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Assessment of the Environmental Advantages and Drawbacks of Existing and Emerging Polymers Recovery Processes

ANNEXES TO FINAL REPORT

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1. ANNEX 1.1 – POLYMERS IN PACKAGING APPLICATIONS

The packaging sector continues to be the major consumer of plastics, with a stable share in total plastic consumption at just over 37% in 2002 and 2003. In terms of product areas, food packaging is the largest single product area in the whole packaging industry, accounting for more than 50% of total production, and is bound to be the major growth market for plastics packaging[1].

Packaging is relatively short-lived and therefore packaging waste can be assumed to correspond roughly to the amount of packaging put on the market annually. Plastic packaging flowing into the household waste stream has been estimated by several sources to amount for 65-75% by weight of total plastic packaging [2, 3, 4]. The remaining percentage is used as distribution packaging (crates, drums, pallets, wrapping) in industry and goes into the industrial and commercial waste flow.

1.1. MAIN APPLICATIONS OF POLYMERS IN PACKAGING

Plastic packaging materials are used in a wide variety of applications. According to the latest figures by APME, the main polymers used in packaging are PE (HDPE and LDPE), PP, PET, (E)PS and PVC. Used extensively for both domestic and industrial purposes, PE and PP films account for the largest proportion of all plastics packaging types (28%

for films, 46% if bags and sacks are included), closely followed by blow-moulded products (27%) —mostly bottles made of PET and HDPE[5, 6]. PET bottles are a market in expansion nowadays, aiming at glass substitution in many applications [7].

1.1.1. Bottles

One of main plastic packaging applications targeted for recycling from domestic sources are bottles, due to their simple identification, relative high weight, little contamination compared to other plastics packaging and existence of markets for the collected materials[8].

The percentage of materials used in plastic bottles varies among European countries, in relation to consumer habits (for example, the use of HDPE for milk in UK is much higher than in Spain or Italy), although the main three polymers used remains the same:

Table 1. Market share of polymers in bottle applications by countries

%	Italy[9]	UK[9]	Spain[10]
PET	77	44	70
HDPE	22,5	50	29
PVC	1,5	6	0,25

In general, PET occupies an outstanding position, and HDPE is right behind PET in the dairy and non-food market. PP is used in mono- and multi-layer bottles and together with PVC accounts for less than 10% of polymer consumption.

The prioritary position of PET is expected to be consolidated in the following years. Some sources report a growth of 14% in Western Europe during 2000-2001 period, in comparison with the positive 3.5% of PE and the 14% decrease of PVC[11]. Amcor[12] expects a yearly growth of 7.7% between 2004 - 2007 in the PET bottle consumption, while ANEP expects even higher increase[13] . However, HDPE is strong in the non-food segment (detergents, toiletries…) and present good perspective in daily packaging in the food segment (milk, juices…). Further details in the analysis of each polymer.

The figures below show the general trend (reported and prospective evolution) of the beverage packaging material. The clear strong position of PET is also supported by the presence of refillable PET/PEN, leaving other packaging material in their historical sector and overtaking many of their applications. The development of new barrier materials (mono and multi-layer that avoid) gas exchange enable the penetration and growth in new markets (for example beer) and traditional markets (like soft drinks).

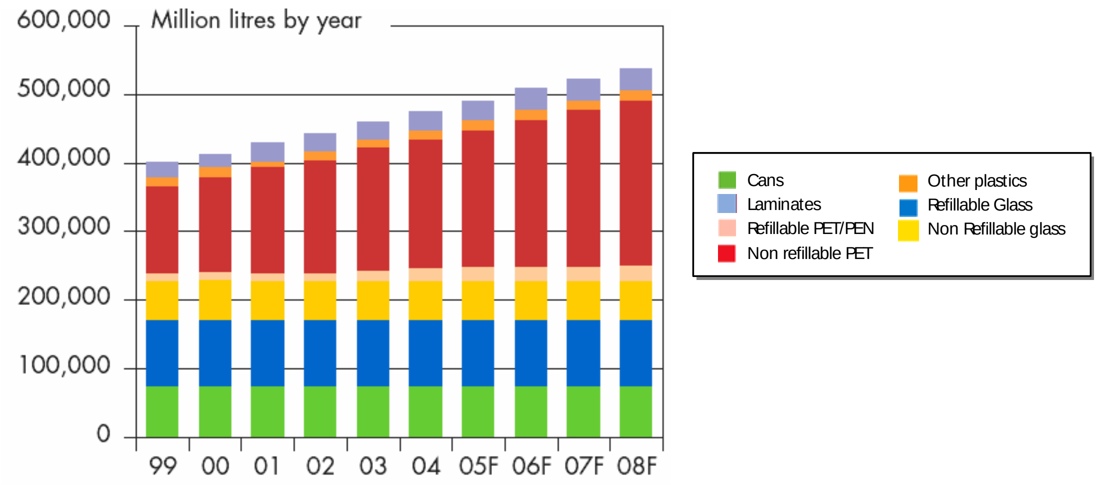
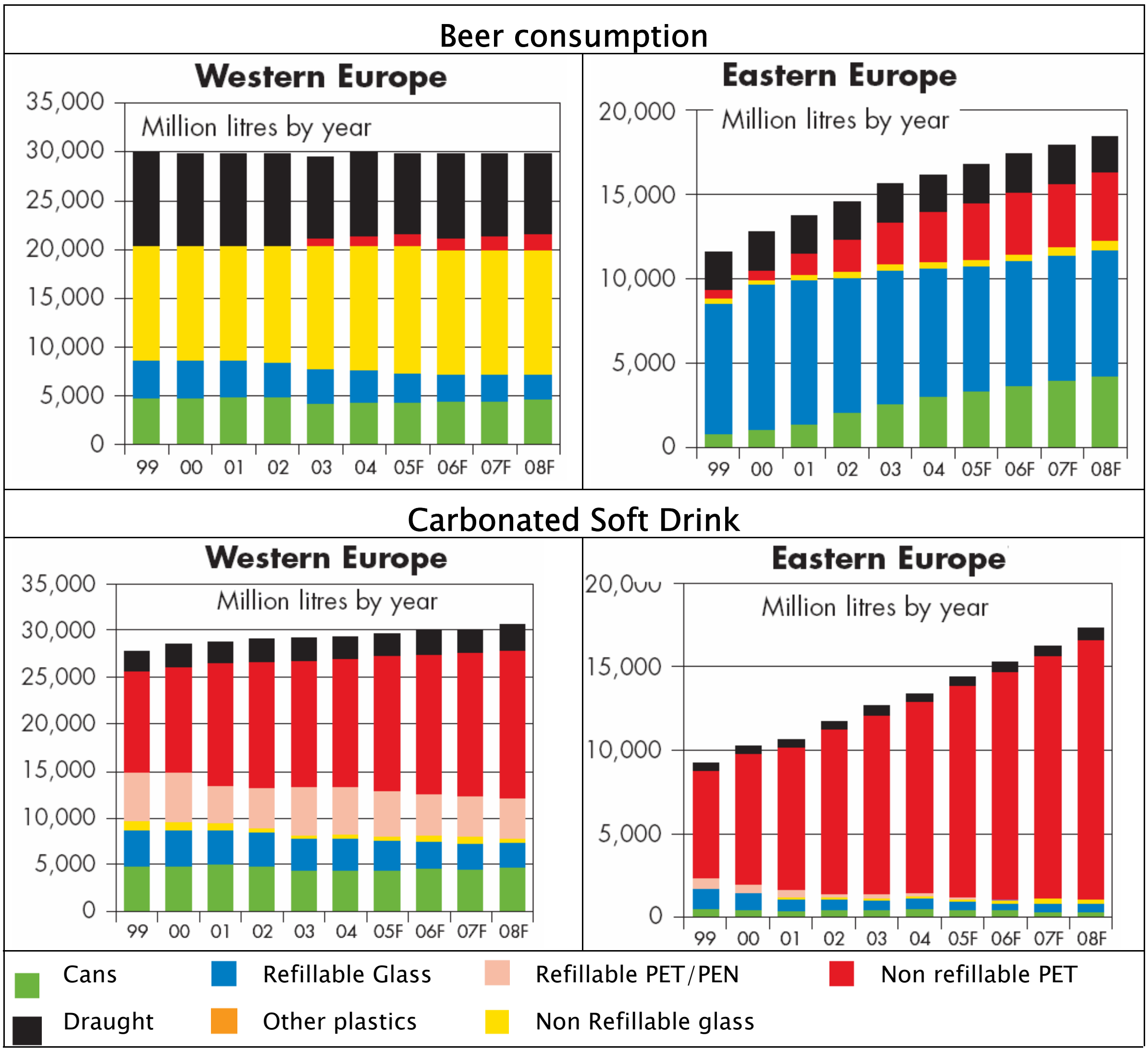


