Eco-profiles of the
European Plastics Industry

POLYSTYRENE
(High impact)(HIPS)

A report by

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for

Plastics*Europe*

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IMPORTANT NOTE

Before using the data contained in this report, you are strongly recommended to look at the following documents:

1. Methodology

This provides information about the analysis technique used and gives advice on the meaning of the results.

2. Data sources

This gives information about the number of plants examined, the date when the data were collected and information about up-stream operations.

In addition, you can also download data sets for most of the upstream operations used in this report. All of these documents can be found at: www.plasticseurope.org.

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THE POLYSTYRENE SYSTEM

Polystyrene is a versatile polymer resin used in a wide range of applications - especially in the packaging industry. It is sold in three main forms: crystal or general purpose polystyrene (GPPS), high impact polystyrene (HIPS) and expandable polystyrene (EPS). The crystal form is pure polystyrene with few additives and is used when clarity is required even though it is very brittle. The high impact form is translucent or opaque because of rubber compounds added to the reaction and incorporated into the resin to inhibit crack propagation and hence reduce brittleness. The expandable form is the same as the crystal form except that low molecular mass hydrocarbons, usually pentane, are incorporated into the finished resin. These additives vaporise during subsequent processing to produce a foam.

The production of styrene monomer can be thought of as replacing one of the hydrogen atoms in ethylene by a benzene ring (C_6H_6) as shown in Figure 1. The monomer is then polymerised is a manner similar to polyethylene; that is, the double bonds in the monomer molecules are opened and neighbouring molecules link together to form a chain as shown in Figure 1. The repeat unit, shown inside the shaded box in Figure 1, has the same chemical composition as the styrene monomer.

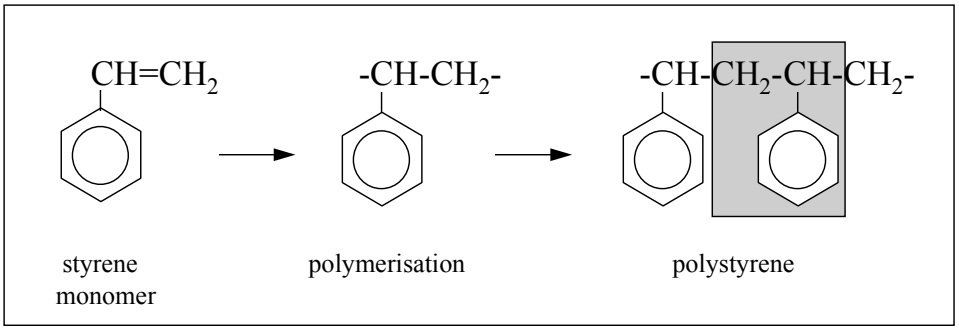

Figure 1
The reaction scheme for producing polystyrene from styrene monomer.

In practice, the production route from crude oil and natural gas is as shown in Figure 2. Crude oil refining produces a fraction known as naphtha which contains a mixture of low molecular weight, saturated hydrocarbons of various composition. This is converted into a smaller group of unsaturated hydrocarbons by cracking - a process in which the naphtha is heated to a high temperature in the absence of air, maintained for a short time at this high temperature and then very rapidly cooled back to a low temperature when all of the reactions stop and the mix of products is essentially fixed. The resulting mixture is then separated into its constituent components by distillation producing principally ethylene (C_2H_4), propylene (C_3H_6), mixed butenes of general formula C_4H_8 and a number of other compounds which find uses

elsewhere in the petrochemical plant either as feedstocks or fuels. The precise mix of products from cracking are determined by a number of factors such as cracker temperature, residence time and the nature of the feedstock and the operation of a cracker can often be adjusted to produce the required mix of products.

