

*Eco-profiles of the
European Plastics Industry*

POLYPROPYLENE (PP)

A report by

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for

PlasticsEurope

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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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OLEFIN POLYMERS

High density polyethylene (HDPE) is one of the olefin polymers and it is useful to examine briefly the four major olefin polymers because it highlights the differences between them and indicates why these different polymers are produced. The polymers are shown in Table 1.

Table 1
Large tonnage polyolefins produced in Europe in 1999.

Polymer	Acronym	Production ('000 tonne) ¹
Low density polyethylene	LDPE	4793
High density polyethylene	HDPE	4308
Linear low density polyethylene	LLDPE	1934
Polypropylene	PP	7395

The polyolefins are chemically the simplest of all polymer structures. They can be produced commercially from olefin (alkene) monomers because the olefins contain a reactive double bond. Schematically the process of converting monomer to polymer is illustrated in Figure 1 for ethylene. Essentially the double bond in the ethylene molecule is opened to form a reactive *radical*, which then attaches itself to another radical. The process repeats itself to produce a long chain molecule or polymer terminating only when the propagating radical attaches itself to an unreactive species.² The starting material, ethylene, is called the *monomer* and the final compound consisting of many thousands of ethylene units is called the *polymer*.³

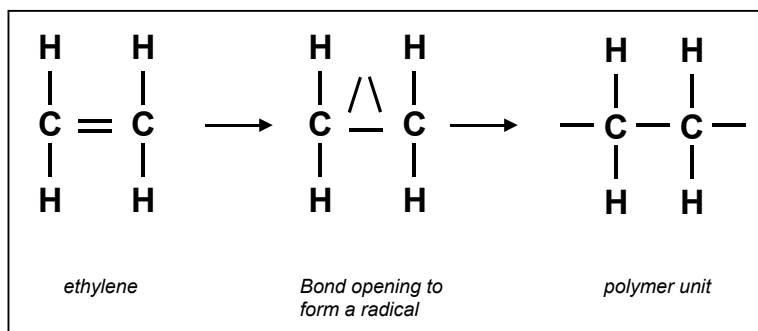


Figure 1
Schematic diagram of the formation of polyethylene.

¹ APME Annual Report 2001.

² The actual polymerisation process is somewhat more complex than this but the concept of opening the double bond is a useful way to think of addition polymerisation.

³ The terms *monomer* and *polymer* are due to Berzelius (1830) from the Greek: poly = many; meros = part; mono = single or alone

Such polymers are often referred to as *addition polymers* because they are formed by continually adding further monomer units to the growing polymer chain and the polymerisation mechanism is known as *free radical polymerisation*.⁴

CHARACTERISTICS OF OLEFIN POLYMERS

All olefin polymers have an unbroken carbon backbone and in its simplest form the structure of polyethylene is schematically of the form shown in Figure 2. (Polyethylene with this highly linear structure is often referred to as polymethylene).

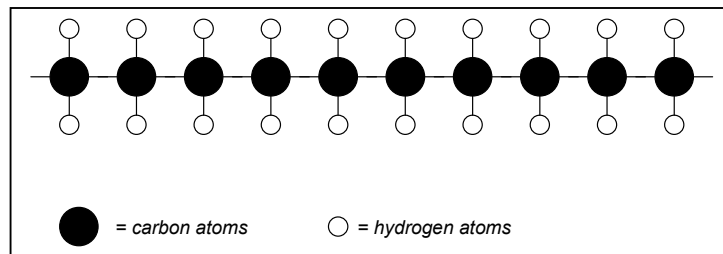


Figure 2
Schematic structure of linear polyethylene

When a highly regular polymer such as that shown in Figure 2 is cooled from the melt, the polymer chains do not remain as a random tangle. Instead they tend to fold and lie alongside each other as shown in Figure 3.

These ordered regions inside polymer solids behave as crystalline regions. However, unlike atomic crystals, the whole of the long molecules cannot be incorporated into these ordered regions and so there will always be regions where the molecules are randomly arranged. These are amorphous regions. Because of the closer packing in the crystalline regions, their density is higher ($\sim 1000 \text{ kg m}^{-3}$) than the amorphous regions ($\sim 850 \text{ kg m}^{-3}$). Thus the higher the density of a specified polymer type, the greater the crystallinity.

The amount of crystallinity in a polymer directly affects the properties because the crystalline regions exhibit superior mechanical properties and for most applications the higher the crystallinity the better.

