Eco-profiles of the
European Plastics Industry

POLYMETHYL METHACRYLATE (PMMA)

A report by

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for

Plastics*Europe*

Data last calculated

March 2005

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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POLYMETHYL METHACRYLATE

Polymethyl methacrylate (PMMA) is a transparent, colourless, thermoplastic polymer with a structure as shown in Figure 1. The structure of the polymer solid gives PMMA a distinctive optical clarity. It is commonly available in either sheet or bead form, is readily fabricated and can be coloured as required.

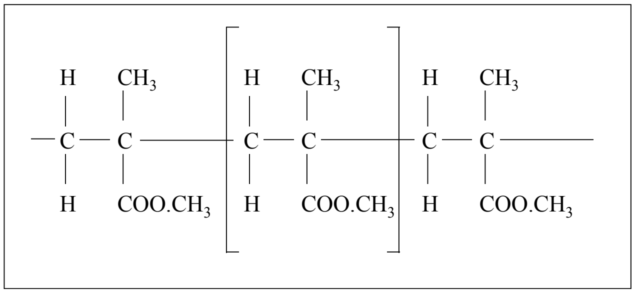

Figure 1.
Structure of polymethyl methacrylate. The brackets indicate the repeat unit.

Its durability, plus its high quality finish, ensures that it is in demand for the longer lasting high quality products, such as baths, sinks and showers. Its mechanical properties of high softening point and high impact strength, when combined with its good weatherability and resistance to most aqueous inorganic reagents, favour its use in external applications. Illuminated signs, glazing and motor vehicle rear lights are only a few of the examples of the use to which it can be put. Because of its optical clarity and stability, PMMA has found uses in the medical field where special grades have long been successfully employed for intra-ocular lenses, contact lenses and implants.

Besides self-polymerisation, methyl methacrylate (MMA), will polymerise with a range of other materials, yielding co-polymers with properties tailored to specific applications. The mechanical properties and finishes of PMMA can be further optimised for specific applications by the addition of inert fillers and plasticisers.

THE PRODUCTION ROUTE TO PMMA

Unlike the polyolefins, the production route for polymethyl methacrylate requires the production of a significant number of intermediates as shown schematically in Figure 2. Essentially the processes produce acetone cyanohydrin which is then converted to methyl methacrylate. The monomer may be polymerised to produce beads which can then be extruded, or the monomer may be directly polymerised as in the production of cast sheet.