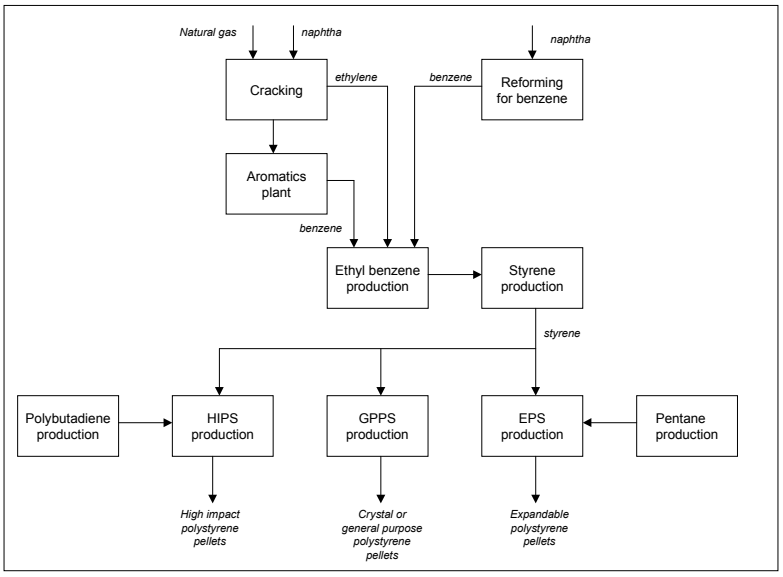

Figure 2
Outline flow chart for the production of polystyrene

Natural gas is also converted into ethylene, propylene, butenes and other products by cracking.

Although benzene is usually present in small quantities in crude oil, its direct extraction is usually uneconomic. However, one by product of naphtha cracking is a liquid usually referred to as pyrolysis gasoline which is high in unsaturated aliphatic and aromatic hydrocarbons. The benzene fraction in pyrolysis gasoline can be extracted by repeated distillation and it is thought that about half of all benzene used in Europe is produced in this way.

Benzene is also produced directly from naphtha by a process known as catalytic reforming. The basic feedstock is converted into a mixture of products of which the principal components are benzene, toluene and xylene (the process is often referred to as the BTX process). Benzene and other aromatics are isolated in the pure state from the output of the reformer by solvent extraction and fractional distillation.

The relative proportions of benzene derived from the two sources vary from one operator to another but, in the later calculations, when the precise mix is unknown - as for example, when benzene is purchased on the open market - it is assumed that 50% is derived from each source.

ECO-PROFILE OF HIPS

Table 1 shows the gross or cumulative energy to produce 1 kg of HIPS and Table 2 gives this same data expressed in terms of primary fuels. Table 3 shows the energy data expressed as masses of fuels. Table 4 shows the raw materials requirements and Table 5 shows the demand for water. Table 6 shows the gross air emissions and Table 7 shows the corresponding carbon dioxide equivalents of these air emissions. Table 8 shows the emissions to water. Table 9 shows the solid waste generated and Table 10 gives the solid waste in EU format.

Table 1
Gross energy required to produce 1 kg of HIPS. (Totals may not agree because of rounding)

Fuel type	Fuel prod'n & delivery energy (MJ)	Energy content of delivered fuel (MJ)	Energy use in transport (MJ)	Feedstock energy (MJ)	Total energy (MJ)
Electricity	4.32	1.58	0.38	-	6.28
Oil fuels	0.83	13.81	1.07	30.60	46.31
Other fuels	0.88	18.08	0.09	15.78	34.82
Totals	6.02	33.46	1.54	46.38	87.41

Table 2
Gross primary fuels required to produce 1 kg of HIPS. (Totals may not agree because of rounding)

Fuel type	Fuel prod'n & delivery energy (MJ)	Energy content of delivered fuel (MJ)	Fuel use in transport (MJ)	Feedstock energy (MJ)	Total energy (MJ)
Coal	1.29	3.50	0.15	<0.01	4.94
Oil	1.11	14.00	1.17	30.60	46.88
Gas	1.90	17.81	0.12	15.78	35.61
Hydro	0.12	0.06	<0.01	-	0.18
Nuclear	1.52	0.61	0.09	-	2.21
Lignite	<0.01	<0.01	<0.01	-	<0.01
Wood	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphur	<0.01	<0.01	<0.01	<0.01	<0.01
Biomass (solid)	0.02	0.01	<0.01	<0.01	0.03
Hydrogen	<0.01	0.31	<0.01	-	0.31
Recovered energy	<0.01	-2.86	<0.01	-	-2.86
Unspecified	<0.01	<0.01	<0.01	-	<0.01
Peat	<0.01	<0.01	<0.01	-	<0.01
Geothermal	0.01	<0.01	<0.01	-	0.01
Solar	<0.01	<0.01	<0.01	-	<0.01
Wave/tidal	<0.01	<0.01	<0.01	-	<0.01
Biomass (liquid/gas)	0.03	0.01	<0.01	-	0.04
Industrial waste	0.01	<0.01	<0.01	-	0.01
Municipal Waste	0.02	0.01	<0.01	-	0.03
Wind	0.01	<0.01	<0.01	-	0.01
Totals	6.02	33.46	1.54	46.38	87.41

Table 3
Gross primary fuels used to produce 1 kg of HIPS expressed as mass.

