Eco-profiles of the
European Plastics Industry

LIQUID EPOXY RESINS

A report by

I Boustead

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.

Plastics*Europe* may be contacted at

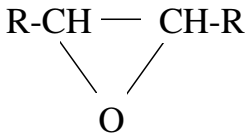
Ave E van Nieuwenhuyse 4
Box 3
B-1160 Brussels

Telephone: 32-2-672-8259
Fax: 32-2-675-3935

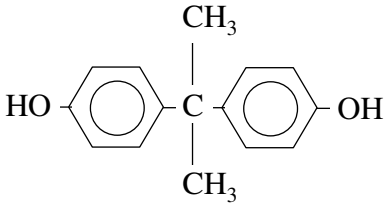
CONTENTS

LIQUID EPOXY RESINS

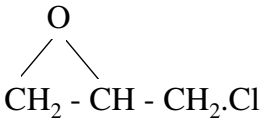
Epoxy resins are a group of thermosetting plastics all of which possess one common feature in that they incorporate the epoxide group:



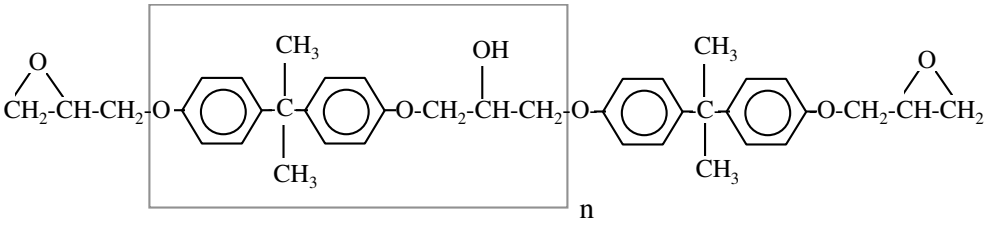
into their structure. The most commonly used epoxy resins are produced from bisphenol-A



and epichlorohydrin



The reaction proceeds by a series of steps but yields a structure of the form:



The segment surrounded by the box is repeated a number of times. If the value of n is low (<10) then the resin is a liquid but as n increases the resin gradually becomes a viscous liquid and eventually a solid; at n=25 it is a tough, hard solid.

Epoxy resins should really be regarded as intermediates in the production of finished components because they are further reacted (cured) so that the chains are increased in length (advancement) and cross-linked to produce a three dimensional network (reticulation). The cross linking is achieved by opening

the epoxide group and most curing agents or hardeners which accomplish this are amines, acid anhydrides and mercaptans, most of which have active hydrogen atoms available to initiate the curing reaction. One major advantage of the epoxy resins is that they can be cured over a wide range of temperatures and during the curing process exhibit very low shrinkage.

Depending on molecular weight and choice of hardener, epoxy resins find many applications ranging from adhesives to metal coatings. Table 1 summarises some of the principal applications.

Table 1. Typical applications of epoxy resins.

Curing agent	Application
Carboxyl-terminated polyester resins	● Powder coatings
Acid anhydrides	● Electrical castings ● Powder coatings ● White pigmented can coatings ● Composites made by filament winding, resin transfer moulding
Aromatic and cycloaliphatic polyamines	● Powder coatings ● Moulding powders ● Adhesives ● Tooling compounds
Dicyandiamides	● Printed circuit boards ● Moulding powders ● Powder coatings ● Composites via prepreg ● Adhesives
PF, MF and UF resins	● Can coatings ● Coil coatings ● Drum linings
Imidazoles	● Potting compounds ● Powder coatings ● Moulding powders
Boron halide complexes	● Electrical machine insulation ● Composites ● Adhesives
Blocked isocyanates	● Electrodeposited automotive primers ● Powders
Polyamines & polyamide resins	● Maintenance paints ● Marine paints ● Do-it-yourself adhesives ● Industrial flooring ● Civil engineering adhesives ● Construction industry mortars & grouts
Polyisocyanates	● Paints with good acid resistance
Polymercaptans	● Fast curing adhesives

There are many producers and distributors of epoxy hardeners in the European market. Table 1 lists only the major hardener families. Commercially available

hardeners are usually offered as mixtures or formulations to achieve special technical performance. Epoxy hardener products are numerous and vary widely in their precise composition; in most cases, the composition is proprietary. This makes gathering the necessary up-stream information extremely difficult and explains why there are currently no meaningful LCI data available for these products.

However, if a complete life-cycle inventory of an epoxy system needs to be performed, it is recommended that the product is treated as 100% epoxy resin. In most cases this will provide a reasonable approximation.

