The Facts about PET

What is PET?

history

The abbreviation PET stands for polyethylene terephthalate, a substance that, from a chemical point of view, is a polyester. Polyesters were first manufactured in the 1930's, for use as synthetic fibres. Much of the PET produced today is still used to produce fibre. Fleece sweaters, for example, are made of PET. Later, PET came to be used for packaging films. Film and magnetic tape also use PET film as a carrier. Then, in the 1970's, a production process for PET bottles was finally developed. PET bottles were initially used for soft drinks, but gradually their use with bottled water became more popular.

polyester chemistry

PET is manufactured from terephthalic acid (a dicarboxylic acid) and ethylene glycol (a dialcohol). The two substances react together to form long polymer chains, with water as a by-product (Figure 1). As in most processes of polymerisation, a catalyst is also required.

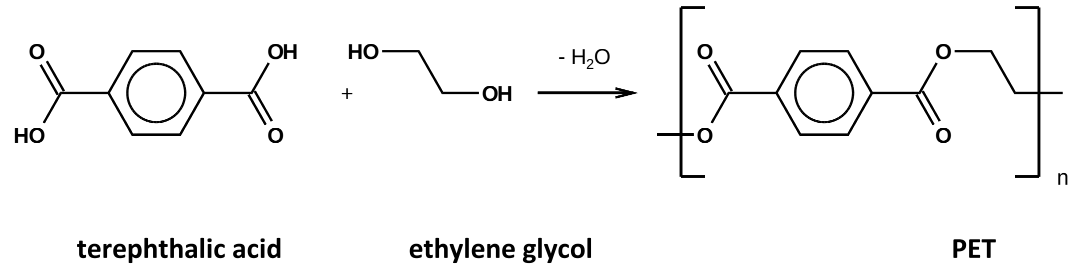

Figure 1: Structure and chemical equation of PET

Why use PET?

colourless

unbreakable

lightweight

PET is a virtually unbreakable, colourless, lightweight, transparent polymer. As PET is transparent, it allows the content of the container to remain visible. The robustness of PET is vitally important for beverage packaging since it makes the bottles completely safe for on-the-go or sports use. PET is also very light. Over recent years, the weight of PET bottles has been constantly reduced and today a bottle can weigh as little as 20 to 30 grams. This process of lightweighting represents a true benefit with regard to the environmental impact a bottle will have during its lifetime: production, transport to the consumer and end of life cycle. With such excellent material properties, PET is widely used today as a packaging material for beverages and is one of the most suitable materials for the packaging of natural mineral and spring water.

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PET as a packaging material

Use of PET in Packaging applications

PET in packaging

PET is used in the packaging sector in the form of films, trays or bottles, its principle use being in bottles. In 2010, almost 70% of all bottled water and soft drinks sold globally was supplied in PET bottles (Figure 2).

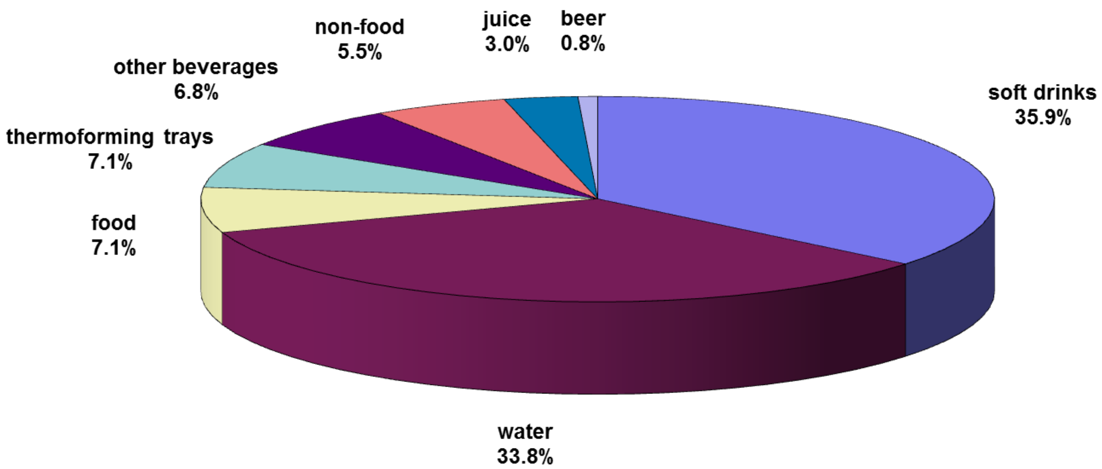

Figure 2: Global uses of PET packaging in 2010 (excluding fibre), amounting to a total of 11.5 million metric tonnes (Source: Pira International)