Fuel type	Input in mg
Crude oil	1000000
Gas/condensate	700000
Coal	170000
Metallurgical coal	740
Lignite	37
Peat	120
Wood	45

Table 4
Gross raw materials required to produce 1 kg of HIPS.

Raw material	Input in mg
Air	450000
Animal matter	330
Barytes	2
Bauxite	650
Bentonite	80
Biomass (including water)	7700
Calcium sulphate (CaSO4)	8
Chalk (CaCO3)	<1
Clay	<1
Cr	<1
Cu	160
Dolomite	22
Fe	1800
Feldspar	<1
Ferromanganese	2
Fluorspar	13
Granite	<1
Gravel	7
Hg	<1
Limestone (CaCO3)	680
Mg	<1
N2	200000
Ni	23
O2	2200
Olivine	17
Pb	12
Phosphate as P2O5	<1
Potassium chloride (KCl)	6
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	1
S (elemental)	160
Sand (SiO2)	350
Shale	23
Sodium chloride (NaCl)	2000
Sodium nitrate (NaNO3)	<1
Talc	<1
Unspecified	<1
Zn	75

Table 5
Gross water consumption required for the production of 1 kg of HIPS. (Totals may not agree because of rounding)

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	1700000	-	1700000
River canal	6800000	8400000	15000000
Sea	470000	5000000	5500000
Well	6	190000	190000
Unspecified	1300000	116000000	117000000
Totals	10000000	129000000	140000000

Table 6
Gross air emissions associated with the production of 1 kg of HIPS. (Totals may not agree because of rounding)

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	From biomass (mg)	From fugitive (mg)	Totals (mg)
dust (PM10)	460	260	64	190	-	-	970
CO	1500	2500	750	440	-	-	5200
CO2	390000	2100000	85000	200000	-49	-	2800000
SOX as SO2	2100	4900	370	460	-	-	7800
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	1400	3100	910	230	-	-	5600
NH3	<1	-	<1	<1	-	-	<1
Cl2	<1	<1	<1	1	-	-	1
HCl	34	26	<1	<1	-	-	61
F2	<1	<1	<1	<1	-	-	<1
HF	1	1	<1	<1	-	-	2
hydrocarbons not specified	1100	280	250	1600	-	4	3200
aldehyde (-CHO)	<1	-	<1	<1	-	-	<1
organics	<1	<1	<1	200	-	-	200
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	<1	2	<1	<1	-	-	3
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	<1	-	-	<1
H2	35	<1	<1	21	-	-	56
dichloroethane (DCE) C2H4Cl2	<1	-	<1	<1	-	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	-	<1	<1
CFC/HCFC/HFC not specified	<1	-	<1	<1	-	-	<1
organo-chlorine not specified	<1	-	<1	1	-	-	1
HCN	<1	-	<1	<1	-	-	<1
CH4	25000	480	<1	2300	-	<1	28000
aromatic HC not specified elsewhere	<1	-	3	43	-	5	51
polycyclic hydrocarbons (PAH)	<1	4	<1	<1	-	-	4
NMVOC	<1	-	<1	37	-	-	37
CS2	<1	-	<1	<1	-	-	<1
methylene chloride CH2Cl2	<1	-	<1	<1	-	-	<1
Cu+compounds as Cu	<1	<1	<1	<1	-	-	<1
As+compounds as As	-	-	-	<1	-	-	<1
Cd+compounds as Cd	<1	-	<1	<1	-	-	<1
Ag+compounds as Ag	-	-	-	<1	-	-	<1
Zn+compounds as Zn	<1	-	<1	<1	-	-	<1
Cr+compounds as Cr	<1	2	<1	<1	-	-	2
Se+compounds as Se	-	-	-	<1	-	-	<1
Ni+compounds as Ni	<1	4	<1	<1	-	-	4
Sb+compounds as Sb	-	-	<1	<1	-	-	<1
ethylene C2H4	-	-	<1	7	-	-	7
oxygen	-	-	-	<1	-	-	<1
asbestos	-	-	-	<1	-	-	<1
dioxin/furan as Teq	-	-	-	<1	-	-	<1
benzene C6H6	-	-	-	6	-	12	18
toluene C7H8	-	-	-	2	-	2	4
xylenes C8H10	-	-	-	<1	-	1	1
ethylbenzene C8H10	-	-	-	10	-	4	14
HCFC-22 CHClF2	-	-	-	<1	-	-	<1
styrene	-	-	-	73	-	13	86
propylene	-	-	-	6	-	-	6

