PlasticsEurope
Association of Plastics Manufacturers

Eco-profiles of the
European Plastics Industry

GLASS FILLED POLYAMIDE 6

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 that can also be down loaded:

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.

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NYLON 6

The polyamides are a group of polymers characterised by a carbon chain with -CO-NH- groups interspersed at regular intervals along it (See Figure 1). They are commonly referred to by the generic name *nylon* and may be produced by the direct polymerisation of amino-acids or by the reaction of a diamine with a dibasic acid. Different nylons are usually identified by a numbering system that refers to the number of carbon atoms between successive nitrogen atoms in the main chain. Polymers derived from amino-acids are referred to by a single number; for example, nylon-6 is polycaprolactam[1] and has the structure shown in Figure 1.

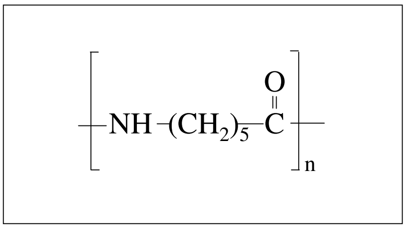

Figure 1. Structure of the repeat unit in nylon 6.

Nylon 6 is sold both as the pure homopolymer and as a glass filled compound. The data given here refers to a mixture of nylon 6 with 30% glass fibre which is used in engineering mouldings.

THE PRODUCTION OF NYLON 6

There are a number of different routes to the production of nylon 6 and these are summarised in Figure 2. The starting chemical is benzene, which is used to produce cylohexanone. This conversion can be achieved by two distinct routes. One route hydrogenates the benzene to produce cyclohexane, which is then oxygenated to give cyclohexanone. The alternative route is to react the benzene with propylene. This gives cumene that can then be oxygenated to phenol giving acetone as by-product. The phenol can then be hydrogenated to cyclohexanone.

The cyclohexanone is then converted into the oxime by reacting with hydroxyamine (NH_2OH).

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[1] The unusual name for this polymer comes from the original name, caproic acid, for the C6 carboxylic acid.

Finally the oxime is converted to caprolactam, the immediate precursor for nylon 6, by an acid catalysed reaction called the Beckmann rearrangement. The most common route employs sulphuric acid but an alternative uses phosphoric acid.

COPRODUCT ALLOCATION IN CAPROLACTAM PRODUCTION

The manufacture of caprolactam results in the co-production of significant quantities of ammonium sulphate as is clearly shown by the overall reaction from cyclohexanone to caprolactam:

$$2C_6H_{10}O+12NH_3+2H_2O+3O_2+4SO_2+H_2SO_4 \rightarrow 2C_6H_{11}NO+5(NH_4)_2SO_4 \quad (1)$$

If the process is carried out under stoichiometric conditions then the production of 1 mole of caprolactam is accompanied by 2.5 moles of ammonium sulphate; that is 2.9 kg of ammonium sulphate per kg of caprolactam. In practice, an excess ammonia is used and this is subsequently neutralised with sulphuric acid so that the production rate of ammonium sulphate is sometimes closer to 4 moles per mole of caprolactam (i.e. 4.6 kg ammonium sulphate per kg caprolactam); this corresponds to an overall reaction of the form:

$$2C_6H_{10}O+18NH_3+2H_2O+3O_2+4SO_2+4H_2SO_4 \rightarrow 2C_6H_{11}NO+8(NH_4)_2SO_4 \quad (2)$$

The crude ammonium sulphate from this reaction is usually sold on for further processing into fertiliser. However, it is not a particularly valuable product and a number of modificiations to the process have been introduced in an attempt to reduce its production. It cannot, however, be eliminated completely and all process data sets show an ammonium sulphate production rate between 2.9 kg and 4.6 kg per kg caprolactam.

To analyse the process, it is necessary to partition the inputs and outputs between nylon 6 and ammonium sulphate. Because of the relatively high mass of ammonium sulphate produced compared to nylon 6, a simple mass partition would assign most of the burdens to ammonium sulphate. Since the primary aim of the process is the production of nylon 6, it is thought to be inappropriate to allow most of the burdens to be assigned to, what is essentially, an unwanted by-product, especially as there are considerably simpler routes available for the production of ammonium sulphate if this really is a desired product.