⁴ All addition polymers rely on the opening of a double bond to form the polymer backbone and this concept presents a useful way of determining polymer structures once the structural formula of the monomer is known.

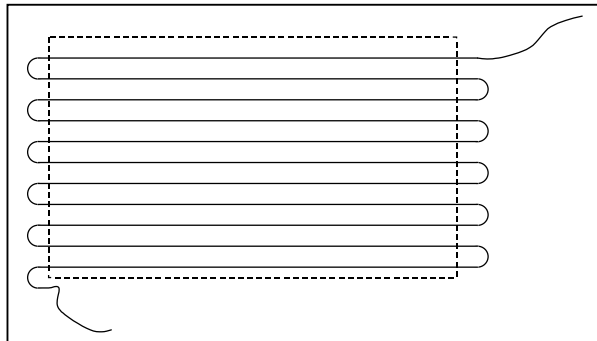


Figure 3
Chain folding in regular polymers. The region inside the broken line is regarded as a polymer crystal.

A critical factor in promoting the formation of crystalline regions in polymers is the regularity of the polymer chains. In practice, when ethylene is polymerised it does not form a simple linear chain of the type shown in Figure 2. Instead, it grows side branches. These side branches may be short (up to 8 carbon atoms) or very long (up to several thousand carbon atoms). Short, irregularly positioned side branches of different length tend to inhibit crystal formation but long side branches can usually be incorporated into the crystalline regions. The production technology determines the number, positioning and length of the side branches.

HISTORICAL BACKGROUND

The first record of polyolefin production was in 1898 when von Pechmann in Germany produced the first polymethylene structure in the laboratory. It was not, however, until 1935 that Perrin at ICI showed that it was possible to produce large quantities of low density polyethylene by subjecting ethylene to pressures up to 350 MPa and temperatures up to 350°C. This process was developed commercially and production of LDPE started in 1938 in the UK.

In 1950, Hogan and Bank at Phillips Petroleum Co invented a catalyst containing chromium oxide on silica that allowed polymerisation at lower pressures (3 – 4 MPa) and temperatures (70 - 100°C). These Phillips catalysts were used to produce the first HDPE.

In 1953, Ziegler in Germany developed catalysts containing titanium halides and alkylaluminium which promoted polymerisation at atmospheric pressure and temperatures of 50 - 100°C. By adjusting the precise composition of the catalyst, he found that it was possible to obtain a wide range of polyethylenes that could be used in different applications. In 1954, Natta at Montecatini

modified the Ziegler catalysts to produce isotactic polypropylene and commercial production of polypropylene started in 1957.

During the period 1956-1976 considerable research by Phillips, Solvay, Montedison and Mitsui Petrochemical went into different catalyst systems with the aim of obtaining high yield isotactic polypropylene.

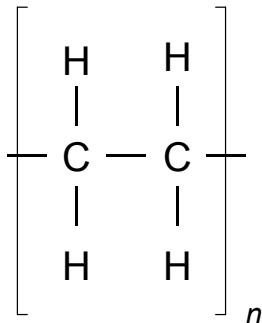
In 1976, Kaminsky and Sunn developed a new family of catalysts which allowed the production of ethylene polymers and copolymers and controlled the regularity of the chain branching. These were the catalysts that allowed the first commercial production of LLDPE.

As this brief history shows, most of the research in this area has been concerned with catalysts which achieve two main factors: obtaining more benign production conditions and producing polymers with more controlled structures.

POLYETHYLENE

Low density polyethylene

The repeat unit of polyethylene is:



Low density polyethylene (LDPE) has traditionally been defined as polyethylene with a density less than 940 kg m^{-3} . It is produced by a high pressure process and so is often referred to as high pressure polyethylene. The polymer contains both long and short chain side branching with the number of branches being from 2 and 50 per 1000 carbon atoms on the carbon backbone. LDPE can be produced with chain lengths ranging from 50,000 to 100,000 repeat units, with crystallinities in the range 35 to 75% and with densities in the range 915 to 940 kg m^{-3} .

High density polyethylene

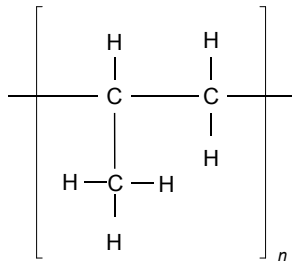
High density polyethylene (HDPE) has the same repeat unit as LDPE and is usually regarded as polyethylene with a density greater than 940 kg m^{-3} . It is produced in low pressure reactors and so is often referred to as low pressure polyethylene. It differs from LDPE in that it contains fewer side branches at 5 to 10 per 1000 carbon atoms on the backbone. Most of the side branches are short with long side branches being rare. Molecular weights are similar to low density polyethylene but crystallinities are usually high (50 – 85%) and densities range from 940 to 960 kg m^{-3} .