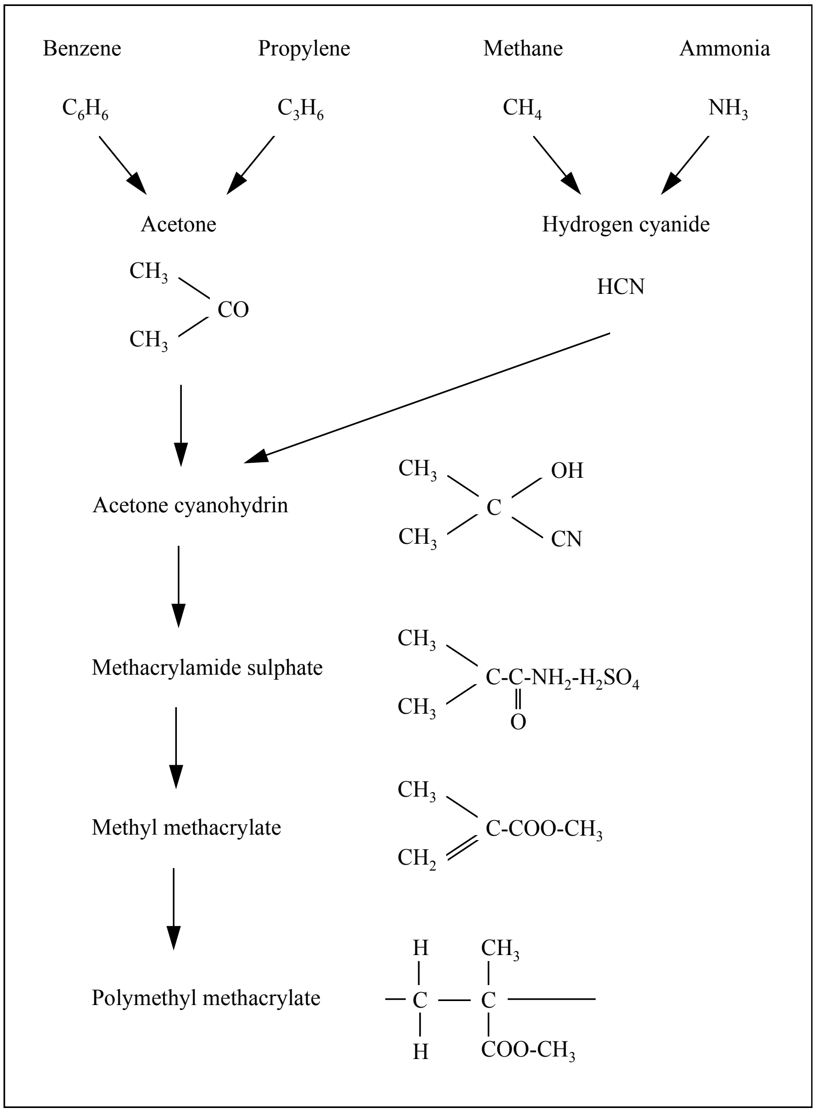

Figure 2. Production route to polymethyl methacrylate.

There are a number of different routes to acetone but the most commonly used is as a by-product in the manufacture of phenol and this route has been used in the present work. Hydrogen cyanide is mainly produced by the reaction of methane (natural gas) with ammonia. A small proportion of hydrogen cyanide, however, is obtained as a by-product from acrylonitrile production. For the purposes of this report, it has been assumed that all hydrogen cyanide is produced from the reaction of methane and ammonia. Acetone is then reacted with hydrogen cyanide to produce acetone cyanohydrin and this is converted to methyl methacrylate in an acid solution of sulphuric acid. The intermediate, methacrylamide sulphate is not isolated but the spent sulphuric acid from the process is recovered and regenerated for further use.

RECYCLABILITY OF PMMA

Physical recycling, in which off-cuts of PMMA are crushed and re-ground to be used again in conversion operations, is widely practised. A small proportion of this form of recycling is included in the data reported here but only when the scrap arises within the PMMA manufacturing process. In this respect, this report is no different from the earlier reports for other plastics.

It is, however, important to recognise that PMMA is different from virtually all other plastics in that it can be readily recycled back to the original monomer. Thermal cracking, the process by which PMMA is converted to MMA, can be carried out with almost 100% recovery. The resulting monomer can be separated from any fillers, distilled and decolourised, so that it is almost indistinguishable from virgin material. This important characteristic potentially has a great impact on the practicability of recycling products made from the polymer and may, therefore, significantly influence the life-cycle assessment of articles made from PMMA.

ECO-PROFILE OF PMMA

Table 1 shows the gross or cumulative energy to produce 1 kg of PMMA resin as beads for further conversion 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 PMMA beads. (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	9.43	4.13	0.40	-	13.95
Oil fuels	2.25	27.92	0.33	21.45	51.95
Other fuels	2.25	26.27	0.08	21.63	50.24
Totals	13.93	58.31	0.81	43.08	116.14

Table 2
Gross primary fuels required to produce 1 kg of PMMA beads. (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	3.59	4.60	0.12	<0.01	8.32
Oil	2.05	28.13	0.48	21.45	52.11
Gas	4.23	40.93	0.11	21.32	66.59
Hydro	0.31	0.16	0.01	-	0.48
Nuclear	3.54	1.56	0.08	-	5.18
Lignite	<0.01	<0.01	<0.01	-	<0.01
Wood	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphur	<0.01	0.09	<0.01	0.30	0.40
Biomass (solid)	0.03	0.01	<0.01	<0.01	0.05
Hydrogen	<0.01	0.02	<0.01	-	0.02
Recovered energy	<0.01	-17.18	<0.01	-	-17.18
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	-	0.02
Solar	<0.01	<0.01	<0.01	-	<0.01
Wave/tidal	<0.01	<0.01	<0.01	-	<0.01
Biomass (liquid/gas)	0.05	0.02	<0.01	-	0.07
Industrial waste	0.04	0.02	<0.01	-	0.05
Municipal Waste	0.05	0.02	<0.01	-	0.08
Wind	0.03	0.01	<0.01	-	0.05
Totals	13.93	58.41	0.81	43.08	116.23