Figure 1. Global beverage packaging mix, consumption (Source Rexam[14])

Beer packaging differs from region to region. Recyclable packaging such as beverage cans and glass is very popular in the USA and continues to lead the world in this category. Refillable packaging is still a major market segment in Eastern Europe and South America. Refillable glass was substituted at a relatively early stage by recyclable glass bottles and cans in the USA. It is expected that other countries will reduce their dependence on refillables over the longer term[14].

Tests have been undertaken by some of the major brewers, who have been looking at selling beer in a variety of PET and PEN bottles. In Western Europe, 1% of beer is now sold in plastic bottles, as a percentage of the total filled beer volume. However, the percentage is higher in some developing markets, such as Russia[14].



Note:Eastern Europe considers Bulgaria, Czech Republic, Poland, Romania, Russia, Serbia & Montenegro and Turkey

Figure 2. Beverage packaging evolution and prospective for Beer and Carbonated Soft Drinks (source: Rexam) [14].

In Western Europe, the carbonated soft drink pack mix has stabilised after a period of transition, but still shows a continues increase of PET. During the last 15 years, glass has been largely replaced by plastic, while beverage cans have maintained their share. Plastic continues to dominate in Eastern Europe, where the market shows exceptional growth.

1.1.2. Closures

Nearly 400 billion closures were manufactured in Western Europe in 2004 and plastics accounted for nearly 40% (nearly 158 billion units). Over the next five years the production of plastic caps and closures is expected to grow on average by 5.6% per year, while that for metal will decline by nearly 3% per year. As a result plastic closures will account for nearly half of the market by 2009[15] .

66% of plastic closures were used for beverages in 2004. Beverage closures can be sub-divided into standard (one or two-pieces) and custom closures. The major trend in this sector is the move from two-piece to one-piece closures, driven by the replacement of glass bottles by PET. The market for standard beverage closures is forecast to grow by 6.2% per year to 2009. Custom beverage closures in contrast are forecast to show growth nearly double this, driven by developments in sports tops and carton mechanisms.

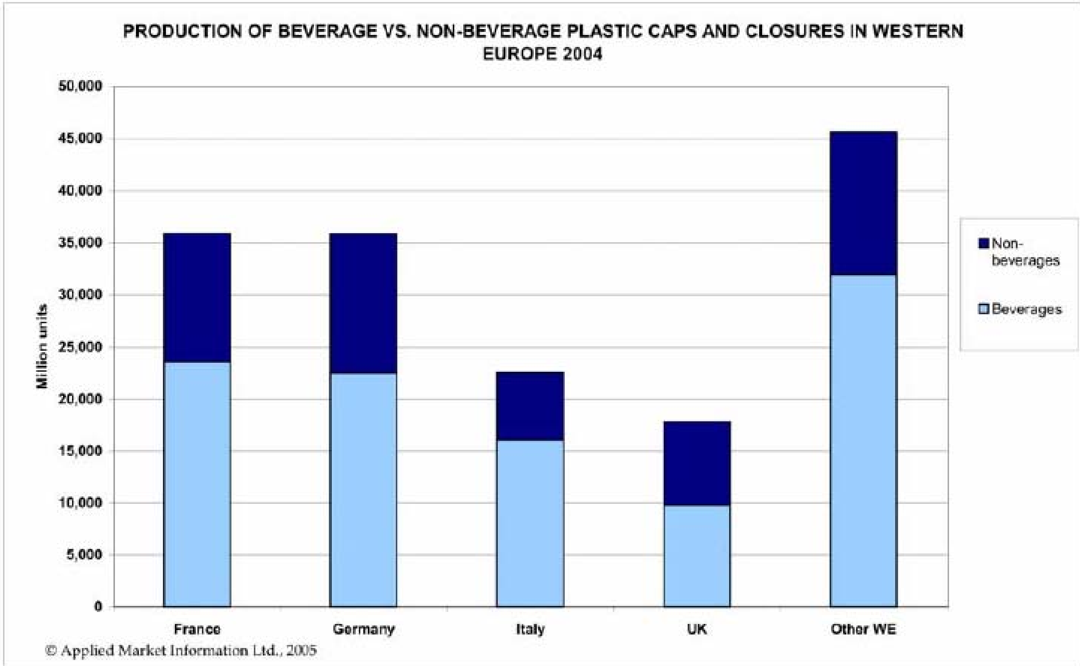


Figure 3. Production of beverage *vs* non-beverage plastic caps and closures in Western Europe 2004. (Source: Applied Market Information Ltd.[15])

In non-beverage applications the market is seen as stable showing little future growth. The main applications are in packaging for toiletries and cosmetics, household chemicals and liquid food (milk, etc).

