PlasticsEurope
Association of Plastics Manufacturers

Eco-profiles of the European Plastics Industry

GLASS FILLED POLYAMIDE 66

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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NYLON 66

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 which 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. Polymers derived from a diamine and a dibasic acid are given two numbers with the first referring to the number of carbon atoms contributed by the diamine and the second referring to the number of carbon atoms supplied by the dibasic acid. Thus nylon 66 is derived from hexamethylene diamine and adipic acid to give the structure shown in Figure 1.

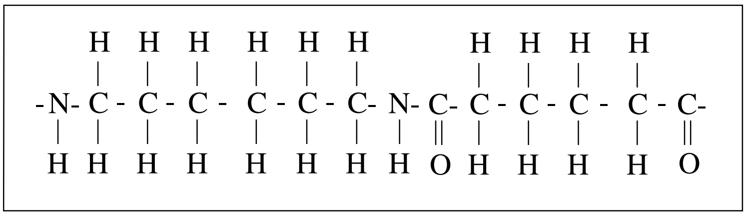

Figure 1. Structure of the repeat unit in nylon 66.

The research leading to the discovery of polyamides began in 1928 when Carothers began research into polymerisation mechanisms. The work was not aimed at producing any specific polymers but one accidental discovery was the method of producing polyamides, the first, all synthetic polymer ever produced. After perfecting the technique of producing high molecular weights in various polyamides, attention was turned to producing a polymer which could be made into fibres. The polymer that was eventually chosen for commercial development was nylon 66 because of its good balance of properties and the relative ease with which the raw materials could be produced.

About two thirds of the nylon produced in Europe is used for fibres (textiles, carpets, etc.) while most of the remainder is used in injection moulded components (automotive parts, consumer goods, etc.) Other smaller uses are films and filaments.

Nylon 66 is often selected for use because of its combination of toughness, stiffness, high melting point and chemical resistance. It is a relatively easy polymer to modify, so the range of different nylon resins available is wider than for most other polymers. Typical modifiers are flame retardents to reduce flammability, rubber to improve impact resistance and glass or minerals to improve stiffness and dimensional stability. Typical uses of the different types of nylon are shown in Table 1.

Table 1. Typical uses of nylons

Modifier	Typical application
Unmodified	Cable ties Lighter bodies
Glass with or without mineral	Radiator end tanks Air intake manifolds Covers of various types
Mineral reinforced	Wheel covers Throttle bodies
Toughened	Clips Fasteners Ski bindings
Flame retarded	Switchgear Circuit breakers Other electrical/electronic components

THE PRODUCTION OF GLASS FILLED NYLON 66

The principal operations leading to the production of nylon 66 are shown in Figure 2. The essential precursors for nylon 66 are hexamethylene diamine, $H_2N\text{-}(CH_2)_6\text{-}NH_2$, and adipic acid, $HOOC\text{-}(CH_2)_4\text{-}COOH$. When they are reacted they produce hexamethylene diammonium adipate, commonly referred to as nylon salt, $H_3N(CH_2)_6NH_3OOC(CH_2)_4COO$-. For fibre applications, it is important to ensure that the precursors are reacted in equimolar proportions and that the product is highly purified. The formation, extraction and purification of the salt ensures that these conditions are met.

Adipic acid is made by the oxidation of cyclohexane to a mixture of cyclohexanol and cyclohexanone (called KA oil). This mixture is further oxidised with nitric acid to adipic acid. Hexamethylene diamine is made by the reduction of adiponitrile, which is made either by the electronic coupling of acrylonitrile or by the hydrocyanation of butadiene. Adipic acid and hexamethylene diamine are combined in water to make a salt solution. This solution is then passed through a batch or continuous reactor in which the water is removed at high temperature and the nylon polymerises. The polymer is expelled from the reactor and granulated. Higher molecular weights are achieved by solid phase polymerisation. Modified nylons are made by extrusion compounding of the nylon with the modifiers or reinforcements. In some cases, it is possible to compound directly at the reactor without granulating the nylon.

