directive are also important to consider in relation to chemicals and standards set out.

Another regulatory system is the Strategic Approach to International Chemicals Management (SAICM), which was adopted in 2006 by the International Conference on Chemicals Management (ICCM). This policy framework sets the target that chemicals are produced and used in ways that minimize the adverse effects on environment and human health by 2020 <sup>42</sup>.

In the U.S., the Food and Drug Administration (FDA) regulates packaging materials under section 409 21USC348 <sup>74</sup> of the federal Food, Drug, and Cosmetic Act. All food contact substances that may reasonably migrate to food under conditions of intended use are identified and regulated as food additives <sup>75</sup>, so they are assumed to be safe for the purpose of the application, or the conditions of safe use are regulated. However, a substance used in a food-contact article that migrates or is expected to migrate can be exempted from regulation as food additive if it is not carcinogenic; if it doesn't present a health or safety concern because is not expected to result in dietary concentrations of 1.5 ug/person per day or above, if it is already registered for food additive, if the substance has no technical effect on the food, or if the substance has no significant adverse impact on the environment

<sup>76</sup>.



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## Annex 1 From oil to styrene

The production of styrene begins with oil. Crude oil is distilled in a refinery into a range of products such as petrol, kerosene, naphta and liquid petroleum gas. These products are used as fuel for transportation and domestic uses and are the start off point for industrial processes such as cracking which transform them into other useful compounds such as ethylene.

Ethylene is one of the products of steam cracking. This process turns saturated hydrocarbons into smaller unsaturated hydrocarbons. A gas or liquid hydrocarbon such as naphta or liquid petroleum gas is very briefly heated to around 850 °C in the presence of steam and absence of oxygen to produce lighter alkenes such as ethylene and propylene. Ethylene from steam cracking is used in the manufacture of vinyl chloride, ethylbenzene, ethylene oxide, and ethanol. Additionally, both ethylene and propylene can be polymerised to produce the plastics polyethylene and polypropylene.

Benzene is produced by several industrial processes. Catalytic reforming blends a mixture of hydrocarbons with hydrogen gas at high temperature and pressure to form aromatic hydrocarbons. These are then removed from the mixture by a solvent, after which the benzene is isolated by distillation. Toluene hydroalkylation turns toluene into benzene by mixing it with hydrogen gas in the presence of a catalyst at high temperature and pressure. Toluene disproportionation produces benzene and xylene in equal quantities by shifting methyl groups from one toluene molecule to another. Finally, steam cracking can also be used for benzene production by using the right feedstock which can produce a benzene rich byproduct.

The ethylene and benzene are combined in a Lewis acid catalysis at 180 °C and under 9 bar to produce ethylbenzene. Ethylbenzene is also used as a solvent in paints and as an anti-knock additive in automotive gasoline. It can have harmful effects on the central nervous system. Additionally, ingestion may cause pneumonia, it is a CMR class compound (carcinogenic, mutagenic, and toxic for reproduction), and it is lethal by inhalation.

Styrene is produced from ethylbenzene by dehydrogenation. In this catalytic dehydrogenation using e.g. iron oxide or aluminium chloride as catalyst, the ethylbenzene is heated to 600 °C using steam which also prevents excessive carbon formation and helps shift the reversible reaction towards the end product.



## Annex 2 Chemicals found in GPPS, HIPS, EPS, and XPS

**Table A:** Summary of chemicals described, found or approved for use in polystyrene materials for general polystyrene products.

Polystyrene (PS, GPPS)				
Chemical	CAS	Function	Reference	Use
Styrene	100-42-5	intermediate	41	
DiBP (Diisobutyl phthalate, Phtalic acid)	84-69-5	Specialist plasticiser	41, 25	Food contact
Cadmium and cadmium components	7440-43-9, 10108-64-2, 542-83-6, 7790-79-6, 4464-23-7, 7790-80-9, 17010-21-8, 1306-19-0, 10124-36-4, 1306-23-6 etc.	Pigment	41	
Lead chromate	7758-97-6	Pigment	41	
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	12656-85-8	Pigment (red)	41	
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	1344-37-2	Pigment (yellow)	41	
<i>N</i> -[4-[(2-hydroxy-5-methylphenyl)azo]phenyl]acetamide, C.I. Disperse Yellow 3	2832-40-8	Pigment (yellow)	41	
1-phenylazo-2-naphthol, C.I. Solvent Yellow 14	842-07-9	Pigment (yellow)	41	
Malachite green hydrochloride, malachite green oxalate	569-64-2, 18015-76-4	Pigment (green)	41	
Polyaromatic Hydrocarbons (PAHs)		Plastics coloured black.	41	
1,4-Diamino-2-methoxy-9		Pigment	85	
9,10-anthracenedione		Pigment	85	
2-methyl-4-((2-methylphenyl)azo)-benzenamine		Pigment	85	