In terms of the polymer materials used, polypropylene and polyethylene are the main types. Polymer consumption is forecast to grow at a lower rate than that for unit growth, at 2.9% per year, reflecting the fact that unit growth will be higher for beverage closures which use smaller, lighter closures. As polyethylene finds greater use in beverage closures, this will result in stronger growth for this material compared with PP. Demand for polyethylene is forecast to grow by over 4% per year to 2009, while PP use will increase by 2% per year to 2009 driven mainly by developments in carton openings.

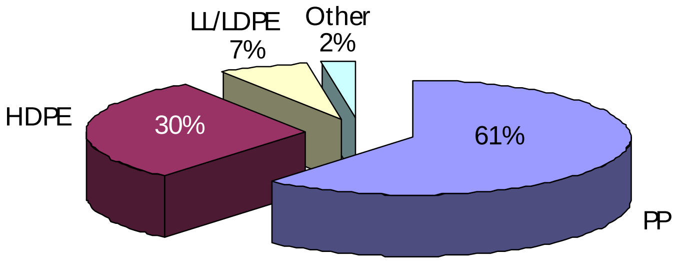


Figure 4. Polymer distribution in closure applications (Source AMI 2005[15])

1.1.3. Films

22% of the total plastic used in packaging is used in film applications (excluding bags and sacks. Films are dominated by PE, with minor contribution of PP and PVC, as shown in the figure bellow:

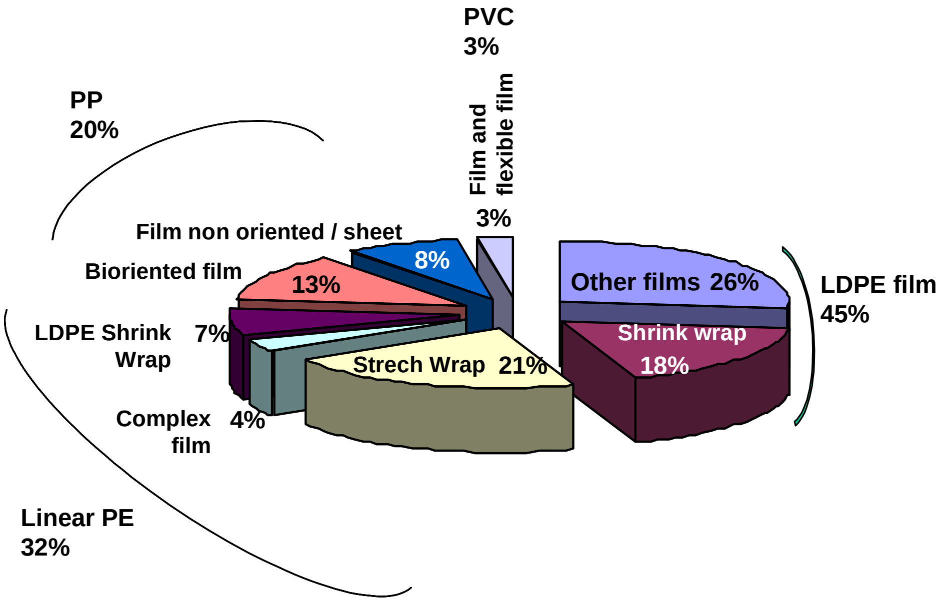


Figure 5. Films (excluding bags and sacks)[10]

In addition to LDPE and LLDPE, high density polyethylene (HDPE) resins are commonly used in film plastics, when higher rigidity is necessary. Some specific film applications are separately analyzed bellow, in order to assess their specific situation and evolution.

- BAGS AND SACKS

According to Spanish[10] data on plastic application in packaging, bags and sacks amount for the third largest group of uses, dominated by PE, with a small presence of PP.

One of the most discussed issues in this film application is the use of plastic carrier bag. In fact, Australia reports that plastic carrier bags amount for around 2,5% of the total plastic used in the country[16], while in the UK they constitute 24% of the plastic generated in household waste[8]

Table 2. Polymers used in bag and sacks applications

Application	Polymer	Share, %
Bags and sacks		18.8
	LDPE	5.95
	HDPE	8.76
	LLDPE	4.07
Garbage bags		1.99
	LDPE	0.79
	HDPE	0.86
	LLDPE	0.34
Other LDPE		1.22
Other PP		1.86

There are 2 main types of disposable plastic bags[17] .

- Disposable high-density polyethylene (HDPE) bags, which offer the consumer lightweight, waterproof, high strength means of carrying shopping. They come both branded and unbranded. These types of bags are favoured supermarkets and other food retail outlets

- Low-density polyethylene (LDPE) bags are stronger and less lightweight and tend to be used by retailers selling higher value goods, particularly department and clothing stores. They are normally branded.

Over recent years there has been an increase in availability of reusable low-density polythene (LDPE) bags, often referred to as ‘bags for life’[17]. There are also non-woven polypropylene bags, which are strong and durable, intended to be used many times, and suitable for everyday shopping. Woven polypropylene uses a strengthening technique to form ‘fibres’, resulting in a stronger bag. Woven polypropylene bags are used, for example, for pet food.

The evolution of this application will have a significant influence on the global plastic waste generation.

- LIDS

Lidding is now a well-established growth area for a wide variety of flexible packaged products. In particular, barrier lidding is finding new applications in the packaging of foods, medical supplies, cosmetics and healthcare products. Materials used for lidding vary, but generally speaking a combination of aluminium foil, paper and plastic films is used. In heat sealing applications Polyester (PET), Nylon (OPA), Polypropylene (OPP) and aluminium foil are the main materials used[18].

In modified atmosphere packaging (MAP) or controlled air packaged (CAP) foods, where extended shelf life is required, a wide range of barrier-layered PET/PE and OPP/PE films are regarded as the optimal solution. Both barrier-layered PET/PE and OPP/PE lidding films have been found to provide greater mechanical protection for packaged food products. This protection provides the product with stability, with regard to the gas mixture composition of the package as well as the taste and appearance of the product. Food quality and the weight of the packaged food product are also maintained by means of barrier-layered lidding materials.

A major growth area for all lidding materials is in dairy food packaging, particularly items such as yoghurts and chilled dairy desserts. In Western Europe, this market is said to be growing at around 2.5% per annum, but in some Eastern European countries, growth rates are much higher. Aluminium foil is slowly losing its historically dominant position in this market to plastic film and paper-based alternatives. In the case of multi-pack lidding, polyester (PET) film and film-based materials are the dominant feature in metallised and barrier lidding configurations. The market for multipack lidding materials is forecast to grow in Europe by 5% a year to 2006. Some 70% of the market is accounted for by paper/metallised PET[18].