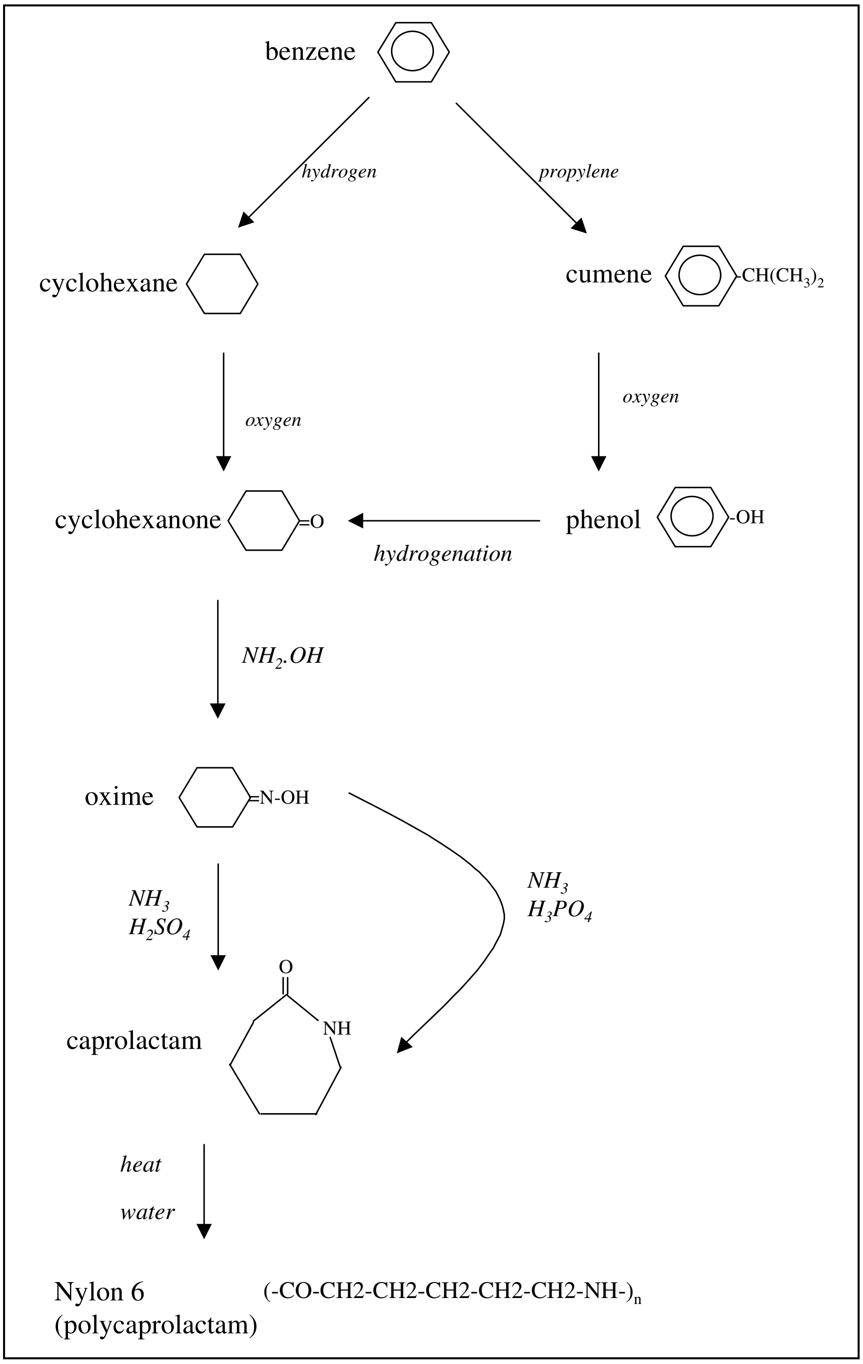

Figure 3
Summary of alternative routes from benzene to nylon 6. Not all routes are used by all producers.

In the calculations, therefore, the burdens associated with the production of the ammonia and sulphuric acid used in the production of ammonium sulphate, have been assigned to the ammonium sulphate by-product. All other burdens have been assigned to the production of nylon 6.