1,4-benzenediol, 2,5-bis(1,1-dimethylethyl)-	88-58-4	Antioxidant	41	
Irganox 1076, E 201, 1135, 2246, 259, 1098, 1222, 1425, 245	2082-79-3	Antioxidant	25, 85	Food contact
Butylated hydroxytoluene (BHT)		Antioxidant	85	
Irgafos TNPP, 168, 126, 12, 38, PS 802, PS 800		Secondary antioxidant	85	
ADK Stab PE, HP-10		Secondary antioxidant	85	
Hostanox P-EPQ		Secondary antioxidant	85	
Ethanox 398		Secondary antioxidant	85	
Weston 618		Secondary antioxidant	85	
Fatty acid esters		Anti-static additives	85	
Ethoxylated alkylamines		Anti-static additives	85	
Diethanolamides		Anti-static additives	85	
Ethoxylated alcohol		Anti-static additives	85	
Alkylsulfonates		Anti-static additives	85	
Alkylphosphates		Anti-static additives	85	
Tetraalkylammonium salt		Anti-static additives	85	
Trialkylbenzylammonium salt		Anti-static additives	85	
Glycerol monooleate			46	Food contact
Polyamide 6/66, 6/12			46	Food contact
Methylpalmitate			25	Food contact
Polysiloxanne			25	Food contact

Phtalic acid		25	Food contact
Sebacic acid (2-methoxyethyl tetradecyl ester)	111-20-6	25	Food contact
Methadone N-oxide	33100-61-7	25	Food contact
Benzene 1,1'-(1,2-cyclobutanediyl) bis-cis, octadecanoic acid		25	Food contact
Methyl ester, benzene 1,10-(1,2-cyclobutanediyl) bis-trans		25	Food contact
Benzyl benzoate (or ascabin or ascabiol	120-51-4	25	Food contact
Butyl ester of propanoic acid ( or UN 1914)	590-01-2	25	Food contact
UV-P, UV-320, UV-326, UV-327, UV-328, UV-329, UV-350, UV-360, UV-571		UV absorbers 85	
Tinuvin 213, Tinuvin 234, Tinuvin 840		UV absorbers 85	
ADK Stab LA		UV absorbers 85	
Seesorb 1000		UV absorbers 85	
Cyasorb UV-9		UV absorbers 85	
Uvinul 400		UV absorbers 85	
Cyasorb UV-24, Cyasorb UV-531		UV absorbers 85	

**Table B:** Summary of chemicals described, found or approved for use in polystyrene materials for high impact polystyrene (HIPS) products.

<b>HIPS</b>				
<b>Chemical</b>	<b>CAS</b>	<b>Function</b>	<b>Reference</b>	<b>Use</b>
Styrene	100-42-5	Intermediate	41, 48	
1,3-butadiene (butadiene rubber)	9003-17-2, 106-99-0	Monomer	41, 48	
Polystyrene	9003-53-6	Polymer	49, 50	
Modified polystyrene	9003-53-8	Polymer	49	
Styrene with 1,3-butadiene polymer	9003-55-8	Polymer	51, 52, 53,54	
Mineral oil	8042-47-5		521	
Methyl chloride	74-87-3	Blowing agent	41	
Diisobutyl phthalate (DiBP)	84-69-5	Specialistplasticiser	41	Food contact
Cadmium and cadmium components	7440-43-9, 10108-64-2, 542-83-6, 7790-79-6, 4464-23-7, 7790-80-9, 17010-21-8, 1306-19-0, 10124-36-4, 1306-23-6 etc.	Pigment	41	Electronics
Lead chromate	7758-97-6	Pigment	41,42	Electronics
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	12656-85-8	Pigment (red)	41,42	Electronics
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	1344-37-2	Pigment (yellow)	41,42	Electronics
<i>N</i> -[4-[(2-hydroxy-5-methylphenyl)azo]phenyl]acetamide, C.I. Disperse Yellow 3	2832-40-8	Pigment (yellow)	41	
1-phenylazo-2-naphthol, C.I. Solvent Yellow 14	842-07-9	Pigment (yellow)	41	
Malachite green hydrochloride, malachite green oxalate	569-64-2, 18015-76-4	Pigment (green)	41	
Polyaromatic Hydrocarbons (PAHs)		Plastics coloured black.	41, 44	Food contact