Linear low density polyethylene

Linear low density polyethylene (LLDPE) is a copolymer of ethylene with another short chain olefin. The most common co-monomers are 1-butene, 1-hexene, 4-methyl-1-pentene and 1-octene. The comonomer is usually present in concentrations of 2.5 to 3.5% and this results in densities in the range 915 to 925 kg m^{-3} with crystallinities of 30 to 45%. The range of molecular weights of LLDPE are considerably narrower than for LDPE and HDPE; typically they lie in the range 50,000 to 200,000.

POLYPROPYLENE

The repeat unit for polypropylene is:



The CH_3 side group can be arranged in three different ways in polypropylene and the three possibilities are shown in Figure 4. In *isotactic polypropylene*, the methyl side groups all lie on the same side of the polymer chain. In three dimensions, the polymer chain forms a helix and can fold to form crystalline regions similar to Figure 3. These crystalline regions have a density of 936 kg m^{-3} . In *syndiotactic polypropylene*, the methyl side groups are arranged regularly on alternate side of the polymer chain. In three dimensions, syndiotactic polypropylene also forms a helical structure although it is more open than the isotactic form and so, although it too can fold to form crystalline regions, the crystal density is lower at 910 kg m^{-3} . In *atactic polypropylene*, the

methyl side groups are randomly arranged on either side of the chain. The resultant structure is amorphous. Of the three forms, isotactic has the most superior properties and so manufacture aims to maximise this form. Some atactic polymer is invariably produced in small quantities and this is often used as a waterproof mastic.

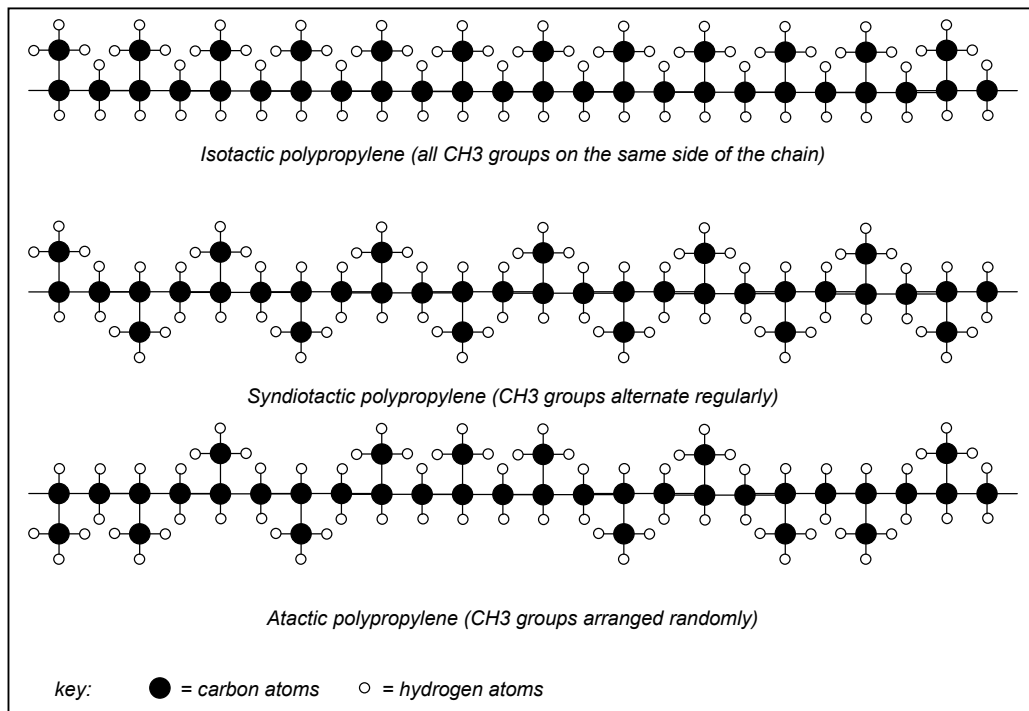


Figure 4
Different types of polypropylene depending on the arrangement of the methyl side group.

PRODUCTION PROCESSES

Three main techniques are employed in the production of polyolefins: high pressure technology, solution or slurry processes and gas phase polymerisation.