ECO-PROFILE OF GLASS FILLED NYLON 6 POLYMER

Table 1 shows the gross or cumulative energy to produce 1 kg of glass filled nylon 6 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 nylon 6 + 30% glass fibre. (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	15.01	6.65	0.36	-	22.01
Oil fuels	0.91	12.41	0.61	13.72	27.65
Other fuels	2.32	41.64	0.14	14.60	58.70
Totals	18.23	60.70	1.11	28.32	108.37

Table 2
Gross primary fuels required to produce 1 kg of nylon 6 + 30% glass fibre. (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	5.28	9.44	0.10	0.01	14.83
Oil	1.30	12.70	0.86	13.72	28.57
Gas	6.18	40.23	0.08	13.75	60.24
Hydro	0.19	0.09	<0.01	-	0.28
Nuclear	4.38	1.89	0.06	-	6.32
Lignite	0.58	0.88	<0.01	-	1.46
Wood	<0.01	<0.01	<0.01	0.06	0.06
Sulphur	<0.01	<0.01	<0.01	0.78	0.78
Biomass (solid)	0.05	0.02	<0.01	<0.01	0.07
Hydrogen	<0.01	0.05	<0.01	-	0.05
Recovered energy	<0.01	-4.72	<0.01	-	-4.72
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)	0.12	0.05	<0.01	-	0.17
Industrial waste	0.04	0.02	<0.01	-	0.06
Municipal Waste	0.09	0.04	<0.01	-	0.13
Wind	0.02	0.01	<0.01	-	0.04
Totals	18.23	60.71	1.10	28.32	108.36

Table 3
Gross primary fuels used to produce 1 kg of nylon 6 + 30% glass fibre expressed as mass.

Fuel type	Input in mg
Crude oil	640000
Gas/condensate	1200000
Coal	520000
Metallurgical coal	570
Lignite	97000
Peat	140
Wood	7200

Table 4
Gross raw materials required to produce 1 kg of nylon 6 + 30% glass fibre.

Raw material	Input in mg
Air	1500000
Animal matter	<1
B	170
Barytes	2
Bauxite	54
Bentonite	62
Biomass (including water)	28000
Calcium sulphate (CaSO4)	6
Chalk (CaCO3)	<1
Clay	<1
Cr	<1
Cu	1
Dolomite	67000
Fe	1400
Feldspar	<1
Ferromanganese	1
Fluorspar	4
Granite	<1
Gravel	5
Hg	<1
Limestone (CaCO3)	130000
Mg	1
N2	410000
Ni	<1
O2	130000
Olivine	13
Pb	10
Phosphate as P2O5	270
Potassium chloride (KCl)	<1
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	85000
Sand (SiO2)	190000
Shale	17
Sodium chloride (NaCl)	170000
Sodium nitrate (NaNO3)	<1
Talc	<1
Ulexite	19000
Unspecified	<1
Zn	17

Table 5
Gross water consumption required for the production of 1 kg of nylon 6 + 30% glass fibre. (Totals may not agree because of rounding)

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	37000000	510	37000000
River canal	2000000	206000000	208000000
Sea	270000	15000000	15000000
Well	620000	6800000	7400000
Unspecified	4000000	41000000	45000000
Totals	44000000	268000000	313000000

Table 6
Gross air emissions associated with the production of 1 kg of nylon 6 + 30% glass fibre. (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)	2300	430	38	1500	-	-	4300
CO	3300	920	450	4000	-	-	8700
CO2	1400000	3200000	53000	670000	-6600	-	5300000
SOX as SO2	6600	9600	240	360	-	-	17000
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	3700	6100	550	5000	-	-	15000
NH3	<1	-	<1	98	-	-	98
Cl2	<1	<1	<1	<1	-	-	<1
HCl	140	46	<1	7	-	-	200
F2	<1	<1	<1	2	-	-	2
HF	6	1	<1	<1	-	-	7
hydrocarbons not specified	1700	600	150	3000	-	1	5500
aldehyde (-CHO)	<1	-	<1	18	-	-	18
organics	<1	<1	<1	350	-	-	350
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	1	5	<1	<1	-	-	6
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	3600	-	-	3600
H2	150	<1	<1	100	-	-	250
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	2	-	-	2
CH4	34000	1200	<1	1800	-	<1	37000
aromatic HC not specified elsewhere	<1	-	2	49	-	1	52
polycyclic hydrocarbons (PAH)	<1	2	<1	<1	-	-	2
NMVOC	<1	-	<1	13	-	-	13
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	2	-	-	2
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 nylon 6 + 30% glass fibre. (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	3500000	3300000	54000	1800000	-6600	15	8600000
100 year equiv	2200000	3200000	54000	1800000	-6600	7	7200000
500 year equiv	1600000	3200000	54000	1300000	-6600	4	6100000