The manufacturing of PET bottles

manufacturing PET bottles

PET bottles are mainly manufactured in a two-stage process. The PET granulate is first melted at about 280 °C and processed into what are called preforms. These preforms already have the bottle cap threads and are small and easy to transport. Shortly before the filling process, the preforms are again heated to about 120 °C and blown into their final bottle shape. "One stage" process can also be used where the preform goes directly from the injection to the blowing stage. After cooling bottles are filled with the beverage. This "stretch blow-moulding process" causes the PET to partially crystallise, which whilst reducing its transparency, improves the stability of the bottle and enhances its barriers against oxygen and carbon dioxide. Non-crystalline PET is highly transparent while fully crystalline PET is opaque and is used, for example, to make microwave dishes and trays.

The interaction of PET with food and water

migration

Food law compliance

No packaging material is fully inert and so there will always be some kind of interaction with the beverage or foodstuff it contains. In the case of food, a degree of the flavour may be absorbed by PET packaging material. Likewise, some carbon dioxide from carbonated beverages will permeate through the packaging material. In certain instances, there may also be a small degree of migration of components from the plastic packaging into the content. For consumer health protection, all such interaction must be reduced to a minimum. As with all other material in contact with food, PET packaging must comply with all European and national legal requirements. Such requirements include an assessment of

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the initial raw materials employed (i.e., monomers and additives) and of compliance with any restrictions that are established, such as migration limits.

Acetaldehyde

acetaldehyde

Acetaldehyde is a by-product of the PET manufacturing process. It forms when PET is heated to a high temperature to produce bottles. Many beverages and foodstuffs naturally contain acetaldehyde (Table 1). The trace quantities of acetaldehyde that may migrate from PET into bottled water are hence totally harmless, although they could cause the water to have a slightly sweet off-taste. When the concentration exceeds 0.01 to 0.02 mg of acetaldehyde per litre, the consumer is able to taste it and this is something that should, of course, be avoided. PET bottle manufacturers have worked closely with the bottled water companies to optimise the PET bottle production process with a view to minimising levels of acetaldehyde migration.

Foodstuff	Concentration in mg per kg food
Vinegar	20 to 1060
Bread	4.9 to 10.0
Wine, sparkling wine	2.5 to 493
Citrus fruit	1.2 to 230
Orange juice	0.7 to 192
Yoghurt	0.7 to 76
Beer	0.6 to 63
Apple juice	0.2 to 11.8
Natural mineral water in PET bottles (typical value)	<0.01
Taste threshold for acetaldehyde in water	0.01 to 0.02
Limit value in Europe for migration from packaging materials	6

Table 1: Concentration of acetaldehyde in different food stuffs [1]

Monomers (ethylene glycol and terephthalic acid)

ethylene glycol

terephthalic acid

In general terms, the migration of monomers from plastics can never be totally prevented. PET, however, is extremely inert compared to other plastics. Thus, only extremely small quantities of monomers may migrate into bottled water. For example, a study [2] has shown that the level of migration of the monomers ethylene glycol and terephthalic acid from PET bottles is well below statutory limits. Nonetheless, water bottling companies constantly monitor levels of monomer migration from PET bottles

Antimony

antimony

Antimony is the catalyst used to polymerise PET. In principle, the catalyst will remain in the PET after polymerisation. Alternative catalysts have also been developed, mostly based on titanium or germanium. However, to date the alternatives developed have not succeeded in making a major commercial breakthrough and antimony remains by far the dominant catalyst employed by resin suppliers.

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As with all the substances employed in the manufacture of PET, antimony is subject to strict statutory regulations in Europe. The maximum permitted level of antimony migration from a PET bottle into the finished product is 0.04 mg per litre. Under normal storage conditions, the level of antimony migration from PET bottles is extremely low. The limit value for antimony migration from PET packaging may not be exceeded during the indicated shelf life of the beverage [3], even when bottles are stored in warm climates for many months. The concerns stated in newspaper reports are hence unfounded. However, the reports are correct when they point out that the concentration of antimony in packaged water supplied in glass bottles could be lower than that found in packaged water kept in PET bottles.