High pressure technology

When monomer is held at high pressures and temperatures above the polymer melting point, the monomer/polymer mixture can act as a polymerisation medium. Initiators and catalysts can be added to this medium. This technology

is used only for LDPE and employs pressures up to 300 MPa⁵ and temperatures up to 300°C.

There are two major problems with this type of technology. The first is the obvious one of handling materials under such high pressures and the second is that of temperature control. Two types of reactor are used to solve these problems. The *stirred autoclave* is essentially a cylindrical, thick-walled reaction vessel stirred by paddles. Because of the very thick walls needed to withstand the pressure, external heat extraction is not possible and temperature is controlled using the monomer as a heat sink. The residence time is usually less than a minute and the conversion per pass is usually less than 20%. Unreacted monomer is cooled and reused. In the *tubular reactor*, the monomer is passed along the inner of a pair of concentric tubes. Coolant passes between the inner and outer tubes. Conversion rates per pass are up to 35% and again, unreacted monomer is recovered for reuse.

Solution/slurry polymerisation

Many low molecular weight, saturated hydrocarbons will dissolve polyolefins. If the temperature is higher than the melting point of the polymer and the concentration of the polymer is low, the polymer will remain as a true solution. However, at lower temperatures and higher concentrations, the polymer will form a suspension or mobile slurry. Using solutions or slurries as the polymerisation medium requires relatively low temperatures (70 - 110°C) and relatively low pressures (1 – 5 MPa).

Reaction vessels can be either stirred tank reactors using solvents such as hexane or closed loop, cooled pipe reactors using solvents such as isopentane. In slurry reactors, the slurry concentration is usually maintained at ~25% and settling chambers at the base of the reactor allow polymer to be removed continuously. The recovered solvent is reused and conversions can be as high as 98%.

Gas phase polymerisation

A gas phase reactor is essentially a fluidised bed of dry polymer particles maintained either by stirring or by passing gas at high speeds through it. Pressures are usually relatively low at ~2MPa and temperatures are usually in the range 70 - 110°C. A variety of different configurations are used mainly to obtain an acceptable particle size and shape in the final product. Gas phase polymerisation is used for HDPE, PP and LLDPE.

⁵ To put these pressures in perspective, 1 atmosphere pressure is approximately 0.101MPa

ECO-PROFILE OF POLYPROPYLENE

Data have been obtained for the production of 5.69 million tonnes of PP. This represents 76.9% of all West European production. The average gross energy required to produce 1 kg of polypropylene is 73 MJ with a range of values extending from 54 MJ to 94 MJ. Table 2 shows the breakdown of this gross energy and Table 3 gives these same data expressed in terms of primary fuels. Table 4 shows the energy data expressed as masses of fuels. Table 5 shows the raw materials requirements and Table 6 shows the demand for water. Table 7 shows the gross air emissions and Table 8 shows the corresponding carbon dioxide equivalents of these air emissions. Table 9 gives the emissions to water. Table 10 shows the gross solid waste generated and Table 11 gives this solid waste in EU format.

Table 2

Gross energy required to produce 1 kg of polypropylene. (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	4.92	1.85	0.50	-	7.27
Oil fuels	0.24	8.51	0.10	36.03	44.89
Other fuels	0.25	4.37	0.02	16.56	21.21
Totals	5.42	14.74	0.61	52.60	73.37

Table 3

Gross primary fuels required to produce 1 kg of polypropylene. (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	1.15	1.06	0.16	<0.01	2.37
Oil	0.88	8.76	0.17	36.03	45.85
Gas	1.24	5.88	0.15	16.56	23.83
Hydro	0.18	0.11	<0.01	-	0.29
Nuclear	1.85	0.78	0.11	-	2.74
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)	0.03	0.01	<0.01	<0.01	0.04
Hydrogen	<0.01	<0.01	<0.01	-	<0.01
Recovered energy	<0.01	-1.91	<0.01	-	-1.91
Unspecified	<0.01	<0.01	<0.01	-	<0.01
Peat	0.01	<0.01	<0.01	-	0.01
Geothermal	0.02	0.01	<0.01	-	0.02
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	-	0.02
Municipal Waste	0.03	0.01	<0.01	-	0.05
Wind	0.01	<0.01	<0.01	-	0.01
Totals	5.42	14.74	0.61	52.60	73.37

Table 4

Gross primary fuels used to produce 1 kg of polypropylene expressed as mass.