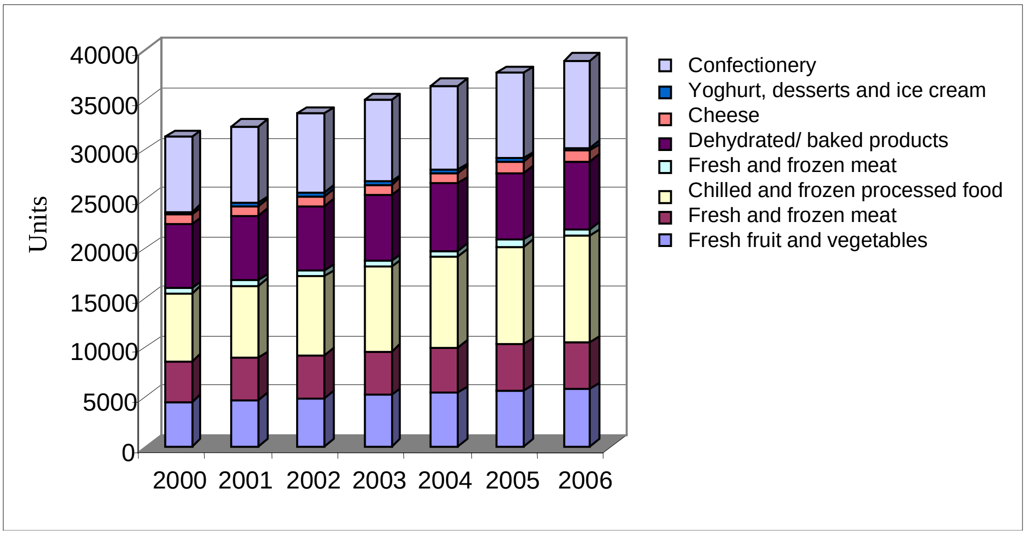


Figure 6. Western European usage of wrapping/lidding films in key food and beverage market segments 2000-2006 (million units)[18]

- COLLATION SHRINK-FLIMS

Shrink films are used mainly for the collation and transportation of non-alcoholic beverages in plastic bottles, cans and cartons, where they are successfully replacing cardboard. In addition to increased visual impact through high quality graphics, this trend is particularly attributable to the ability to master pattern deformation during film shrinking[19] .

In line with the growth dynamics of both non-alcoholic beverages and plastic bottles, the annual growth rate of collation shrink film is predicted at 3.2%. However, the European consumption of shrink films shows some clear geographical disparities. France and Italy are leading consumers with an average consumption per inhabitant in excess of 0.4 kg, followed by Spain, Belgium and the UK with around 0.3 kg. Germany, with less than 0.2 kg/inhabitant made a clear choice through its regulations for returnable bottles using rigid transit boxes.

1.1.4. Trays

Trays, mainly for food products, constitute an important application and waste source, which includes a wide variety of polymers. The following table summarises the main materials used in food trays and their applications.

Table 3. Main materials used in food trays and their applications[20]

Application	Materials used
Microwaveable ready meals	PP, C-PET, Board
Ovenable ready meals	C-PET, Smooth wall foil, Crinkle wall foil, Board
Salads	A-PET, PVC
Vegetables	PP, Smooth wall foil, Crinkle wall foil
Desserts	A-PET, PVC
Puddings	PP, C-PET
Dairy products	PP, PS
Confectionery	PVC, PS
Fish	Smooth wall foil, PP, PVC, A-PET
Meat	A-PET, PVC, Smooth wall foil
Soup	PP, A-PET

Applications like packaging trays for chilled and frozen meals are of rising importance, due to the changing European behaviour patterns, which involve a high variation over different countries. The continuous evolution of the sector is leading the industry towards the development of enhanced materials for keeping food properties and providing easy use (e.g. better ovenable materials).

A study conducted by PIRA and the University of Brighton identify the following main packaging materials for chilled and frozen trays[21]: The figure summarises the market share of this materials and their expected evolution.

- Crystalline polyethylene terephtalate (CPET) tray
- Polypropylene (PP) trays
- Other plastic containers
- Aluminium foil containers
- Dual ovenable board containers

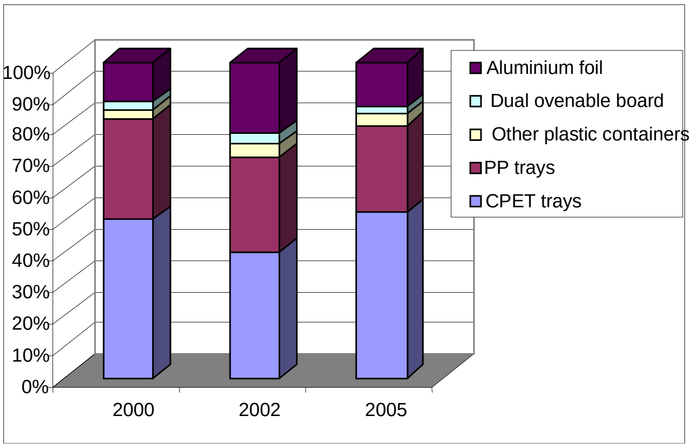


Figure 7. Materials for chilled and frozen food trays (Source: Sturges et al. [21]).

According to the findings of the mentioned study, the UK consumes the greatest number of chilled ready meals in Europe, accounting for approximately 44% of total European consumption. France is the second biggest consumer, accounting for around 26% of total European consumption, with Germany accounting for a further 6%. Italy and Spain account for less than 5% each, whilst the rest EU-15 countries combined account for the remaining 16%. All countries show growth in the chilled ready meals sub-category, with particularly strong growth in UK and France.

Germany consumes the greatest number of frozen ready meals in Europe, representing approximately 40% of total European consumption. The UK is the second biggest consumer, accounting for around 18% of total European consumption, with France and Spain constituting a further 13% and 7% respectively. Italy makes up less than 5%, whilst the other EU-15 countries combined account for the remaining 19%. Overall, the market is fairly static, with a slight increase in Germany and a slight decline predicted for the UK.

In the UK, the major growth in chilled ready meals is in plastic packaging materials (CPET trays, PP trays and other plastics), while aluminium trays and dual ovenable board trays are showing a decline. Frozen ready meal sales show a slight decline, but within the frozen ready meals market plastic packaging materials (CPET trays, PP trays and other plastics) are gaining market share at the expense of aluminium trays and dual ovenable board.

Similar trends are witnessed in other EU countries although in some cases the specific packaging mixes are significantly different. For example, in France there is much greater usage of aluminium trays, especially in the chilled ready meals segment. In Italy and Spain PP and other plastics packaging hold a much greater share of the market in comparison to CPET than in the UK or Germany.