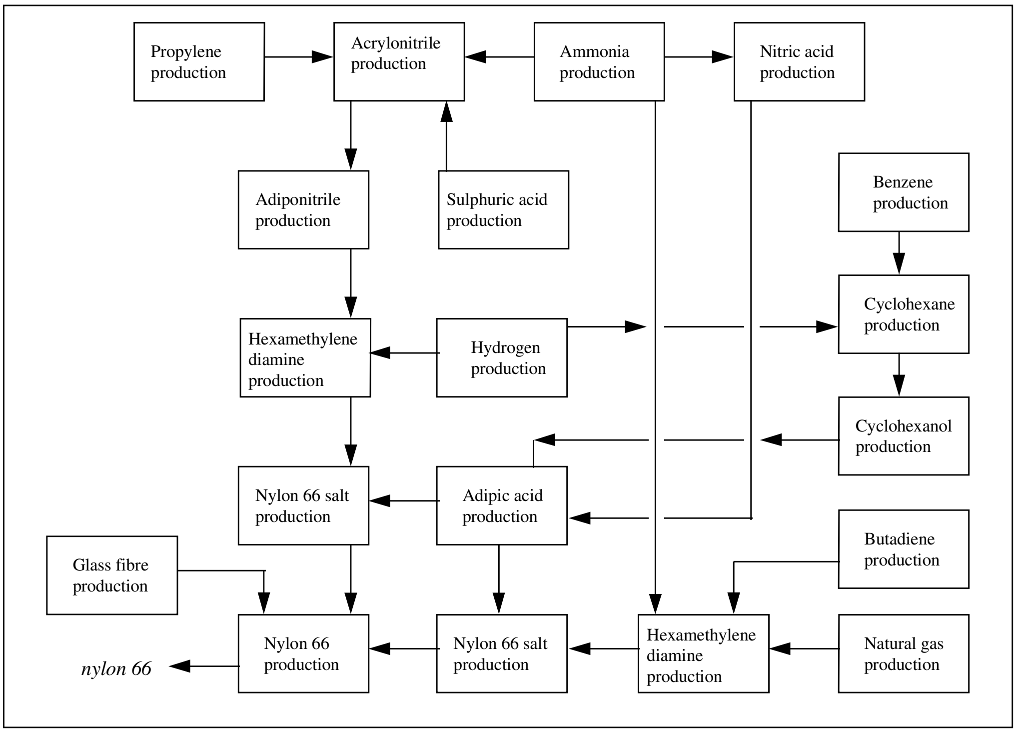

Figure 2
Schematic flow diagram of the principal operations leading to the production of nylon 66.

ECO-PROFILE OF GLASS FILLED NYLON 66

The data given here refer to nylon 66 containing 30% of glass fibre. Table 2 shows the gross or cumulative energy to produce 1 kg of nylon 66 + 30% glass fibre 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 nylon 66 + 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	17.90	7.85	0.45	-	26.20
Oil fuels	0.70	10.84	0.33	18.45	30.32
Other fuels	2.36	38.58	0.18	16.69	57.81
Totals	20.97	57.27	0.96	35.14	114.33

Table 3
Gross primary fuels required to produce 1 kg of nylon 66 + 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	7.19	12.07	0.12	<0.01	19.38
Oil	1.17	11.11	0.65	18.45	31.37
Gas	7.00	35.16	0.10	16.55	58.82
Hydro	0.22	0.13	<0.01	-	0.35
Nuclear	4.95	2.16	0.08	-	7.18
Lignite	<0.01	<0.01	<0.01	-	<0.01
Wood	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphur	<0.01	<0.01	<0.01	0.14	0.14
Biomass (solid)	0.08	0.04	<0.01	<0.01	0.12
Hydrogen	<0.01	0.01	<0.01	-	0.01
Recovered energy	<0.01	-3.56	<0.01	-	-3.56
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)	0.19	0.08	<0.01	-	0.27
Industrial waste	0.03	0.01	<0.01	-	0.05
Municipal Waste	0.10	0.04	<0.01	-	0.14
Wind	0.04	0.02	<0.01	-	0.05
Totals	20.97	57.27	0.96	35.14	114.33

Table 4
Gross primary fuels used to produce 1 kg of nylon 66 + 30% glass fibre expressed as mass.