Fuel type	Input in mg
Crude oil	1000000
Gas/condensate	460000
Coal	83000
Metallurgical coal	66
Lignite	11
Peat	1100
Wood	1

*Table 5
Gross raw materials required to produce 1
kg of polypropylene.*

Raw material	Input in mg
Air	300000
Animal matter	<1
Barytes	<1
Bauxite	2
Bentonite	38
Biomass (including water)	9200
Calcium sulphate (CaSO ₄)	4
Chalk (CaCO ₃)	<1
Clay	<1
Cr	<1
Cu	<1
Dolomite	2
Fe	160
Feldspar	<1
Ferromanganese	<1
Fluorspar	<1
Granite	<1
Gravel	1
Hg	<1
Limestone (CaCO ₃)	140
Mg	<1
N ₂	94000
Ni	<1
O ₂	5
Olivine	2
Pb	<1
Phosphate as P ₂ O ₅	<1
Potassium chloride (KCl)	<1
Quartz (SiO ₂)	<1
Rutile	3
S (bonded)	1
S (elemental)	32
Sand (SiO ₂)	95
Shale	11
Sodium chloride (NaCl)	270
Sodium nitrate (NaNO ₃)	<1
Talc	<1
Unspecified	<1
Zn	61

*Table 6
Gross water consumption required for the production of 1 kg
of polypropylene. (Totals may not agree because of
rounding)*

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	2100000	62000	2200000
River canal	890000	2300000	3200000
Sea	130000	5900000	6000000
Well	55000	<1	55000
Unspecified	1600000	3000000	3100000
Totals	4800000	3800000	4300000

Table 7

Gross air emissions associated with the production of 1 kg of polypropylene.
(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)	270	78	1	250	-	-	590
CO	1200	4400	12	540	-	-	6100
CO2	350000	910000	8100	400000	-3	-	1700000
SOX as SO2	1600	1500	140	580	-	-	3800
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	1400	1400	45	480	-	-	3300
NH3	<1	-	<1	<1	-	-	<1
Cl2	<1	<1	<1	<1	-	-	<1
HCl	32	19	<1	<1	-	-	51
F2	<1	<1	<1	<1	-	-	<1
HF	1	<1	<1	<1	-	-	1
hydrocarbons not specified	680	100	14	2700	-	<1	3500
aldehyde (-CHO)	<1	-	<1	<1	-	-	<1
organics	<1	<1	<1	57	-	-	57
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	<1	1	<1	1	-	-	2
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	<1	-	-	<1
H2	29	<1	<1	1	-	-	30
dichloroethane (DCE) C2H4Cl2	<1	-	<1	<1	-	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	-	<1	<1
CFC/HCFC/HFC not specified	<1	-	<1	23	-	-	23
organo-chlorine not specified	<1	-	<1	<1	-	-	<1
HCN	<1	-	<1	<1	-	-	<1
CH4	8300	250	<1	3300	-	<1	12000
aromatic HC not specified elsewhere	<1	-	<1	99	-	<1	100
polycyclic hydrocarbons (PAH)	<1	<1	<1	<1	-	-	<1
NMVOC	<1	-	<1	18	-	-	18
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	<1	<1	<1	-	-	<1
Se+compounds as Se	-	-	-	<1	-	-	<1
Ni+compounds as Ni	<1	<1	<1	<1	-	-	<1
Sb+compounds as Sb	-	-	<1	<1	-	-	<1
ethylene C2H4	-	-	<1	2	-	-	2
oxygen	-	-	-	<1	-	-	<1
asbestos	-	-	-	<1	-	-	<1
dioxin/furan as Teq	-	-	-	<1	-	-	<1
benzene C6H6	-	-	-	<1	-	<1	<1
toluene C7H8	-	-	-	<1	-	<1	<1
xylenes C8H10	-	-	-	<1	-	<1	<1
ethylbenzene C8H10	-	-	-	<1	-	<1	<1
styrene	-	-	-	<1	-	<1	<1
propylene	-	-	-	1	-	-	1

*Table 8
Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of polypropylene. (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	860000	940000	8100	620000	-3	<1	2400000
100 year equiv	540000	930000	8100	490000	-3	<1	2000000
500 year equiv	410000	920000	8100	440000	-3	<1	1800000