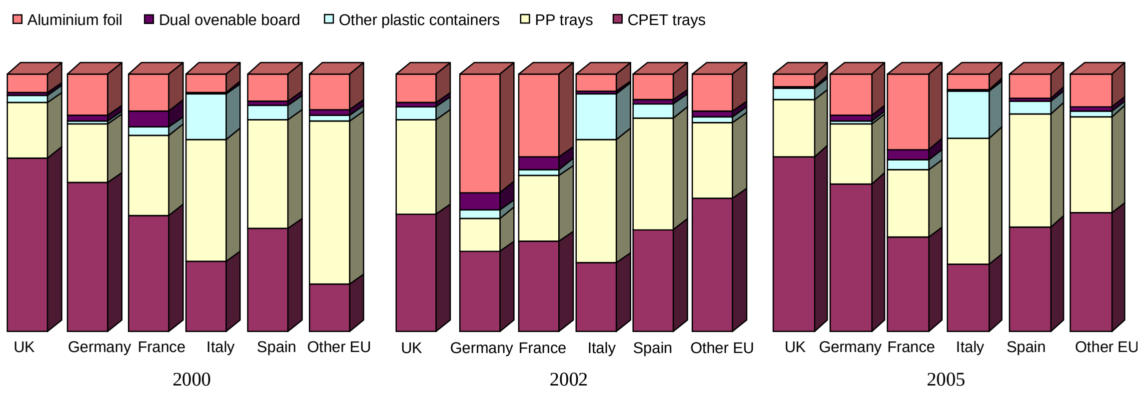


Figure 8. Evolution of trays used in several EU countries (Source: Sturges et al[21]).

In general, the study concludes that the market for frozen ready meals is rather static, with a slight decline predicted for the near future. Aluminium foil trays and dual ovenable board fair worst, with CPET trays and other plastic containers slightly increasing in tonnage terms as they gain market share from aluminium and board trays.

1.2. MOST COMMON POLYMERS IN PACKAGING WASTE

1.2.1. Plastic resins in packaging: LDPE

LDPE is the main polymer used in packaging applications. As shown in the figure, the use of LDPE in bottles is limited. The main application of this material is focused in plastic bags (including retail carry bags, where it is dominant) and shrink/stretch wrap.

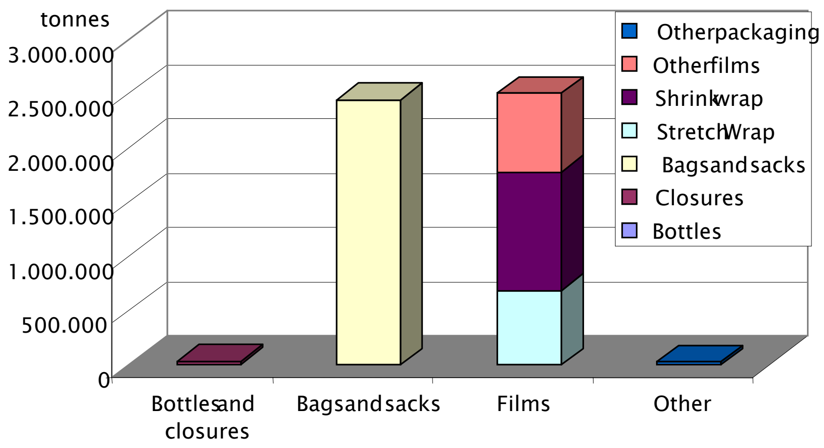


Figure 9. Packaging applications of LDPE in Spain[10]

The US LLDPE market is expected to grow above the average rate for polyethylene, driven by the film sector. A similar trend can be expected for the European market. In general, a market of around 480,000 tonnes of stretch wrap film is estimated in Europe, with some and 9 percent growth each year[22] .

LLDPE is replacing conventional low density polyethylene (LDPE), or is used in blends with LDPE, due to its lower prices, improved properties and technological advances. Growth is occurring from the transition of items presently packaged in rigid containers to high quality flexible packages[23], but main growth areas are high clarity packaging, high barrier thin films and active' packaging that increases shelf life and enhances flavours. In the dairy industry, for example, LDPE gaining market in multi-layer applications, where aluminium foil and multi-pack PET and paper-based alternatives dominate. The Figure 10 (A) shows a lid where the outer layer is paper, which is bound to the aluminium foil/LDPE laminate. In the Figure 10 (B) the PET and LDPE lidding layers combine to form an effective lid for the PP cup[18].

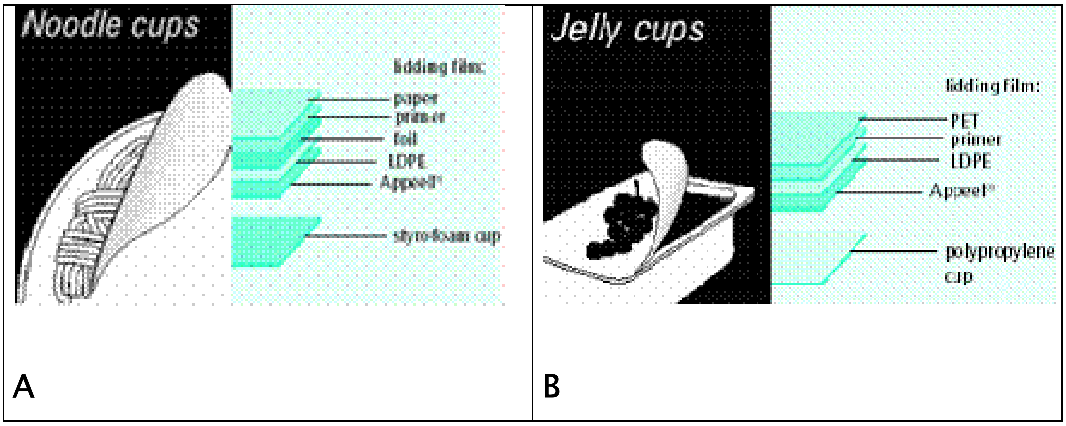


Figure 10. Examples of multi-layer film applications[18]

Although not highly relevant in mass (around 2% of total LDPE in packaging), this market poses an important problem for recycling. The market for multipack lidding materials is forecast to grow in Europe by 5% a year to 2006. Some 70% of the market is accounted for paper/metallised PET[18].

Higher tech so-called metallocene-based LLDPE resins are penetrating the film and packaging markets due to their enhanced physical properties. A clear increase is expected in Western European consumption (from 350,000 tonnes in 2002 to 483,000 tonnes), destined mainly to stretch wrap film for food packaging applications. At the same time, West European LDPE consumption has slightly fallen from the 4.9 million tonnes in 2003[24].

All in all, a compound annual growth of 6.6% is estimated for LLDPE consumption in the European market for the period 2000-2005, with a -1.3% rate for LDPE for the same period[25].