Fuel type	Input in mg
Crude oil	700000
Gas/condensate	1100000
Coal	680000
Metallurgical coal	260
Lignite	13
Peat	180
Wood	140

Table 5

Gross raw materials required to produce 1 kg of nylon 66 + 30% glass fibre.

Raw material	Input in mg
Air	2200000
Animal matter	<1
Barytes	3
Bauxite	2000
Bentonite	46
Biomass (including water)	45000
Calcium sulphate (CaSO4)	5
Chalk (CaCO3)	<1
Clay	<1
Cr	<1
Cu	1
Dolomite	67000
Fe	650
Feldspar	<1
Ferromanganese	1
Fluorspar	39
Granite	<1
Gravel	2
Hg	<1
Limestone (CaCO3)	130000
Mg	<1
N2	300000
Ni	<1
O2	13
Olivine	6
Pb	4
Phosphate as P2O5	6
Potassium chloride (KCl)	12
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	15000
Sand (SiO2)	190000
Shale	13
Sodium chloride (NaCl)	160000
Sodium nitrate (NaNO3)	<1
Talc	<1
Ulexite	19000
Unspecified	<1
Zn	17

Table 6

Gross water consumption required for the production of 1 kg of nylon 66 + 30% glass fibre. (Totals may not agree because of rounding)

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	96000000	23	96000000
River canal	180000	368000000	368000000
Sea	250000	5100000	5300000
Well	2	30000	30000
Unspecified	9000000	47000000	56000000
Totals	105000000	420000000	525000000

Table 7

Gross air emissions associated with the production of 1 kg of nylon 66 + 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)	1400	410	23	1600	-	-	3400
CO	4500	930	260	330	-	-	6000
CO2	1600000	3800000	35000	620000	-130	-	6100000
SOX as SO2	8400	7500	240	360	-	-	16000
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	4200	5600	340	910	-	-	11000
NH3	<1	-	<1	15	-	-	15
Cl2	<1	<1	<1	1	-	-	1
HCl	190	45	<1	4	-	-	240
F2	<1	<1	<1	2	-	-	2
HF	7	2	<1	<1	-	-	9
hydrocarbons not specified	1900	470	97	880	-	1	3300
aldehyde (-CHO)	<1	-	<1	3	-	-	3
organics	<1	<1	<1	300	-	-	300
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	1	4	<1	<1	-	-	5
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	670	-	-	670
H2	220	<1	<1	42	-	-	270
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	27000	1300	<1	1700	-	<1	30000
aromatic HC not specified elsewhere	<1	-	1	20	-	1	22
polycyclic hydrocarbons (PAH)	<1	2	<1	<1	-	-	2
NMVOC	<1	-	<1	15	-	-	15
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	5
toluene C7H8	-	-	-	<1	-	1	1
xylenes C8H10	-	-	-	<1	-	<1	<1
ethylbenzene C8H10	-	-	-	<1	-	<1	<1
styrene	-	-	-	<1	-	<1	<1
propylene	-	-	-	2	-	-	2

Table 8

Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of nylon 66 + 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	3300000	3900000	36000	910000	-130	13	8100000
100 year equiv	2300000	3800000	36000	860000	-130	6	7000000
500 year equiv	1800000	3800000	36000	740000	-130	3	6400000