Table 7
Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of HIPS. (Totals may not agree because of rounding)

Type	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	From biomass (mg)	From fugitive (mg)	Totals (mg)
20 year equiv	2000000	2100000	88000	350000	-49	34	4500000
100 year equiv	980000	2100000	88000	260000	-49	21	3400000
500 year equiv	580000	2100000	88000	230000	-49	15	3000000

Table 8
Gross emissions to water arising from the production of 1 kg of HIPS. (Totals may not agree because of rounding).

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	Totals (mg)
COD	3	4	1	420	430
BOD	1	1	<1	56	58
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	<1	-	1	200	210
acid as H+	2	-	<1	4	6
NO3-	<1	1	<1	6	7
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	<1	-	<1	120	120
ammonium compounds as NH4+	2	<1	<1	8	10
Cl-	1	7	1	350	360
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-hydrocarbon)	1	-	<1	8	9
suspended solids	43	-	120	160	320
detergent/oil	<1	<1	<1	22	23
hydrocarbons not specified elsewhere	9	<1	<1	5	15
organo-chlorine not specified elsewhere	<1	-	<1	<1	<1
dissolved chlorine	<1	-	<1	<1	<1
phenols	<1	-	<1	1	1
dissolved solids not specified elsewhere	<1	-	<1	230	230
P+compounds as P	<1	<1	<1	4	4
other nitrogen as N	<1	<1	<1	3	3
other organics not specified elsewhere	<1	-	<1	<1	<1
SO4--	<1	11	<1	380	390
dichloroethane (DCE)	<1	-	<1	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	<1
K+compounds as K	<1	-	<1	<1	<1
Ca+compounds as Ca	<1	-	<1	15	15
Mg+compounds as Mg	<1	-	<1	<1	<1
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	<1	<1
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	38	38
AOX	<1	-	<1	<1	<1
Al+compounds as Al	<1	-	<1	1	1
Zn+compounds as Zn	<1	-	<1	<1	<1
Cu+compounds as Cu	<1	-	<1	2	2
Ni+compounds as Ni	<1	-	<1	2	2
CO3--	-	-	<1	100	100
As+compounds as As	-	-	<1	<1	<1
Cd+compounds as Cd	-	-	<1	<1	<1
Mn+compounds as Mn	-	-	<1	<1	<1
organo-tin as Sn	-	-	<1	<1	<1
Sr+compounds as Sr	-	-	<1	<1	<1
organo-silicon	-	-	-	<1	<1
benzene	-	-	-	1	1
dioxin/furan as Teq	-	-	<1	<1	<1
Mo+compounds as Mo	-	-	-	<1	<1

Table 9
Gross solid waste associated with the production of 1 kg of HIPS. (Totals may not agree because of rounding)

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	Totals (mg)
Plastic containers	<1	-	<1	1	1
Paper	<1	-	<1	<1	<1
Plastics	<1	-	<1	97	97
Metals	<1	-	<1	82	82
Putrescibles	<1	-	<1	2	2
Unspecified refuse	2500	-	<1	<1	2500
Mineral waste	53	-	960	820	1800
Slags & ash	5300	2600	370	2600	11000
Mixed industrial	1900	-	38	440	2400
Regulated chemicals	3100	-	<1	2000	5100
Unregulated chemicals	2300	-	1	1400	3700
Construction waste	<1	-	<1	74	74
Waste to incinerator	<1	1	<1	23000	23000
Inert chemical	470	-	<1	2200	2700
Wood waste	<1	-	<1	1	1
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	420	420
Waste returned to mine	33000	-	35	14000	47000
Tailings	1	-	32	6800	6900
Municipal solid waste	-3200	-	-	910	-2200
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.					