Table 4. Impacts associated to generated LDPE packaging waste

		%	TONNES	Total calorific value, GJ/t	Total CO_2 , equivalent tonne	Total Energy content, GJ/t
LDPE bottle		0.22	9,622	427,253	19,342	772,712
Closures		4.08	102,607	1,917,977	86,827	3,468,774
Bags and sacks		41.23	1,803,402	80,071,071	3,624,839	144,813,221
Films	Stretch Wrap	15.67	685,406	30,432,056	1,377,667	55,038,156
	Shrink wrap	25.03	1,094,813	48,609,724	2,200,575	87,913,532
	Other films	16.23	709,901	31,519,609	1,426,901	57,005,059
Other		0.99	43,198	4,556,764	308,848	8,239,367

No toxic additives or additional materials posing relevant recyclability or hazardous problems in the end of life phase have been reported.

1.2.2. Plastic resins in packaging: HDPE

The main market for virgin HDPE is in blow moulded products, typically used for consumer packaging. This sector represents about half of the total HDPE consumed in the UK[26].

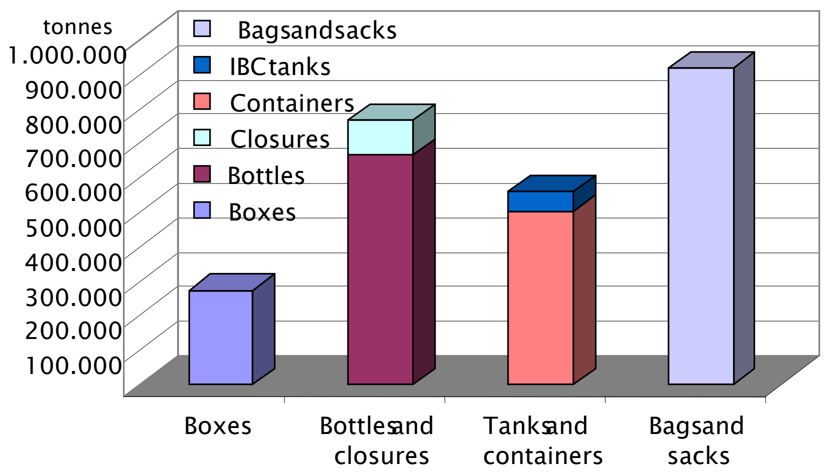


Figure 11. Main applications of HDPE in packaging (Source ANAIP[10])

In bottling, HDPE represents the second most applied polymer. It is estimated that during 2000/01 the market of HDPE bottles in UK was 430,000 tonnes and 300,000 showed in household[26]. HDPE bottles have been traditionally used for packaging liquids such as detergents, cosmetics, lubricants and dairy products (where is right behind PET in the market share)[27]. HDPE bottles have also positively benefited from the expansion of the drinking yoghurt category, while rising sales in sauces is thanks to their "squeezable" attribute. Overall, rigid plastic packaging rose by 28.7% in food over 1998-2002. Developments in the design of HDPE bottles include multi-layer structures with oxygen barrier resins, such as ethylene vinyl alcohol (EVOH), which allows foodstuffs to have an extended shelf life.

Colour is a key factor of the HDPE bottle and container recycling, since it has clear influence on the value of the secondary material obtained. It is difficult to estimate the ratio of dark/clear HDPE bottles in the market, although it can be assumed that water bottles are mainly transparent, juices, milk and dairy products are packaged in cloudy-white bottles, and most cleaning toiletry products use dark coloured bottles.

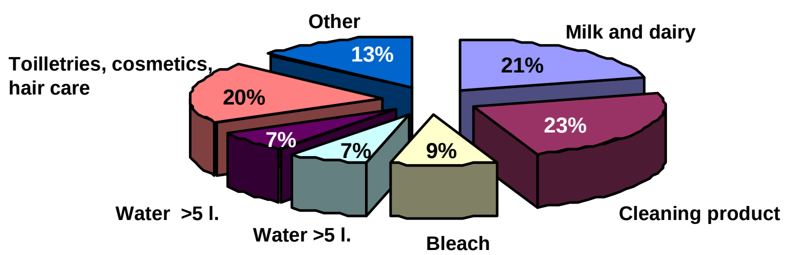


Figure 12. Main application of HDPE bottles (Data from ANAIP[10] and TNO 2000[8]).

In different studies carried out the ratios listed in Table 5 have been reported from HDPE bottles in household waste. For the purpose of this study, an average ratio of 57 natural /42 pigmented has been considered.

Table 5. HDPE coloured bottle ratio in domestic waste

	USA in waste	UK in waste
	APC 2000	MEL (2002) and RECOUP (2002)
Natural	55.84 %	58.68 %
Pigment	44.16 %	41.32 %

Another key issue for recycling HDPE bottles is the contamination with other materials, where labels and caps play a significant role. Caps are injection moulded, using predominantly polypropylene (PP). While the bottles therefore contain two distinct polymers, being polyolefins, they can be recycled as one. As there is not the same contamination risk with creams and shampoos as with drinks and foods, seals tend not to be used. In this sense, studies carried out in Spanish waste HDPE bottle samples have identified the following closure composition[28]

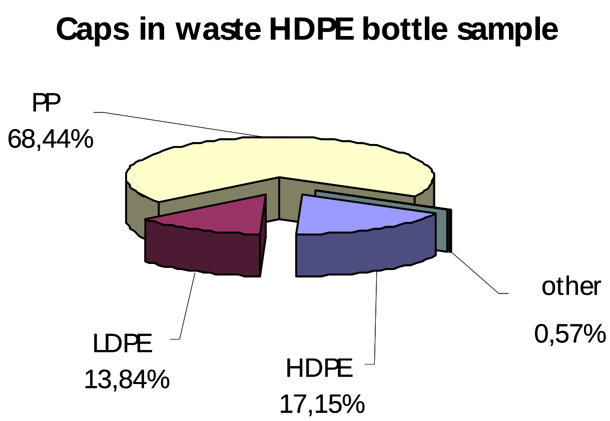


Figure 13. Types of caps in HDPE bottle fraction (Source:GAIKER[28])

The second largest market is for extruded HDPE film and for pipe and conduit manufacture. Combined, these uses represent about a third of the total UK demand for HDPE. While the market for HDPE film has decreased in recent years, it is still a significant consumer of HDPE in the UK[26]. HDPE film is used when higher rigidity is necessary, either in film shape or in bags and sacks, from commercial to industrial use.