PRODUCTION OF LIQUID EPOXY RESINS

In the processes examined in this report, liquid epoxy resins were produced from epichlorohydrin and bisphenol-A. Figure 1 shows schematically the outline sequence of operations needed to produce such resins from raw materials in the earth. Figure 2 shows in somewhat more detail a typical sequence of operations that might be used in the resin production facility.

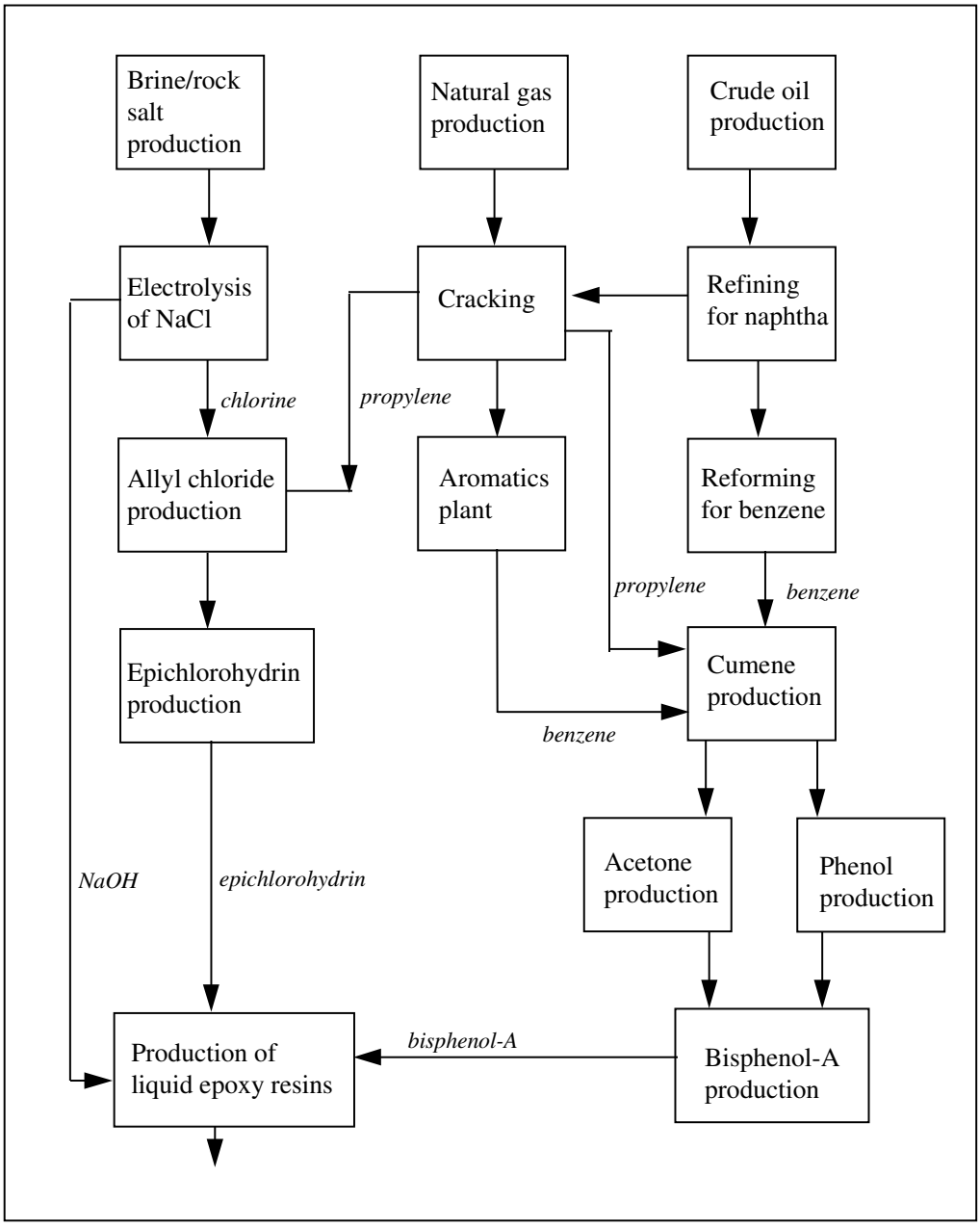


Figure 1
Outline sequence of operations required to produce liquid epoxy resins from raw materials in the earth.

