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Eco-profiles of the European Plastics Industry

Polyethylene Terephthalate (PET) (Bottle grade)

A report by

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for

*Plastics*Europe

Data last calculated

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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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POLYETHYLENE TEREPHTHALATE

Polyethylene terephthalate (PET) was first developed in 1941 by British Calico Printers for use in synthetic fibres. The patent rights were subsequently sold to DuPont and ICI who, in turn, sold regional rights to many other companies.[1] Although originally produced for fibres, the use of PET films in packaging began in the mid-1960's. Then, in the early 1970's The technique for blowing bi-axially oriented bottles was commercially developed so that PET bottles now represent the most significant use of PET moulding resins.

THE STRUCTURE OF PET

PET is a thermoplastic polymer with a structural formula as shown in Figure 1.

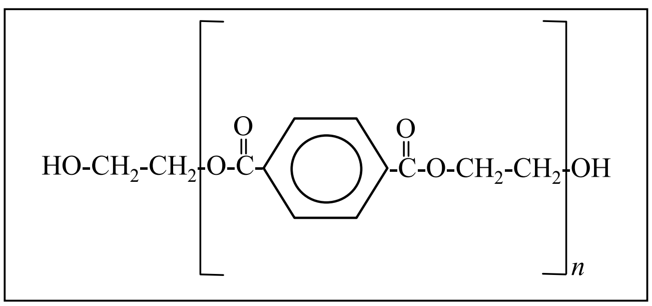


Figure 1
The structure of polyethylene terephthalate. The unit inside the brackets will typically have a repeat value (n) in the range 100 to 200.

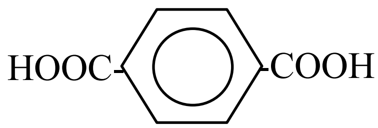
Such condensation polymers are typically produced by reacting a compound containing two acid groups (-COOH) with a compound containing two alcohol groups (-OH) according to a reaction of the form:

$$\underset{\text{acid}}{\text{HOOC.R.COOH}} + \underset{\text{alcohol}}{\text{HO.R'.OH}} \rightarrow \underset{\text{ester}}{\text{HOOC.R.COO.R'.OH}} + H_2O \qquad (1)$$

where R and R' represent other organic groups. The ester in reaction (1) may now react with further acid or alcohol to produce a long chain polymer.

[1] E H Neumann. *Thermoplastic polyesters*. In *Encyclopedia of Packaging Technology*, ed M Bakker. ISBN 0-471-80940-3. John Wiley, New York. (1986).

For PET, the acid used is terephthalic acid:



and the alcohol is ethylene glycol (ethanediol):

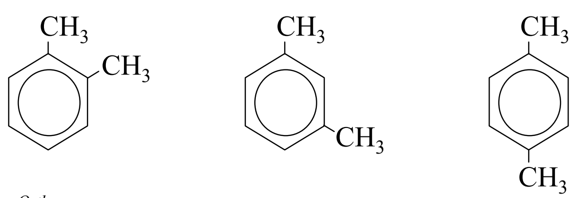
$HO-CH_2-CH_2-OH$

THE COMMERCIAL PRODUCTION OF PET

The starting compounds for the commercial production of PET are ethylene ($CH_2=CH_2$) for the production of ethylene glycol and para-xylene for the production of terephthalic acid.

Naphtha cracking produces only a very small quantity of xylenes. Most xylenes are produced either from pyrolysis gasoline, an aromatic rich fraction produced during naphtha cracking or directly from naphtha in a process known as catalytic reforming. In both cases, the basic feedstock is converted into a mixture of products of which the principal components are benzene, toluene and xylenes (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 output from xylene production is a mixture of the three forms (isomers) of xylene:



Ortho- *Meta-* *Para-*

Before use in the production of terephthalic acid, the different isomers are separated. Para-xylene is used in the production of terephthalic acid because the ‘straight’ chain structure is best suited to linear polymers.