Table 9
Gross emissions to water arising from the production of 1 kg of nylon 66 + 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	9	-	<1	5700	5700
BOD	<1	-	<1	32	33
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	<1	-	<1	940	940
acid as H+	11	-	<1	12	22
NO3-	<1	-	<1	20000	20000
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	3	-	<1	58	60
ammonium compounds as NH4+	10	-	<1	1800	1800
Cl-	1	-	<1	1400	1400
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	1	1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-	1	-	<1	18	19
suspended solids	170	-	33	16000	17000
detergent/oil	<1	-	<1	13	13
hydrocarbons not specified	5	<1	<1	1	6
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	5600	5600
P+compounds as P	<1	-	<1	61	61
other nitrogen as N	2	-	<1	17	20
other organics not specified	<1	-	<1	<1	<1
SO4--	<1	-	<1	4900	4900
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	2	2
Mg+compounds as Mg	<1	-	<1	<1	<1
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	6	6
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	3600	3600
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	14	14
Ni+compounds as Ni	<1	-	<1	13	13
CO3--	-	-	<1	58	58
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 nylon 66 + 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	1	1
Plastics	<1	-	<1	25	25
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	1900	-	<1	3	1900
Mineral waste	91	-	320	100000	100000
Slags & ash	27000	4500	130	440	32000
Mixed industrial	-370	-	13	3600	3200
Regulated chemicals	2400	-	<1	1400	3800
Unregulated chemicals	1800	-	<1	9400	11000
Construction waste	<1	-	<1	14	14
Waste to incinerator	<1	-	<1	78	78
Inert chemical	<1	-	<1	6700	6700
Wood waste	<1	-	<1	3	3
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	140	140
Waste returned to mine	130000	-	12	2100	130000
Tailings	3	-	11	58	72
Municipal solid waste	-13000	-	-	<1	-13000

Table 11
Gross solid waste in EU format associated with the production of 1 kg of nylon 66 + 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	2500
010102 non-metal min'l excav'n waste	230000
010306 non 010304/010305 tailings	29
010308 non-010307 powdery wastes	13
010399 unspecified met. min'l wastes	5
010408 non-010407 gravel/crushed rock	2
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	80
010499 unsp'd non-met. waste	<1
010505*oil-bearing drilling mud/waste	2300
010508 non-010504/010505 chloride mud	1800
010599 unspecified drilling mud/waste	1900
020107 wastes from forestry	3
030399 unsp'd wood/paper waste	1
050106*oil ind. oily maint'e sludges	2
050107*oil industry acid tars	130
050199 unspecified oil industry waste	170
050699 coal pyrolysis unsp'd waste	240
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	74
060314 other salt/sol'n MFSU waste	2
060399 unsp'd salt/sol'n MFSU waste	1100
060404*Hg MSFU waste	1
060405*other h. metal MFSU waste	2
060499 unsp'd metallic MFSU waste	19
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	29
060701*halogen electrol. asbestos waste	5
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	<1
060704*halogen pr. acids and sol'ns	27
060799 unsp'd halogen pr. waste	21
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	1200
070111*org. chem. dan. eff. sludge	<1

continued over …..

Table 11 - continued
Gross solid waste in EU format associated with the production of 1 kg of nylon 66 + 30% glass fibre. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

070112 non-070111 effluent sludge	5
070199 unsp'd organic chem. waste	7500
070204*polymer ind. other washes	<1
070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	170
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	1
070214*polymer ind. dan. additives	120
070215 non-0702130 additive waste	<1
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	3400
080199 unspecified paint/varnish waste	<1
100101 non-100104 ash, slag & dust	31000
100102 coal fly ash	280
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	17
100115 non-100115 co-incin'n ash/slag	9
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd themal process waste	1800
100202 unprocessed iron/steel slag	190
100210 iron/steel mill scales	15
100399 unspecified aluminium waste	38
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
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	14
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	6700
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	23
200140 metals	<1
200199 other separately coll. frac'ns	-2300
200301 mixed municipal waste	9
200399 unspecified municipal wastes	-11000
Note: Negative values correspond to consumption of waste e.g. recycling or	