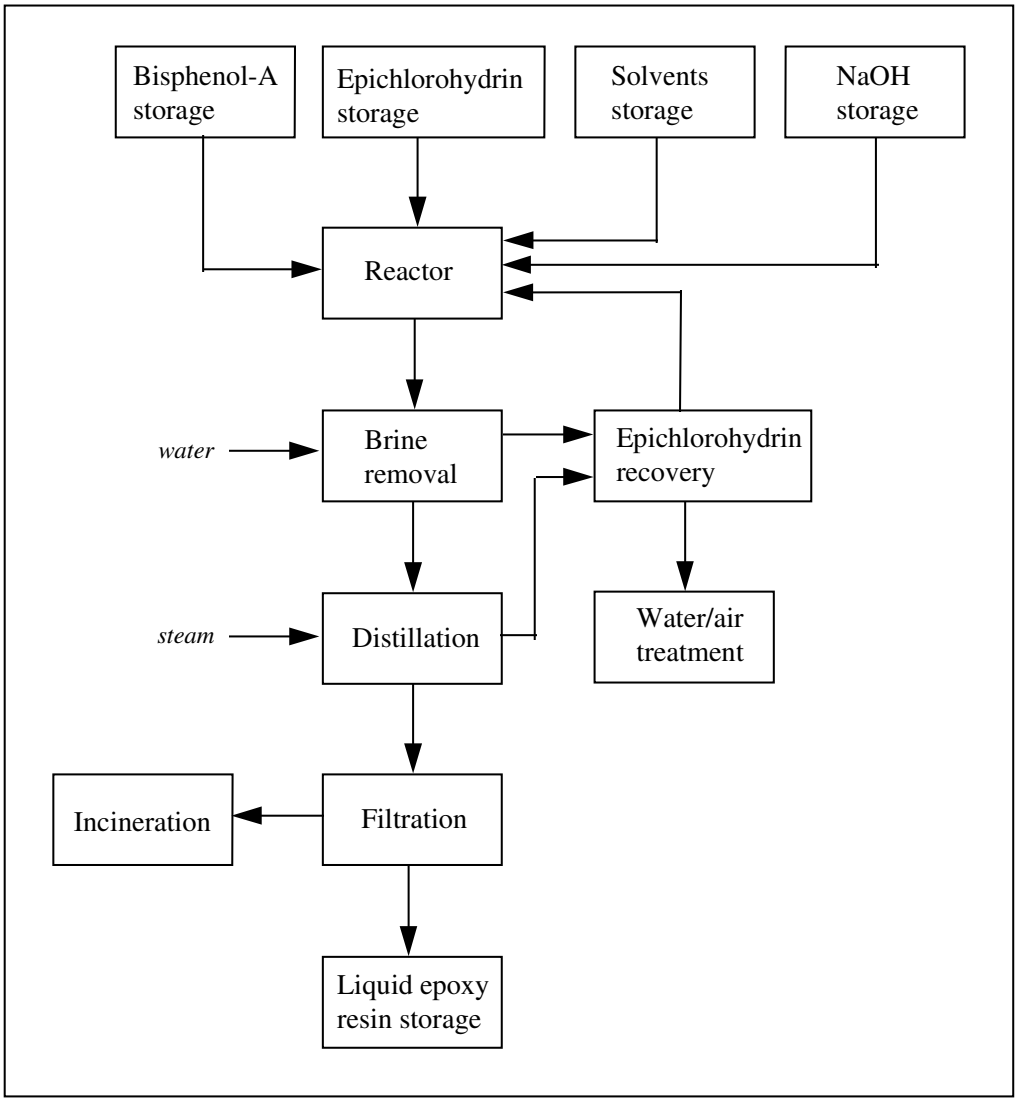


Figure 2
Typical sequence of operations used in the production of liquid epoxy resins.

ECO-PROFILE OF LIQUID EPOXY RESINS

Table 2 shows the gross or cumulative energy to produce 1 kg of liquid epoxy resin and Table 3 gives this 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 shows the emissions to water. Table 10 shows the solid waste generated and Table 11 gives the solid waste in EU format.

Table 2
Gross energy required to produce 1 kg of liquid epoxy resin. (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	16.00	7.61	0.49	-	24.10
Oil fuels	0.46	11.66	0.30	15.51	27.93
Other fuels	2.52	55.04	0.10	27.40	85.06
Totals	18.98	74.31	0.89	42.91	137.09