Table 10
Gross solid waste in EU format associated with the production of 1 kg of HIPS. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

Emission	Totals (mg)
010101 metallic min'l excav'n waste	1800
010102 non-metal min'l excav'n waste	34000
010306 non 010304/010305 tailings	38
010308 non-010307 powdery wastes	31
010399 unspecified met. min'l wastes	7
010408 non-010407 gravel/crushed rock	<1
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	8
010499 unsp'd non-met. waste	2
010505*oil-bearing drilling mud/waste	3000
010508 non-010504/010505 chloride mud	2300
010599 unspecified drilling mud/waste	2500
020107 wastes from forestry	<1
050106*oil ind. oily maint'e sludges	2
050107*oil industry acid tars	210
050199 unspecified oil industry waste	240
050699 coal pyrolysis unsp'd waste	39
060101*H2SO4/H2SO3 MFSU waste	<1
060102*HCl MFSU waste	<1
060106*other acidic MFSU waste	<1
060199 unsp'd acid MFSU waste	<1
060204*NaOH/KOH MFSU waste	<1
060299 unsp'd base MFSU waste	<1
060313*h. metal salt/sol'n MFSU waste	8
060314 other salt/sol'n MFSU waste	1
060399 unsp'd salt/sol'n MFSU waste	330
060404*Hg MSFU waste	<1
060405*other h. metal MFSU waste	1
060499 unsp'd metallic MFSU waste	3
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	<1
060701*halogen electrol. asbestos waste	<1
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	<1
060704*halogen pr. acids and sol'ns	1
060799 unsp'd halogen pr. waste	4
061002*N ind. dangerous sub. waste	<1
061099 unsp'd N industry waste	<1
070101*organic chem. aqueous washes	420
070103*org. halogenated solv'ts/washes	<1
070104*other organic solv'ts/washes	4
070107*hal'd still bottoms/residues	<1
070108*other still bottoms/residues	17000
070111*org. chem. dan. eff. sludge	<1
070112 non-070111 effluent sludge	79
070199 unsp'd organic chem. waste	2300
070204*polymer ind. other washes	37
070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	4500

continued over …..

Table 10 - continued
Gross solid waste in EU format associated with the production of 1 kg of HIPS. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

070209*polymer ind. hal'd fil. cakes	33
070213 polymer ind. waste plastic	310
070214*polymer ind. dan. additives	200
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	1100
070608*fat/deterg. other still waste	200
080199 unspecified paint/varnish waste	1
100101 non-100104 ash, slag & dust	7800
100102 coal fly ash	380
100104*oil fly ash and boiler dust	<1
100105 FGD Ca-based reac. solid waste	470
100113*emulsified hyrdocarbon fly ash	<1
100114*dangerous co-incin'n ash/slag	2100
100115 non-100115 co-incin'n ash/slag	1
100116*dangerous co-incin'n fly ash	180
100199 unsp'd themal process waste	250
100202 unprocessed iron/steel slag	440
100210 iron/steel mill scales	33
100399 unspecified aluminium waste	12
100501 primary/secondary zinc slags	3
100504 zinc pr. other dust	<1
100511 non-100511 Zn pr. skimmings	<1
101304 lime calcin'n/hydration waste	11
130208*other engine/gear/lub. oil	2
150101 paper and cardboard packaging	<1
150102 plastic packaging	1
150103 wooden packaging	<1
150106 mixed packaging	35
150110*dan. sub. contam'd packaging	1
150202*dan. sub. absorbents	10
160807*spent dangerous sub. catalyst	16
161001*dan. aq. liquid waste	2
170107 non-170106 con'e/brick/tile mix	<1
170405 iron and steel	<1
170604 non-170601/3 insul'n material	48
170904 non-170901/2/3 con./dem'n waste	74
190199 unspecified incin'n/pyro waste	<1
190814 non-190813 ind'l water sludge	180
190905 sat./spent ion exchange resins	2200
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	1
200140 metals	<1
200199 other separately coll. frac'ns	-510
200301 mixed municipal waste	8
200399 unspecified municipal wastes	110
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.	