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

Fuel type	Input in mg
Crude oil	1200000
Gas/condensate	1300000
Coal	290000
Metallurgical coal	240
Lignite	5
Peat	150
Wood	99

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

Raw material	Input in mg
Air	-150000
Animal matter	<1
Barytes	70
Bauxite	510
Bentonite	41
Biomass (including water)	13000
Calcium sulphate (CaSO4)	4
Chalk (CaCO3)	<1
Clay	<1
Cr	<1
Cu	1
Dolomite	7
Fe	600
Feldspar	<1
Ferromanganese	1
Fluorspar	12
Granite	<1
Gravel	2
Hg	<1
Limestone (CaCO3)	6800
Mg	<1
N2	110000
Ni	<1
O2	130000
Olivine	6
Pb	4
Phosphate as P2O5	1900
Potassium chloride (KCl)	4
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	33000
Sand (SiO2)	3300
Shale	12
Sodium chloride (NaCl)	32000
Sodium nitrate (NaNO3)	<1
Talc	<1
Unspecified	<1
Zn	<1

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

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	2000000	-	2000000
River canal	530000	13000000	14000000
Sea	240000	4700000	4900000
Well	160000	33000	200000
Unspecified	4800000	50000000	55000000
Totals	7700000	68000000	76000000

Table 6
Gross air emissions associated with the production of 1 kg of PMMA beads.
(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)	1100	660	17	240	-	-	2000
CO	2800	1400	200	1100	-	-	5500
CO2	960000	3900000	28000	990000	-74	-	5900000
SOX as SO2	4100	21000	190	3200	-	-	29000
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	2900	8300	270	910	-	-	12000
NH3	<1	-	<1	9	-	-	9
Cl2	<1	<1	<1	<1	-	-	<1
HCl	100	57	<1	2	-	-	160
F2	<1	<1	<1	<1	-	-	<1
HF	4	2	<1	1	-	-	7
hydrocarbons not specified	4800	1300	76	5900	-	1	12000
aldehyde (-CHO)	<1	-	<1	89	-	-	89
organics	<1	<1	<1	1900	-	-	1900
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	1	11	<1	<1	-	-	12
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	<1	-	-	<1
H2	82	<1	<1	32	-	-	110
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	3	-	-	3
CH4	44000	1500	<1	2600	-	<1	48000
aromatic HC not specified	<1	-	1	18	-	1	20
polycyclic hydrocarbons (PAH)	<1	2	<1	<1	-	-	2
NMVOC	<1	-	<1	19	-	-	19
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	2	<1	<1	-	-	2
Sb+compounds as Sb	-	-	<1	<1	-	-	<1
ethylene C2H4	-	-	<1	3	-	-	3
oxygen	-	-	-	<1	-	-	<1
asbestos	-	-	-	<1	-	-	<1
dioxin/furan as Teq	-	-	-	<1	-	-	<1
benzene C6H6	-	-	-	1	-	5	6
toluene C7H8	-	-	-	<1	-	1	1
xylenes C8H10	-	-	-	<1	-	<1	<1
ethylbenzene C8H10	-	-	-	<1	-	<1	<1
styrene	-	-	-	<1	-	<1	<1
propylene	-	-	-	2	-	-	2

Table 7
Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of PMMA beads. (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	3700000	4000000	29000	1200000	-74	14	8900000
100 year equiv	2000000	3900000	29000	1100000	-74	7	7000000
500 year equiv	1300000	3900000	29000	1000000	-74	4	6200000