Table 3
Gross primary fuels required to produce 1 kg of liquid epoxy resin. (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	5.36	5.40	0.13	1.32	12.21
Oil	1.53	12.18	0.53	15.51	29.75
Gas	5.15	58.17	0.12	26.01	89.46
Hydro	0.68	0.51	0.01	-	1.19
Nuclear	5.71	2.68	0.09	-	8.48
Lignite	0.12	0.05	<0.01	-	0.18
Wood	<0.01	<0.01	<0.01	0.02	0.02
Sulphur	<0.01	<0.01	<0.01	0.04	0.04
Biomass (solid)	0.04	0.02	<0.01	<0.01	0.07
Hydrogen	<0.01	2.84	<0.01	-	2.84
Recovered energy	<0.01	-7.71	<0.01	-	-7.71
Unspecified	<0.01	<0.01	<0.01	-	<0.01
Peat	<0.01	<0.01	<0.01	-	0.01
Geothermal	0.07	0.03	<0.01	-	0.10
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	-	0.08
Industrial waste	0.08	0.04	<0.01	-	0.12
Municipal Waste	0.11	0.05	<0.01	-	0.17
Wind	0.06	0.03	<0.01	-	0.08
Totals	18.98	74.31	0.89	42.91	137.09

Table 4
Gross primary fuels used to produce 1 kg of liquid epoxy resin expressed as mass.

Fuel type	Input in mg
Crude oil	660000
Gas/condensate	1700000
Coal	430000
Metallurgical coal	960
Lignite	12000
Peat	590
Wood	2400

Table 5
Gross raw materials required to produce 1 kg of liquid epoxy resin.

Raw material	Input in mg
Air	1100000
Animal matter	<1
Barytes	690
Bauxite	2100
Bentonite	160
Biomass (including water)	17000
Calcium sulphate (CaSO4)	16
Chalk (CaCO3)	<1
Clay	8
Cr	<1
Cu	<1
Dolomite	290
Fe	2300
Feldspar	<1
Ferromanganese	2
Fluorspar	40
Granite	<1
Gravel	9
Hg	4
Limestone (CaCO3)	670000
Mg	<1
N2	170000
Ni	<1
O2	40000
Olivine	22
Pb	4
Phosphate as P2O5	460
Potassium chloride (KCl)	4700
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	4600
Sand (SiO2)	1200
Shale	45
Sodium chloride (NaCl)	1900000
Sodium nitrate (NaNO3)	<1
Talc	<1
Unspecified	<1
Zn	<1

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

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	3100000	81	3100000
River canal	119000000	159000000	278000000
Sea	460000	55000000	55000000
Well	14000	13000	27000
Unspecified	14000000	56000000	70000000
Totals	136000000	270000000	406000000

Table 7
Gross air emissions associated with the production of 1 kg of liquid epoxy resin. (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)	1300	510	17	6800	-	-	8600
CO	2600	1600	200	390	-	-	4700
CO2	1300000	4100000	27000	320000	-2200	-	5700000
SOX as SO2	5000	6100	190	660	-	-	12000
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	3600	8700	260	880	-	-	13000
NH3	<1	-	<1	1	-	-	1
Cl2	<1	<1	<1	570	-	-	570
HCl	150	42	<1	200	-	-	400
F2	<1	<1	<1	<1	-	-	<1
HF	6	2	<1	<1	-	-	7
hydrocarbons not specified	1500	430	73	1800	-	<1	3700
aldehyde (-CHO)	<1	-	<1	37	-	-	37
organics	<1	<1	<1	580	-	-	580
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	1	3	<1	<1	-	-	4
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	<1	-	-	<1
H2	71	<1	<1	4400	-	-	4500
dichloroethane (DCE) C2H4Cl2	<1	-	<1	<1	-	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	-	<1	<1
CFC/HCFC/HFC not specified	<1	-	<1	9	-	-	9
organo-chlorine not specified	<1	-	<1	11	-	-	11
HCN	<1	-	<1	<1	-	-	<1
CH4	98000	2200	<1	1800	-	<1	100000
aromatic HC not specified elsewhere	<1	-	1	39	-	<1	40
polycyclic hydrocarbons (PAH)	<1	1	<1	<1	-	-	1
NMVOC	<1	-	<1	8	-	-	9
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	-	2	2
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 liquid epoxy resin. (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	7400000	4200000	28000	440000	-2200	6	12000000
100 year equiv	3600000	4100000	28000	370000	-2200	3	8100000
500 year equiv	2000000	4100000	28000	340000	-2200	2	6400000