Table 6. Impacts associated to generated HDPE packaging waste

		%	TONNES	Total calorific value, GJ/t	Total CO_2 equivalent tonne	Total Energy content GJ/t
Boxes		10.83	272,562	11,502,136	493,338	21,723,228
Bottles	Clear bottles	15.12	380,530	16,058,383	688,760	30,328,274
	Coloured bottles	11.,29	284,139	11,990,684	514,292	22,645,913
Closures		4.08	102,607	4,330,028	288,327	8,280,410
Containers		19.95	502,089	21,188,145	908,781	40,016,472
	Tanks / IBC containers	2.25	56,627	2,389,640	102,494	4,513,136
Bags and sacks		36.48	918,181	38,747,222	1,661,907	73,178,995

No toxic additives or additional materials posing relevant reciclability or hazardous problems in the end of life phase have been reported.

1.2.3. Plastic resins in packaging: PP

Polypropylene is the most widely used plastics material for rigid-type food packaging, with the exception of beverage bottles, where PET is the leader, and milk bottles, where the plastic type is usually HDPE[29].

The major forms of polypropylene packaging and examples of food types for which they are used are:

- Pots/containers: yoghurt, desserts, margarine, cottage cheese, soups, sauces, chilled salads, pot noodles (microwave heating)
- Cast film bags: bread, filled baguettes
- OPP film bags/wraps: crisps, wide range of snacks, muesli, peanuts and other nuts, biscuits, confectionery, spices, pasta, rice, sugar, porridge, bakery products
- OPP film over wraps with food on trays/in cartons: fresh and chilled fruit and vegetables, cooked meats, pasties, bakery products, tea
- Multilayer lidding films: controlled atmosphere packs for food products such as meat and fish
- Film pouches: sauces, dried and liquid soups, cooked meats

- Bottles with barrier resins: sauces
- Bottle caps and closures: soft drinks, cider, mineral waters, oils
- Paperboard/polypropylene (PP) laminates: dairy products, ready meals (microwave heating)

Films are produced as either cast or biaxially oriented OPP films. The gas barrier (oxygen and carbon dioxide) and UV protection of OPP films can be improved with coatings and multilayer structures, for example in heat-sealing applications. In modified atmosphere packaging (MAP) or controlled air packaged (CAP) foods, where extended shelf life is required, a wide range of barrier-layered lids are also used (e.g. OPP/PE films).

Metallised (aluminium) surface treatments or by lamination with aluminium foils. Coated and laminated films are used in the form of bags or pouches, as sealed wrapping, as overwraps with the food product on plastic trays, in cardboard containers or as lidding on containers. Polypropylene is coated or laminated onto paperboard for containers and disposable items for direct consumption of foods and beverages.

OPP films also are used as bottle labels, because unlike paper, they eliminate mould growth, do not easily rip, have good abrasion resistance and do not come off bottles when chilled in iced water.

Polypropylene pots and containers are either produced by injection moulding or by thermoforming processes. PP pots are widely used in dairy industry (for example for yoghurt), where the market share PP/PS may be estimated 16/84[30]. However, due to its good resistance to oils and fats, is now the principal plastic type used for margarine tubs.

On the other hand, PP trays are also applied in many other food packaging applications, amounting for the 28% of the market share for trays for chilled and frozen food market, for example[20].

The relatively high melting point of polypropylene means that the plastic, either in the form of containers or as coated board, can be used for microwave heating/cooking of foods such as ready meals.

Bottles are produced by the blow moulding process. However, as mentioned in section 1.1.1, the total bottle market is dominated by PET and HDPE, and PP has very low market share.

When bottles, containers and trays require improved gas barrier properties, for example those used for sauces and ready-meals, they are made as a multilayer structure with a barrier resin, typically EVOH, as a core layer sandwiched between polypropylene layers[29].

Polypropylene and the co-polymer plastics also find extensive use for caps and closures for bottles, pots and containers[29]. In this market PP is the dominant material (around 61% of the total closure in European market). However, total polymer consumption in this field is forecast to grow at a lower rate than that for unit growth, at 2.9% per year, reflecting the fact that unit growth will be higher for beverage closures which use smaller, lighter closures. As polyethylene finds greater use in beverage closures, this will result in stronger growth for this material compared with PP. Demand for polyethylene is forecast to grow by over 4% per year to 2009, while PP use will increase by 2% per year to 2009 driven mainly by developments in carton openings[31].

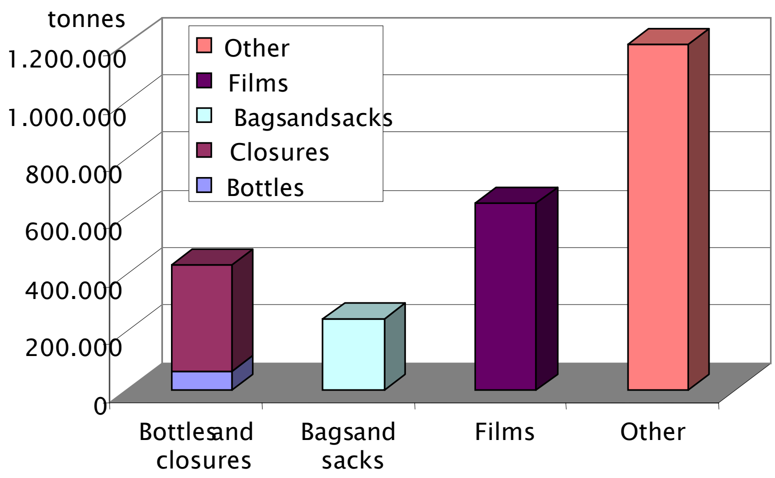


Figure 14. Main packaging applications of PP

In recent years polypropylene has replaced other plastics in a number of applications. A typical replacement is for regenerated cellulose films (cellophane) for wrapping confectionery. Both the “crinkle” and dead-twist properties of cellophane can now be reproduced with polypropylene films[29].

Recycling PP poses certain difficulties, mainly due to the high diversity of types and grades of polypropylene. Moreover, it is hard to separate polypropylene from other plastics in packaging, and studies have shown that used polypropylene parts that are gathered and sorted centrally by trained personnel can still contain up to 10% foreign material[32].

Table 7. Impacts associated to generated PP packaging waste

	%	TONNES	Total calorific value, GJ/t	Total CO_2, equivalent tonne	Total Energy content, GJ/t
Bottles	2.63	66,544	2,728,308	127,765	5,123,896
Closures	14.59	369,155	15,135,367	708,778	28,424,958
Film	25.59	647,477	26,546,542	1,243,155	49,855,702
Bags and sacks	9.88	249,983	10,249,310	479,968	19,248,704
Other packaging	47.31	1,197,035	49,078,426	2,298,307	92,171,678

1.2.4. Plastic resins in packaging: PET

This is the fourth main polymer in packaging applications, with a clear growing evolution, due to its consolidation in conventional applications and the opening of new markets.