Table 8
Gross emissions to water arising from the production of 1 kg of nylon 6 + 30% glass fibre. (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	6	-	1	4500	4500
BOD	1	-	<1	400	400
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	1	1
Na+compounds as Na	<1	-	1	7000	7000
acid as H+	6	-	<1	15	21
NO3-	<1	-	<1	7300	7300
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	1	-	<1	130	130
ammonium compounds as NH4+	5	-	<1	800	800
Cl-	1	-	1	2100	2100
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-	1	-	<1	150	150
suspended solids	150	-	78	16000	17000
detergent/oil	<1	-	<1	14	14
hydrocarbons not specified	8	<1	<1	1	9
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	2300	2300
P+compounds as P	<1	-	<1	170	170
other nitrogen as N	1	-	<1	510	510
other organics not specified	<1	-	<1	12	12
SO4--	<1	-	<1	16000	16000
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	23	23
Mg+compounds as Mg	<1	-	<1	4	4
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	9	9
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	1200	1200
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	6	6
Ni+compounds as Ni	<1	-	<1	5	5
CO3--	-	-	<1	76	76
B+compounds as B	-	-	-	440	440
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 nylon 6 + 30% glass fibre. (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	830	830
Plastics	<1	-	<1	44	44
Metals	<1	-	<1	14	14
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	2200	-	<1	2500	4700
Mineral waste	41000	-	780	100000	140000
Slags & ash	25000	11000	300	410	36000
Mixed industrial	-550	-	31	2400	1900
Regulated chemicals	2600	-	<1	14000	17000
Unregulated chemicals	2000	-	1	1100	3100
Construction waste	<1	-	<1	17	17
Waste to incinerator	<1	-	<1	760	760
Inert chemical	<1	-	<1	8600	8600
Wood waste	<1	-	<1	98	98
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	13000	13000
Waste returned to mine	76000	-	33	150	76000
Tailings	2	-	31	52	84
Municipal solid waste	-12000	-	-	<1	-12000
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 nylon 6 + 30% glass fibre. 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	1100
010102 non-metal min'l excav'n waste	180000
010306 non 010304/010305 tailings	34
010308 non-010307 powdery wastes	31
010399 unspecified met. min'l wastes	9
010408 non-010407 gravel/crushed rock	2
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	110
010499 unsp'd non-met. waste	41000
010505*oil-bearing drilling mud/waste	2600
010508 non-010504/010505 chloride mud	2000
010599 unspecified drilling mud/waste	2200
020107 wastes from forestry	98
030399 unsp'd wood/paper waste	830
050106*oil ind. oily maint'e sludges	1
050107*oil industry acid tars	110
050199 unspecified oil industry waste	160
050699 coal pyrolysis unsp'd waste	120
060101*H2SO4/H2SO3 MFSU waste	<1
060102*HCl MFSU waste	<1
060106*other acidic MFSU waste	<1
060199 unsp'd acid MFSU waste	<1
060201*Ca(OH)2 MFSU waste	22
060204*NaOH/KOH MFSU waste	<1
060299 unsp'd base MFSU waste	<1
060313*h. metal salt/sol'n MFSU waste	100
060314 other salt/sol'n MFSU waste	<1
060399 unsp'd salt/sol'n MFSU waste	60
060404*Hg MSFU waste	<1
060405*other h. metal MFSU waste	2
060499 unsp'd metallic MFSU waste	88
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	170
060701*halogen electrol. asbestos waste	7
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	<1
060704*halogen pr. acids and sol'ns	41
060799 unsp'd halogen pr. waste	22
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	240
070111*org. chem. dan. eff. sludge	<1
070112 non-070111 effluent sludge	6

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Table 10 - continued
Gross solid waste in EU format associated with the production of 1 kg of nylon 6 + 30% glass fibre. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

070199 unsp'd organic chem. waste	150
070204*polymer ind. other washes	9
070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	14000
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	12000
070214*polymer ind. dan. additives	91
070215 non-0702130 additive waste	<1
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	2400
080199 unspecified paint/varnish waste	1
100101 non-100104 ash, slag & dust	23000
100102 coal fly ash	12000
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	12
100115 non-100115 co-incin'n ash/slag	11
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd themal process waste	820
100202 unprocessed iron/steel slag	410
100210 iron/steel mill scales	28
100399 unspecified aluminium waste	<1
100501 primary/secondary zinc slags	3
100504 zinc pr. other dust	<1
100511 non-100511 Zn pr. skimmings	<1
100899 unspecified o.n.f.m. waste	<1
101304 lime calcin'n/hydration waste	9
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	16
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	8600
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	42
200140 metals	12
200199 other separately coll. frac'ns	-2800
200301 mixed municipal waste	2500
200399 unspecified municipal wastes	-10000
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.	