Table 9

Gross emissions to water arising from the production of 1 kg of liquid epoxy resin. (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	-	<1	51000	51000
BOD	<1	-	<1	1100	1100
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	1	1
Na+compounds as Na	<1	-	<1	360000	360000
acid as H+	2	-	<1	11	13
NO3-	<1	-	<1	4	4
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	<1	-	<1	300	300
ammonium compounds as NH4+	2	-	<1	3	5
Cl-	1	-	<1	970000	970000
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	1	1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-hydrocarbon)	1	-	<1	310	310
suspended solids	110	-	31	82000	82000
detergent/oil	<1	-	<1	7	7
hydrocarbons not specified elsewhere	19	<1	<1	30	49
organo-chlorine not specified	<1	-	<1	75	75
dissolved chlorine	<1	-	<1	2	2
phenols	<1	-	<1	6	6
dissolved solids not specified	<1	-	<1	16000	16000
P+compounds as P	<1	-	<1	180	180
other nitrogen as N	<1	-	<1	9	10
other organics not specified elsewhere	<1	-	<1	5200	5200
SO4--	<1	-	<1	12000	12000
dichloroethane (DCE)	<1	-	<1	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	<1
K+compounds as K	<1	-	<1	150	150
Ca+compounds as Ca	<1	-	<1	54000	54000
Mg+compounds as Mg	<1	-	<1	21	21
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	700	700
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	11000	11000
AOX	<1	-	<1	50	50
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	15000	15000
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 liquid epoxy resin. (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	570	570
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	1700	-	<1	60	1800
Mineral waste	8300	-	310	180000	190000
Slags & ash	27000	5500	120	7900	41000
Mixed industrial	-4100	-	12	43000	38000
Regulated chemicals	2100	-	<1	17000	19000
Unregulated chemicals	1600	-	<1	28000	30000
Construction waste	<1	-	<1	35	35
Waste to incinerator	<1	-	<1	5800	5800
Inert chemical	<1	-	<1	900	900
Wood waste	<1	-	<1	49	49
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	110	110
Waste returned to mine	77000	-	11	2100	80000
Tailings	2	-	10	49	61
Municipal solid waste	-16000	-	-	<1	-16000
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 liquid epoxy resin. 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	120000
010102 non-metal min'l excav'n waste	140000
010306 non 010304/010305 tailings	28
010308 non-010307 powdery wastes	12
010399 unspecified met. min'l wastes	40000
010408 non-010407 gravel/crushed rock	22
010410 non-010407 powdery wastes	39
010411 non-010407 potash/rock salt	4000
010499 unsp'd non-met. waste	7000
010505*oil-bearing drilling mud/waste	2100
010508 non-010504/010505 chloride mud	1600
010599 unspecified drilling mud/waste	1700
020107 wastes from forestry	49
030399 unsp'd wood/paper waste	1
050106*oil ind. oily maint'e sludges	1
050107*oil industry acid tars	130
050199 unspecified oil industry waste	160
050699 coal pyrolysis unsp'd waste	44
060101*H2SO4/H2SO3 MFSU waste	7
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	22000
060313*h. metal salt/sol'n MFSU waste	5100
060314 other salt/sol'n MFSU waste	630
060399 unsp'd salt/sol'n MFSU waste	3000
060404*Hg MSFU waste	5500
060405*other h. metal MFSU waste	740
060499 unsp'd metallic MFSU waste	2000
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	9
060701*halogen electrol. asbestos waste	120
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	25
060704*halogen pr. acids and sol'ns	440
060799 unsp'd halogen pr. waste	2000
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	14000
070108*other still bottoms/residues	1000
070111*org. chem. dan. eff. sludge	<1
070112 non-070111 effluent sludge	2
070199 unsp'd organic chem. waste	460
070204*polymer ind. other washes	48

continued over …..

Table 11 - continued
Gross solid waste in EU format associated with the production of 1 kg of liquid epoxy resin. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	1800
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	26
070214*polymer ind. dan. additives	110
070215 non-0702130 additive waste	<1
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	430
080199 unspecified paint/varnish waste	<1
100101 non-100104 ash, slag & dust	31000
100102 coal fly ash	3200
100104*oil fly ash and boiler dust	1300
100105 FGD Ca-based reac. solid waste	<1
100113*emulsified hyrdocarbon fly ash	14
100114*dangerous co-incin'n ash/slag	12
100115 non-100115 co-incin'n ash/slag	210
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd themal process waste	76
100202 unprocessed iron/steel slag	680
100210 iron/steel mill scales	26
100399 unspecified aluminium waste	40
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	23
110199 unspecified surf. t waste	<1
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	34
190199 unspecified incin'n/pyro waste	<1
190899 unsp'd water treatment waste	590
190905 sat./spent ion exchange resins	900
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	550
200140 metals	<1
200199 other separately coll. frac'ns	-5900
200301 mixed municipal waste	10
200399 unspecified municipal wastes	-14000
Note: Negative values correspond to consumption of waste e.g. recycling or	