1,4-Diamino-2-methoxy-9		Pigment	85	
9,10-anthracenedione		Pigment	85	
2-methyl-4-((2-methylphenyl)azo)-benzenamine		Pigment	85	
BFRs		Flame retardants	41, 42	Housing
HBCD	25637-99-4; 3194-55-6; 134237-50-6; 134237-51-7; 134237-52-8	Flame retardant	41	Electronics, housing
Bis(hexachlorocyclopentadieno) cyclooctane (Dechlorane Plus)	13560-89-9	Flame retardant	41	Electronics, housing
Decabromodiphenyl ethane (DBDPE)	84852-53-9	Flame retardant	41	Electronic, housing
Ethylene (bistetra-bromophthalimide) (EBTEBPI)	32588-76-4	Flame retardant	41	Electronics
Tetrabromobisphenol A bis (2,3-dibromopropyl) ether (TBBPA-BDBPE)	21850-44-2	Flame retardant	41	Electronics
Tris(tribromophenoxy) triazine (TTBPTAZ)	25713-60-4	Flame retardant	41	Electronics
Bisphenol A bis-(diphenyl phosphate) (BPA)	181028-79-5	Flame retardant	41	Electronics
Ethylenebis (tetrabro-mophthalimide) (EBTPI)	32588-76-4	Flame retardant	41	Electronics
Diphenyl cresyl phosphate (DCPP)	26444-49-5	Flame retardant	41	Electronics
Bisphenol A bis-(diphenyl phosphate ) (BAPP)	181028-79-5	Flame retardant	41	
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	Flame retardant	41	Electronics
1,4-benzenediol, 2,5-bis(1,1-dimethylethyl)-	88-58-4	Antioxidant	41	
Irganox 1076, E 201, 1135, 2246, 259, 1098, 1222, 1425, 245	2082-79-3	Antioxidant	25, 85	Food contact
Butylated hydroxytoluene (BHT)		Antioxidant	85	

Irgafos TNPP, 168, 126, 12, 38, PS 802,  
PS 800

ADK Stab PE, HP-10

Hostanox P-EPQ

Ethanox 398

Weston 618

Fatty acid esters

Ethoxylated alkylamines

Diethanolamides

Ethoxylated alcohol

Alkylsulfonates

Alkylphosphates

Tetraalkylammonium salt

Trialkylbenzylammonium salt

Ethylenebis(oxyethylene) bis[3-(5-tert- 36443-68-2  
butyl-4-hydroxy-m-tolyl)propionate  
(Irganox 245, 1076, B 900)

Phenol, 2-(2H-benzotriazol-2-yl)-4,6- 70321-86-7  
bis(1-methyl-1-phenylethy 70321-86-  
7(45) (Tinuvin P and 234)

N,N'-1,6-hexanedylbis(N-(2,2,6,6- 124172-53-8  
tetramethyl-piperidin-4-yl)formamide  
(Univul 4050)

UV-P, UV-320, UV-326, UV-327, UV-328,  
UV-329, UV-350, UV-360, UV-571

Secondary 85  
antioxidant

Secondary 85  
antioxidant

Secondary 85  
antioxidant

Secondary 85  
antioxidant

Secondary 85  
antioxidant

Anti-static 85  
additives

Anti-static 85  
additives

Anti-static 85  
additives

Anti-static 85  
additives

Anti-static 85  
additives

Anti-static 85  
additives

Anti-static 85  
additives

Anti-static 85  
additives

Stabilizer 77 Housing

Light 77 Housing  
stabilizer

Light 77 Housing  
stabilizer

UV absorbers 85

Tinuvin 213, Tinuvin 234, Tinuvin 840		UV absorbers	85	
ADK Stab LA		UV absorbers	85	
Seesorb 1000		UV absorbers	85	
Cyasorb UV-9		UV absorbers	85	
Uvinul 400		UV absorbers	85	
Cyasorb UV-24, Cyasorb UV-531		UV absorbers	85	
Irgastat P		Specialities	77	Housing
2,5-Thiophenediylbis(5-tert-butyl-1,3-benzoxazole) (Tinopal OB	7128-64-5	Specialities	77	Housing
DMP			43	Food contact
Di(2-ethylhexyl)adipate (DEHA)	103-23-1		43	Food contact

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**Table C:** Summary of chemicals described, found or approved for use in polystyrene materials for foamed polystyrene (expanded [EPS] or extruded [XPS]) products.