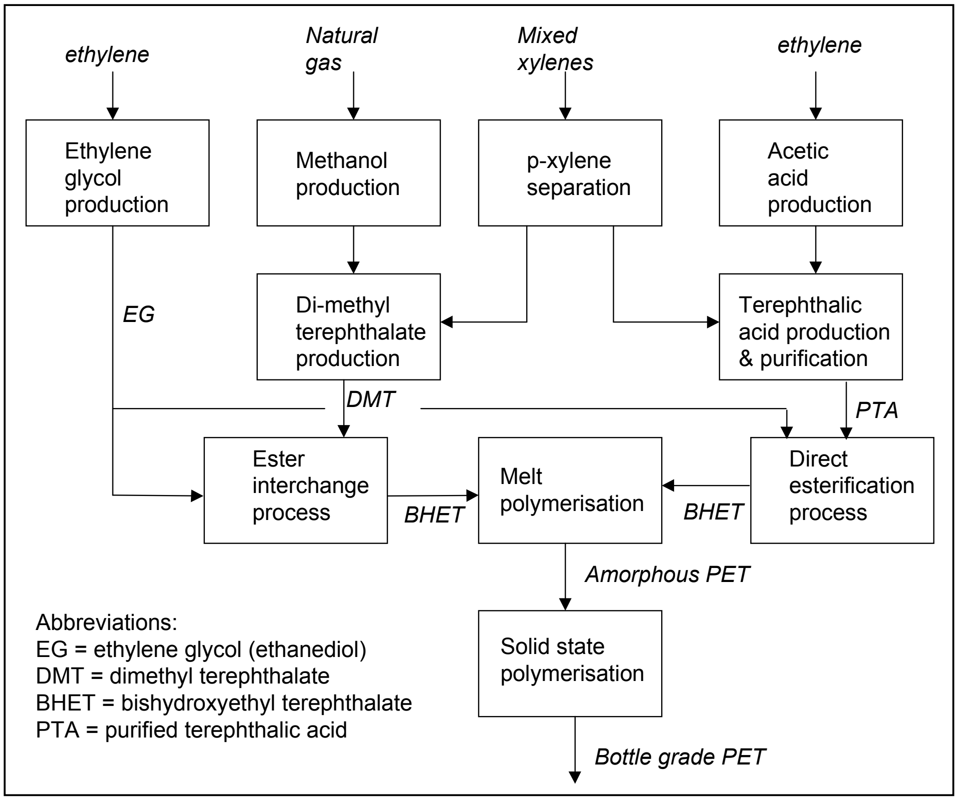
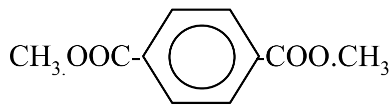


Figure 2
Schematic flow diagram showing the two routes to polyethylene erephthalate.

In practice there are two routes used in the production of PET and these are shown schematically in Figure 2.

In the first, shown on the right hand side of Figure 2, p-xylene is oxidised to terephthalic acid which is then purified. This purified terephthalic acid (PTA) is then reacted with ethylene glycol to produce bishydroxyethyl terepthalate (BHET) with water as a by-product in a manner similar to that shown in equation (1).

The alternative route, shown on the left hand side of Figure 2, oxidises p-xylene to terephthalic acid but then immediately reacts the acid with methanol to produce dimethyl terephthalate (DMT):



When DMT is reacted with ethylene glycol, the result is again BHET, as in the alternative route, but the by-product is now methanol rather than water. The methanol is recovered and re-used.

The monomer from either route can now be polymerised in the liquid phase to produce amorphous PET. This form of the polymer is suitable for the production of fibres and film.

A second polymerisation in the solid state increases the molecular weight of the polymer and produces a partially crystalline resin that can be used to produce bottles via injection moulding and stretch blow moulding.

ECO-PROFILE OF BOTTLE GRADE PET

Table 1 shows the gross or cumulative energy to produce 1 kg of bottle grade PET 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 bottle grade PET. (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	12.48	5.23	0.42	-	18.12
Oil fuels	0.49	9.64	0.08	22.47	32.68
Other fuels	0.64	13.94	0.03	17.29	31.90
Totals	13.61	28.81	0.53	39.76	82.71

Table 2
Gross primary fuels required to produce 1 kg of bottle grade PET. (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	4.62	3.68	0.11	<0.01	8.41
Oil	1.07	9.95	0.21	22.46	33.70
Gas	4.18	14.89	0.11	17.29	36.47
Hydro	0.18	0.08	<0.01	-	0.26
Nuclear	3.30	1.38	0.09	-	4.76
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)	0.05	0.02	<0.01	<0.01	0.07
Hydrogen	<0.01	<0.01	<0.01	-	<0.01
Recovered energy	<0.01	-1.29	<0.01	-	-1.29
Unspecified	<0.01	<0.01	<0.01	-	<0.01
Peat	<0.01	<0.01	<0.01	-	<0.01
Geothermal	0.03	0.01	<0.01	-	0.05
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	0.01	<0.01	<0.01	-	0.01
Municipal Waste	0.05	0.02	<0.01	-	0.07
Wind	0.01	0.01	<0.01	-	0.02
Totals	13.61	28.81	0.53	39.76	82.71

Table 3
Gross primary fuels used to produce 1 kg of bottle grade PET expressed as mass.

Fuel type	Input in mg
Crude oil	750000
Gas/condensate	670000
Coal	290000
Metallurgical coal	140
Lignite	19
Peat	150
Wood	10

Table 4
Gross raw materials required to produce 1 kg of bottle grade PET.

Raw material	Input in
Air	4700000
Animal matter	<1
Barytes	<1
Bauxite	2
Bentonite	72
Biomass (including water)	28000
Calcium sulphate (CaSO4)	7
Chalk (CaCO3)	<1
Clay	<1
Cr	<1
Cu	<1
Dolomite	4
Fe	330
Feldspar	<1
Ferromanganese	<1
Fluorspar	1
Granite	<1
Gravel	1
Hg	<1
Limestone (CaCO3)	280
Mg	<1
N2	310000
Ni	<1
O2	6
Olivine	3
Pb	1
Phosphate as P2O5	16
Potassium chloride (KCl)	1
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	82
Sand (SiO2)	240
Shale	20
Sodium chloride (NaCl)	1700
Sodium nitrate (NaNO3)	<1
Talc	<1
Unspecified	<1
Zn	<1