The limit value for antimony in water is considerably lower than the limit value for migration from PET packaging. In Europe, for example, a maximum of 0.005 mg of antimony may be present in one litre of natural mineral, spring or drinking water at the time of packaging. Even if, from a legal point of view, the migration limit of 0.04 mg per litre is valid for bottled water, natural mineral and spring water companies evidently comply with the lower value established for water, taking it as the maximum acceptable level of antimony.

PET does not contain plasticisers

plasticisers?

Plasticisers are additives employed in various kinds of plastic to alter their properties and make them "softer". Amongst the most commonly used plasticisers, we find phthalic acid ester and adipic acid ester. In the case of polyvinyl chloride (PVC), for example, the use of plasticisers is essential. However, with PET, the aim is for the bottle to be stiff and rigid so that the plastic can be thinner and lighter weight and to facilitate the stacking of packs on pallets. It would, therefore, be a contradiction to use plasticisers in PET. *It can be definitively stated that PET bottles are completely free from any kind of plasticiser.*

phthalates?

The name of one of the products used to make PET, terephthalic acid, does indeed sound very much akin to phthalic acid, the material used as a starter for plasticisers, and this often leads to the mistaken belief that PET contains plasticisers. With respect to the chemistry, plasticisers are small molecules, capable of moving between long polymer chains to thus make plastics softer. In contrast, PET comprises very large, so-called macromolecules.

There is no bisphenol A in PET

bisphenol A?

Bisphenol A is a monomer used in the production of polycarbonate (PC). Bisphenol A and polycarbonate are not, however, used in the manufacture of plastic water bottles, although polycarbonate is used for baby feeding bottles. The properties of polycarbonate make it ideally suited to this application as they can be repeatedly boiled and sterilised, something that would not be possible if they were made of PET. Traces of bisphenol A monomer are known to migrate from polycarbonate baby bottles. Bisphenol A is classified as an endocrine disruptor. There is currently some discussion as to whether or not said levels of migration are significant enough to produce adverse health effects. Exercising due responsibility, legislators have recently banned the use of bisphenol A in polycarbonate baby bottles as a precautionary measure.

Do any endocrine disruptors from PET bottles leach into the water they contain?

endocrine disruptors?

In 2009 it was reported in the media that endocrine disruptors were migrating from PET bottles into natural mineral water. Endocrine disruptors have a similar effect on humans to the naturally produced hormone, estradiol. For this reason, the concentration of such endocrine disruptors is expressed as estradiol-equivalents. It has been alleged that a peak value of 75 ng estradiol-equivalents was detected in natural mineral water contained in PET bottles. The substances responsible for this were, however, never found. The *German Bundesinstitut für Risikobewertung* (Federal Institute for Risk Assessment) immediately

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reported on said allegations and concluded that there was no evidence to indicate that the origin of the endocrine disruptors was the PET bottles [4, 5]. Several subsequent studies by national monitoring laboratories, such as the Swiss Federal Office of Public Health, were unable to confirm the presence of such exceedingly high values, nor find any significant difference between the water contained in glass and PET bottles, or even between bottled and tap water [6,7]. The concentrations found were of the order of 5 pg per litre of natural mineral water, a factor approximately 15,000 lower than the value originally reported (75 ng). Interestingly, even the work group that published the report stating the original high value were later unable to verify it in a follow-up study [8].

In 1999, the WHO Joint FAO/WHO Expert Committee on Food Additives (JECFA) panel set the Acceptable Daily Intake (ADI) value for estradiol at 0.05 µg per kg body weight per day, but as a veterinary drug [10]. On the basis of the abovementioned exposure scenario, the 5 pg estradiol-equivalent limit still remains beneath the recommendation by a factor of 100,000.