EPS/ XPS				
Chemical	CAS	Function	Reference	Use
Styrene	100-42-5	Intermediate	40, 62	Food contact, insulation
Polystyrene	9003-53-6	Polymer	54, 55, 63, 62, 66	Food contact, insulation
Polymer with ethene	9010-79-1	Polymer	64	
Talc	14807-96-6	Filler	54	Insulation
Graphite		Filler	56, 58	Insulation
Diatomaceous silica		Filler	45	Food contact
Pentane	109-66-0	Blowing agent	61, 8, 65, 56, 58, 66	Food contact, insulation
Iso-pentane	78-78-4	Blowing agent	62, 8, 66	Food contact
Cyclopentane	287-92-3	Blowing agent	62, 8	Insulation
Methyl chloride	74-87-3	Blowing agent	40	
1-Propene	115-07-1	Blowing agent	64	
Isobutane	75-28-5	Blowing agent	7	Food contact
HFC 134a, HFC 152a, HCFC-22, HCFC 142b	811-97-2, 75-37, 75-68-3, 75-45-6	Blowing agent	60, 54, 40	Insulation
DME	78-78-4	Blowing agent	55, 56, 58	Insulation
Acetone	67-64-1	Blowing agent	45	Food contact
Azodicarbonamide (ADC)		Blowing agent	85	
p-toluenesulfonylhydrazide (TSH)		Blowing agent	85	
4,4'-oxibis (benzenesulfonylhydrazide) (OBSH)		Blowing agent	85	
p-toluenesulfonyl semicarbazide (TSSC),		Blowing agent	85	
5-phenyltetrazole (5-PT)		Blowing agent	85	



N,N'-dinitroso-pentamethylenetetramine (DNPT)		Blowing agent	85	
4,4'-Diaminodiphenylmethane (MDA)		Curing agent	85	
2,2'-dichloro-4,4'-methylenedianiline (MOCA)		Curing agent	85	
formaldehyde – reaction products with aniline		Curing agent	85	
hydrazine		Curing agent	85	
TGIC/β-TGIC		Curing agent	85	
DiBP (Diisobutyl phthalate, Phtalic acid)	84-69-5	Specialist plasticiser	40, 24	Food contact
Cadmium and cadmium components	7440-43-9, 10108-64-2, 542-83-6, 7790-79-6, 4464-23-7, 7790-80-9, 17010-21-8, 1306-19-0, 10124-36-4, 1306-23-6 etc.	Pigment	40, 41	Electronics
Lead chromate	7758-97-6	Pigment	40, 41	Electronics
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	12656-85-8	Pigment (red)	40, 41	Electronics
C.I. Solvent Red 23	85-86-9	Pigment (red)	45	Food contact
Solvent Red 24 (Sicostyren Red or Sudan IV)	85-83-6	Pigment (red)	26, 45	Food contact
Solvent Red 26	4477-79-6	Pigment (red)	45	Food contact
Disperse Orange 47	5718-26-3	Pigment (orange)	45	Food contact
Solvent Orange 60	6925-69-5	Pigment (orange)	45	Food contact
Solvent Yellow 72	4645-07-2	Pigment (yellow)	45	Food contact
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	1344-37-2	Pigment (yellow)	40	

<i>N</i> -[4-[(2-hydroxy-5-methylphenyl)azo]phenyl]acetamide, C.I. Disperse Yellow 3	2832-40-8	Pigment (yellow)	40	
1-phenylazo-2-naphthol, C.I. Solvent Yellow 14	842-07-9	Pigment (yellow)	40	
Malachite green hydrochloride, malachite green oxalate	569-64-2, 18015-76-4	Pigment (green)	40	
C.I. Solvent Blue 36	14233-37-5	Pigment (blue)	45	Food contact
colorant 2,4-dihydro-4-((2-methoxyphenyl)azo)-5-methyl-2-phenyl-3H-pyrazol-3-one	4645-07-2	Pigment	45	Food contact
solvent violet 13 (13 (1-hydroxy-4-((4-methylphenyl)amino)-9,10-anthracenedione)	81-48-1	Pigment	45	Food contact
Polyaromatic Hydrocarbons (PAHs)		Plastics coloured black.	43, 40	Food contact
1,4-Diamino-2-methoxy-9		Pigment	85	
9,10-anthracenedione		Pigment	85	
2-methyl-4-((2-methylphenyl)azo)-benzenamine		Pigment	85	
Butadiene styrene brominated copolymer	1195978-93-8	Flame retardant	56, 67, 58	Insulation
IC RK-972 (1,1'-(isopropylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)benzene])	97416-84-7	Flame retardant	18	Insulation
Boric acid	10043-35-3, 50-1	11113-Flame retardant	40	Foam
BFRs		Flame retardant	40	Insulation
1,3,5-tribromo-2-[2-(2,4,6-tribromophenoxy)ethoxy]benzene (BTBPE)	37853-59-1	Flame retardant	44	Several
HBCD	25637-99-4; 3194-55-6; 134237-50-6; 134237-51-7; 134237-52-8, 14807-96-6	Flame retardant	54, 55, 63, 61, 65, 40	Insulation