Table 9

Gross emissions to water arising from the production of 1 kg of polypropylene.
(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	1	-	<1	240	240
BOD	<1	-	<1	29	29
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	<1	-	<1	58	58
acid as H+	1	-	<1	1	2
NO3-	<1	-	<1	120	120
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	<1	-	<1	9	9
ammonium compounds as NH4+	1	-	<1	3	3
Cl-	<1	-	<1	150	150
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-suspended solids)	<1	-	<1	10	11
detergent/oil	21	-	2	64	86
hydrocarbons not specified	<1	-	<1	14	14
organo-chlorine not specified	5	<1	<1	1	5
dissolved chlorine	<1	-	<1	<1	<1
phenols	<1	-	<1	2	2
dissolved solids not specified	<1	-	<1	23	23
P+compounds as P	<1	-	<1	96	96
other nitrogen as N	<1	-	<1	1	1
other organics not specified	<1	-	<1	<1	<1
SO4--	<1	-	<1	930	930
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	<1	<1
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	9	9
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	<1	<1
Ni+compounds as Ni	<1	-	<1	<1	<1
CO3--	-	-	<1	28	28
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

*Table 10
Gross solid waste associated with the production of 1 kg of polypropylene.
(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	340	340
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	2	2
Unspecified refuse	930	-	<1	<1	930
Mineral waste	25	-	16	160	210
Slags & ash	6000	950	6	590	7600
Mixed industrial	-130	-	1	1300	1100
Regulated chemicals	1100	-	<1	560	1700
Unregulated chemicals	860	-	<1	1000	1900
Construction waste	<1	-	<1	2	2
Waste to incinerator	<1	-	<1	1100	1100
Inert chemical	<1	-	<1	810	810
Wood waste	<1	-	<1	<1	<1
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	1600	1600
Waste returned to mine	16000	-	1	190	16000
Tailings	1	-	1	240	250
Municipal solid waste	-4600	-	-	<1	-4600
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.					

Table 11

Gross solid waste in EU format associated with the production of 1 kg of polypropylene. 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	130
010102 non-metal min'l excav'n waste	16000
010306 non 010304/010305 tailings	1
010308 non-010307 powdery wastes	1
010399 unspecified met. min'l wastes	1
010408 non-010407 gravel/crushed rock	<1
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	1
010499 unsp'd non-met. waste	<1
010505*oil-bearing drilling mud/waste	1100
010508 non-010504/010505 chloride mud	860
010599 unspecified drilling mud/waste	930
020107 wastes from forestry	<1
050106*oil ind. oily maint'e sludges	3
050107*oil industry acid tars	230
050199 unspecified oil industry waste	210
050699 coal pyrolysis unsp'd waste	13
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	1
060314 other salt/sol'n MFSU waste	<1
060399 unsp'd salt/sol'n MFSU waste	<1
060404*Hg MFSU waste	<1
060405*other h. metal MFSU waste	<1
060499 unsp'd metallic MFSU waste	<1
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	<1
061002*N ind. dangerous sub. waste	<1
061099 unsp'd N industry waste	<1
070101*organic chem. aqueous washes	<1
070103*org. halogenated solv'ts/washes	<1
070107*hal'd still bottoms/residues	<1
070108*other still bottoms/residues	9
070111*org. chem. dan. eff. sludge	<1
070112 non-070111 effluent sludge	<1
070199 unsp'd organic chem. waste	16

continued over

Table 11 - continued

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

070204*polymer ind. other washes	<1
070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	2200
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	420
070214*polymer ind. dan. additives	1200
070215 non-0702130 additive waste	300
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	1400
080199 unspecified paint/varnish waste	<1
100101 non-100104 ash, slag & dust	6800
100102 coal fly ash	720
100104*oil fly ash and boiler dust	<1
100105 FGD Ca-based reac. solid waste	<1
100113*emulsified hydrocarbon fly ash	<1
100114*dangerous co-incin'n ash/slag	32
100115 non-100115 co-incin'n ash/slag	2
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd thermal process waste	<1
100202 unprocessed iron/steel slag	49
100210 iron/steel mill scales	4
100399 unspecified aluminium waste	<1
100501 primary/secondary zinc slags	<1
100504 zinc pr. other dust	<1
100511 non-100511 Zn pr. skimmings	<1
101304 lime calcin'n/hydration waste	5
130208*other engine/gear/lub. oil	<1
150101 paper and cardboard packaging	<1
150102 plastic packaging	<1
150103 wooden packaging	<1
150106 mixed packaging	<1
170107 non-170106 con'e/brick/tile mix	<1
170904 non-170901/2/3 con./dem'n waste	<1
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	810
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	-1100
200301 mixed municipal waste	1
200399 unspecified municipal wastes	-3600
Note: 1. Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.	