Background information on concentrations:

1 mg per litre	0.001 g per litre	parts per million (ppm)
1 µg per litre	0.000,001 g per litre	parts per billion (ppb)
1 ng per litre	0.000,000,001 g per litre	parts per trillion (ppt)
1 pg per litre	0.000,000,000,001 g per litre	parts per quadrillion (ppq)

Recycling of PET bottles

Selective bottle collection

PET is easily identified by its recycling code 01 (Figure 3). In terms of recycling, PET bottles are a special case in all respects. PET bottles represent a large fraction of total packaging waste and are easy to sort automatically. Large quantities of used (post-consumer) bottles are therefore available and can be economically recycled. Over recent years, the number of bottles collected for recycling in Europe has grown significantly. In 2011, some 1,590,000 metric tonnes of used PET bottles were collected and recycled Europe-wide (Figure 4), representing approximately 51% of all the PET bottles in the marketplace. In certain countries, such as Germany, Iceland, Norway and Switzerland, the amount recycled accounted for approximately 90% of the total. Moreover, *PET is 100% recyclable* and can be re-melted and recycled pretty much as often as required. The PET bottle recycling industry has grown into a well-established business over recent years. Used PET bottles can be recycled into fibres and textiles, or processed into new PET bottles. Thus, with recycling, PET forms part of a closed material cycle, significantly reducing the net utilisation of valuable resources such as crude oil.

recollection rates

100% recyclable

Figure 3: PET recycling code

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Selectively collected PET bottles (1000 t)

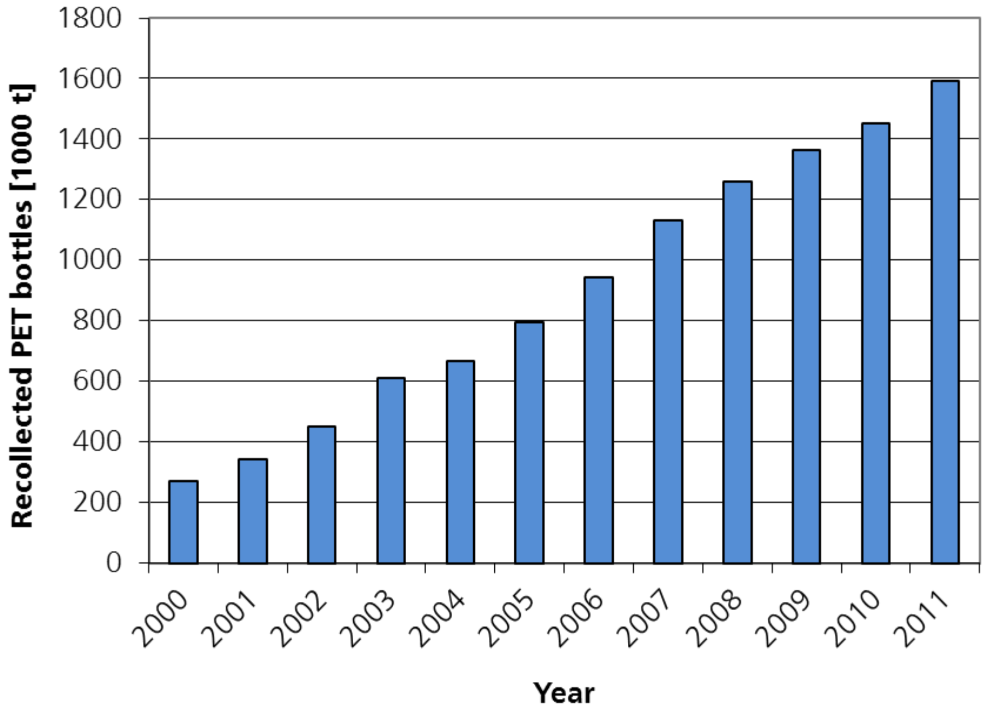

Figure 4: Growth in the amount of used PET bottles selectively collected in Europe (Source: PETCORE)

How PET recycling works

PET recycling

The recycling process first involves removing the labels and closures and shredding the PET bottles. After an intensive wash process, the PET recyclate can again be used as the raw material for high-quality products such as fleece sweaters, sleeping bags and insulating materials. The constant improvement of the recycling processes over recent years has resulted in PET recyclates of such high quality that they can be used to manufacture new PET bottles [11]. Used PET bottles are thus turned into new PET bottles. This requires a so-called "super-clean" recycling process, a process yet to gain full European Food Safety Authority (EFSA) approval. Only recycling companies that employ an effective decontamination process and possess adequate quality assurance procedures are allowed to manufacture the "super-clean" recyclate which, on analysis, should not be distinguishable from virgin PET. Thus PET bottles made from recyclate are as good and "safe" as bottles made from virgin PET. The current amount of recyclate used to make new PET bottles can be up to 50%. Technically, it is entirely feasible to make PET bottles from 100% recyclate.

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Further Information

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