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

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	3500000	-	3500000
River canal	240000	5100	240000
Sea	370000	3400000	3800000
Well	440	190	630
Unspecified	710000	58000000	59000000
Totals	4800000	61000000	66000000

Table 6
Gross air emissions associated with the production of 1 kg of bottle grade PET. (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)	1500	220	2	230	-	-	1900
CO	2800	4300	20	360	-	-	7400
CO2	1100000	1700000	7500	140000	-9	-	2900000
SOX as SO2	5100	4800	110	340	-	-	10000
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	2800	4200	48	150	-	-	7200
NH3	<1	-	<1	<1	-	-	<1
Cl2	<1	<1	<1	<1	-	-	<1
HCl	130	33	<1	<1	-	-	160
F2	<1	<1	<1	<1	-	-	<1
HF	5	1	<1	<1	-	-	6
hydrocarbons not specified	1100	270	15	6800	-	<1	8200
aldehyde (-CHO)	<1	-	<1	<1	-	-	<1
organics	<1	<1	<1	310	-	-	310
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	140	<1	<1	1	-	-	140
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	16000	610	<1	2500	-	<1	19000
aromatic HC not specified	<1	-	<1	350	-	4	360
polycyclic hydrocarbons (PAH)	<1	7	<1	<1	-	-	7
NMVOC	<1	-	<1	1200	-	-	1200
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	4	<1	<1	-	-	4
Se+compounds as Se	-	-	-	<1	-	-	<1
Ni+compounds as Ni	<1	7	<1	<1	-	-	7
Sb+compounds as Sb	-	-	<1	<1	-	-	<1
ethylene oxide C2H4O	-	-	-	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 7
Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of bottle grade PET. (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	1800000	7600	310000	-9	<1	4100000
100 year equiv	1400000	1700000	7600	210000	-9	<1	3400000
500 year equiv	1200000	1700000	7600	180000	-9	<1	3100000

Table 8

Gross emissions to water arising from the production of 1 kg of bottle grade PET. (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	2	-	<1	1200	1200
BOD	<1	-	<1	2000	2000
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	<1	-	<1	220	220
acid as H+	1	-	<1	4	5
NO3-	<1	-	<1	3	3
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	<1	-	<1	19	20
ammonium compounds as NH4+	1	-	<1	1	3
Cl-	1	-	<1	220	220
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-	1	-	<1	16	17
suspended solids	74	-	3	290	370
detergent/oil	<1	-	<1	20	20
hydrocarbons not specified	9	<1	<1	100	110
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	150	150
P+compounds as P	<1	-	<1	<1	<1
other nitrogen as N	<1	-	<1	2	2
other organics not specified	<1	-	<1	300	300
SO4--	<1	-	<1	350	350
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	41	41
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	81	81
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 bottle grade PET. (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	2300	2300
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	1500	-	<1	<1	1500
Mineral waste	58	-	30	310	400
Slags & ash	18000	3300	12	320	22000
Mixed industrial	1000	-	1	370	1400
Regulated chemicals	1800	-	<1	1000	2800
Unregulated chemicals	1300	-	<1	7500	8900
Construction waste	<1	-	<1	54	54
Waste to incinerator	<1	-	<1	800	800
Inert chemical	<1	-	<1	1900	1900
Wood waste	<1	-	<1	<1	<1
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	180	180
Waste returned to mine	57000	-	1	2	57000
Tailings	2	-	1	1	3
Municipal solid waste	-6900	-	-	<1	-6900
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 bottle grade PET. 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	260
010102 non-metal min'l excav'n waste	57000
010306 non 010304/010305 tailings	3
010308 non-010307 powdery wastes	3
010399 unspecified met. min'l wastes	2
010408 non-010407 gravel/crushed rock	<1
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	5
010499 unsp'd non-met. waste	<1
010505*oil-bearing drilling mud/waste	1700
010508 non-010504/010505 chloride mud	1300
010599 unspecified drilling mud/waste	1500
020107 wastes from forestry	<1
050106*oil ind. oily maint'e sludges	<1
050107*oil industry acid tars	160
050199 unspecified oil industry waste	160
050699 coal pyrolysis unsp'd waste	26
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	5
060314 other salt/sol'n MFSU waste	<1
060399 unsp'd salt/sol'n MFSU waste	2
060404*Hg MSFU 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	2
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	43
070111*org. chem. dan. eff. sludge	<1

continued over …..

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

070112 non-070111 effluent sludge	<1
070199 unsp'd organic chem. waste	70
070204*polymer ind. other washes	<1
070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	1600
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	2800
070214*polymer ind. dan. additives	200
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	16000
100102 coal fly ash	370
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	21
100115 non-100115 co-incin'n ash/slag	5300
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd themal process waste	<1
100202 unprocessed iron/steel slag	100
100210 iron/steel mill scales	8
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	10
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	54
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	1900
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	2
200140 metals	<1
200199 other separately coll. frac'ns	-460
200301 mixed municipal waste	1
200399 unspecified municipal wastes	-5400
Note: Negative values correspond to consumption of waste e.g. recycling or	