Tetrabromobisphenol A bis (allyl ether)	25327- 89-3	Flame retardant	40	Insulation
1,2,5,6- tetrabromocy-clo- octane (TBCO)	3194- 57-8	Flame retardant	40	Insulation
2,4,6- tribromophenyl allyl ether	3278-89-5	Flame retardant	40	Insulation
Tetrabromobisphenol A bis(2,3- di-bromopropyl ether) (TBBPA- DBPE), with dicumene for XPS and dicumyl peroxide for EPS, as usual synergists	21850-44-2	Flame retardant	40	Insulation
Tetrakis(2,6-dimethylphenyl)-m-phenylene biphosphate	139189-30-3	Flame retardant	40	Insulation
Tetrakis[methylene(3,5-di-tert-butyl-4-hydroxyhydrocinnamate)methane]	6683-19-8		45	Food contact
Octadecyl 3,5-di-tert-butyl-4-hydroxyhydrocinnamate	2082-79-3		45	Food contact
Di-tert-butylphenyl phosphonite condensation product with biphenyl	119345-01-6		45	Food contact
Tri(mixed mono- and di-nonylphenyl) phosphate	26523-78-4		45	Food contact
Tris(2,4-di-tert-butylphenyl)phosphite	31570-04-4		45	Food contact
Cyclic neopentantetrayl bis(octadecyl phosphite)	3806-34-6		45	Food contact
Butylated hydroxytoluene (BHT)			45	Food contact
Butadiene styrene brominated copolymer	1195978-93-8		59, 56, 58	Insulation
2,2'-dichloro-4,4'-methylenedianiline (MOCA)	101-14-4	Curing agent	40	
1,4-benzenediol, 2,5-bis(1,1-dimethylethyl)-	88-58-4	Antioxidant	40	
4-tert-octylphenol (OP)		Antioxidant	42, 40	Food contact
Irganox 1076, E 201, 1135, 2246, 259, 1098, 1222, 1425, 245	2082-79-3	Antioxidant	25, 85	Food contact
Butylated hydroxytoluene (BHT)		Antioxidant	85	
Irgafos TNPP, 168, 126, 12, 38, PS 802, PS 800		Secondary antioxidant	85	

ADK Stab PE, HP-10		Secondary antioxidant	85	
Hostanox P-EPQ		Secondary antioxidant	85	
Ethanox 398		Secondary antioxidant	85	
Weston 618		Secondary antioxidant	85	
Di(2-ethylhexyl)phthalate (DEHP)	117-81-7	Plastizer	42, 40	Food contact
Nonylphenol (NP)		Catalist?	42, 40	Food contact
DMP			42	Food contact
Di(2-ethylhexyl)adipate (DEHA)	103-23-1		42	Food contact
Benzyl benzoate (or ascabin or ascabiol)	120-51-4		24	Food contact
Irganox 1076	2082-79-3		24	Food contact
DiBP (Diisobutyl phthalate, Phtalic acid)	84-69-5	Specialist plasticiser	40, 24	Food contact
Diisobutyl ester			24	Food contact
Diisooctyl phtalate	27554-26-3		24	Food contact
Methadone N-oxide	33100-61-7		24	Food contact
Benzoic acid	65-85-0	Intermediate	24	Food contact
Methyl ester (niobe oil)	93-58-3		24	Food contact
Dibutyl phtalate	84-74-2		24	Food contact
Decanedioic acid			24	Food contact
Polycizer DBS (or dibutyl sebacate)	109-43-3		24	Food contact
UV-P, UV-320, UV-326, UV-327, UV-328, UV-329, UV-350, UV-360, UV-571		UV absorbers	85	
Tinuvin 213, Tinuvin 234, Tinuvin 840		UV absorbers	85	
ADK Stab LA		UV absorbers	85	
Seesorb 1000		UV absorbers	85	
Cyasorb UV-9		UV absorbers	85	
Uvinul 400		UV absorbers	85	
Cyasorb UV-24, Cyasorb UV-531		UV absorbers	85	