Table 8
Gross emissions to water arising from the production of 1 kg of PMMA beads. (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	7	-	<1	1700	1700
BOD	2	-	<1	510	510
Pb+compounds as Pb	<1	-	<1	2	2
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	1	-	<1	18000	18000
acid as H+	2	-	<1	76	78
NO3-	<1	-	<1	9	9
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	1	-	<1	58	58
ammonium compounds as NH4+	3	-	<1	1100	1100
Cl-	3	-	<1	8700	8700
CN-	<1	-	<1	4	4
F-	<1	-	<1	7	7
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-	3	-	<1	1100	1100
suspended solids	73	-	34	1600	1700
detergent/oil	<1	-	<1	12	12
hydrocarbons not specified	5	<1	<1	<1	5
organo-chlorine not specified	<1	-	<1	<1	<1
dissolved chlorine	<1	-	<1	<1	<1
phenols	<1	-	<1	1	1
dissolved solids not specified	<1	-	<1	400	400
P+compounds as P	<1	-	<1	880	880
other nitrogen as N	<1	-	<1	1	2
other organics not specified	<1	-	<1	<1	<1
SO4--	<1	-	<1	27000	27000
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	110	110
Mg+compounds as Mg	<1	-	<1	<1	<1
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	4	4
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	17	17
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	55	55
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 9
Gross solid waste associated with the production of 1 kg of PMMA beads. (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	19	19
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	6700	-	<1	<1	6700
Mineral waste	43	-	340	2800	3200
Slags & ash	16000	5700	130	1400	23000
Mixed industrial	4000	-	13	8100	12000
Regulated chemicals	8200	-	<1	760	8900
Unregulated chemicals	6200	-	<1	9400	16000
Construction waste	<1	-	<1	15	15
Waste to incinerator	<1	-	<1	290	290
Inert chemical	<1	-	<1	6300	6300
Wood waste	<1	-	<1	2	2
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	160	160
Waste returned to mine	57000	-	12	600	57000
Tailings	1	-	11	50	63
Municipal solid waste	-7200	-	-	<1	-7200
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 PMMA beads. 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	1600
010102 non-metal min'l excav'n waste	58000
010306 non 010304/010305 tailings	17
010308 non-010307 powdery wastes	12
010399 unspecified met. min'l wastes	230
010408 non-010407 gravel/crushed rock	1
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	57
010499 unsp'd non-met. waste	15
010505*oil-bearing drilling mud/waste	7900
010508 non-010504/010505 chloride mud	6200
010599 unspecified drilling mud/waste	6700
020107 wastes from forestry	2
050106*oil ind. oily maint'e sludges	3
050107*oil industry acid tars	150
050199 unspecified oil industry waste	360
050699 coal pyrolysis unsp'd waste	46
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	52
060314 other salt/sol'n MFSU waste	<1
060399 unsp'd salt/sol'n MFSU waste	570
060404*Hg MSFU waste	<1
060405*other h. metal MFSU waste	1
060499 unsp'd metallic MFSU waste	12
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	66
060701*halogen electrol. asbestos waste	3
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	<1
060704*halogen pr. acids and sol'ns	20
060799 unsp'd halogen pr. waste	13
061002*N ind. dangerous sub. waste	210
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	56
070111*org. chem. dan. eff. sludge	<1
070112 non-070111 effluent sludge	5

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

070199 unsp'd organic chem. waste	3500
070204*polymer ind. other washes	<1
070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	690
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	1
070214*polymer ind. dan. additives	150
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	7200
080199 unspecified paint/varnish waste	<1
100101 non-100104 ash, slag & dust	21000
100102 coal fly ash	170
100104*oil fly ash and boiler dust	<1
100105 FGD Ca-based reac. solid waste	<1
100113*emulsified hyrdocarbon fly ash	<1
100114*dangerous co-incin'n ash/slag	1100
100115 non-100115 co-incin'n ash/slag	3
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd themal process waste	6
100202 unprocessed iron/steel slag	180
100210 iron/steel mill scales	14
100399 unspecified aluminium waste	10
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	6
130208*other engine/gear/lub. oil	2
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	15
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	6300
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	17
200140 metals	<1
200199 other separately coll. frac'ns	-2700
200301 mixed municipal waste	5700
200399 unspecified municipal wastes	-500
Note: Negative values correspond to consumption of waste e.g. recycling or	