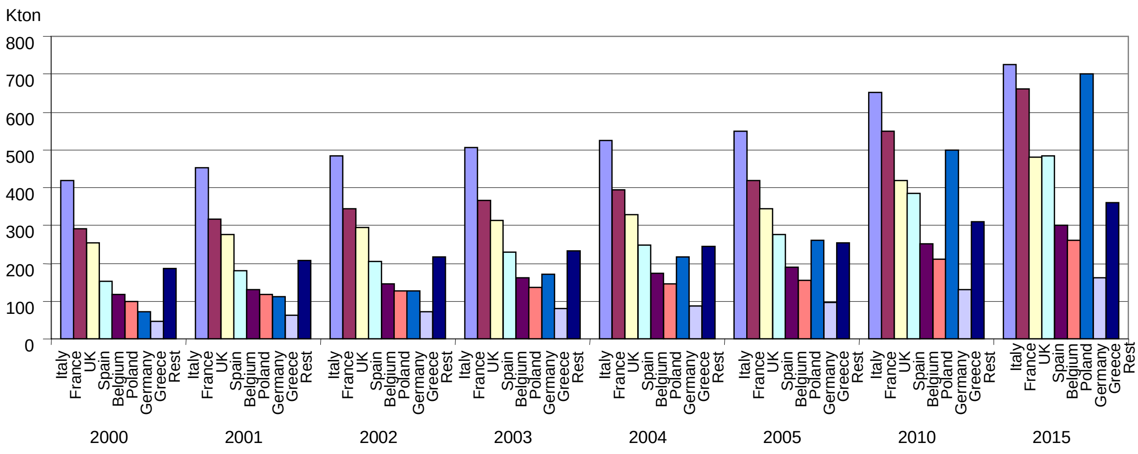


Figure 15. Evolution of consumption of PET in packaging in EU countries (Source: Sturges et al.[21])

Table 8 lists the main applications of PET in food packaging. The Table 9 offers a more detailed overview of the applications consolidated nowadays and the ones that are being implemented at the moment, where further growth can be expected.

Table 8. Main applications of PET in packaging (Source: ILSI[33])

PET Product	Applications
Bottles	Beverages, soft drinks, fruit juices, and mineral waters. Especially suitable for carbonated drinks. Cooking and salad oils, sauces and dressings.
Wide mouth jars and tubs	Jams, preserves, fruits and dried foods
Trays	Pre-cooked meals for re-heating in either microwave or conventional ovens, pasta dishes, meats and vegetables
Films and metallised foils	Boil in bag' pre-cooked meals, snack foods, nuts, sweets, long life confectionery, ice creams, and spreads
Coatings	Microwave susceptors
PET products with added oxygen barrier	Beer, vacuum packed dairy products e.g. cheese, processed meats, 'Bag in Box' wines, condiments, coffee, cakes, syrups,

Table 9. Evolution of PET markets (Source: ANEP[13])

Sector	Size (Vol.), L	Material substituted	Situation
Soft drinks	0,2-2,0	Glass, can	Consolidated
Mineral water	0,2-2,0	Glass PVC,HDPE	
Oil (food)	0,5-5,0	PVC, HDPE, glass	
Vinegar	1	PVC, HDPE, glass	
Spirits	0,1-0,5	glass	
Chemicals	1,0-5,0	glass, aluminium	

Cleaning products	1,0-1,5	PVC,HDPE	
Sauces	0,3-0,5	Glass, HDPE	Implementing
Cosmetic	0,3-1,0	HDPE, PVC	
Pharmacy	0,3-0,5	Glass	
Nuts	0,3-1,0	Glass	
Pre-cooked		Ceramics	
Prepared food		PS	
Beer	0,5-1,5	Glass	
Fruits		LDPE,PS,PVC	
Juices	0,5-1,5	Glass, cardboard	
Dairy	0,3-1,5	PS, cardboard	

The quantitative evaluation of the PET packaging shown in Figure 16 reflects the clear dominance of its use in bottles (where substitutes glass, being lighter and much less breakable), while films amount for the lowest ratio.

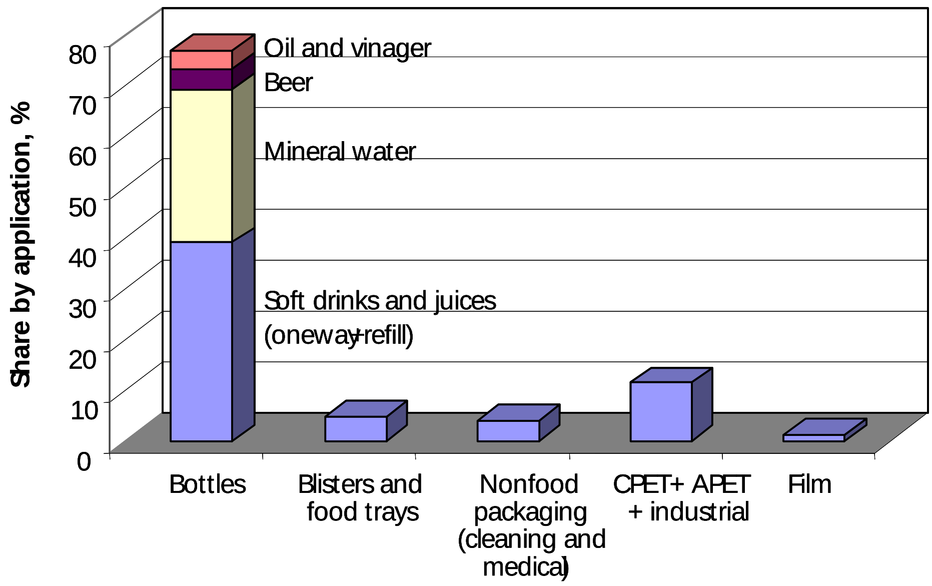


Figure 16. Consumption of PET by packaging application (Source: ANEP estimations for 2005[13], completed with data from AMCOR[12] and ANAIP[10])

The use of PET for bottling water is a consolidated market. Most of the PET for these bottles in Europe is consumed in countries such as Italy, United Kingdom, France and Spain, where the PET bottles are mainly one-way (single use) bottles. This is in contrast to other countries such as The Netherlands, Scandinavia, Germany, Austria and Switzerland, where PET-bottles are used in refillable delivery systems, in some cases in combination with a one-way system[9].

The largest application however is in soft-drink and juice market (AMCOR estimates even larger bottle use for carbonated soft drinks than ANEP or ANAIP, reaching the 42% of total PET use in packaging), which is also growing due to the incorporation of new barrier materials (mono-and multi-layer) that enable longer “shelf-life”, limiting the gas exchange. Beer is also becoming a growing market, where PET barrier is finding a clear application, with a market growing trend, as shown in the following figure.

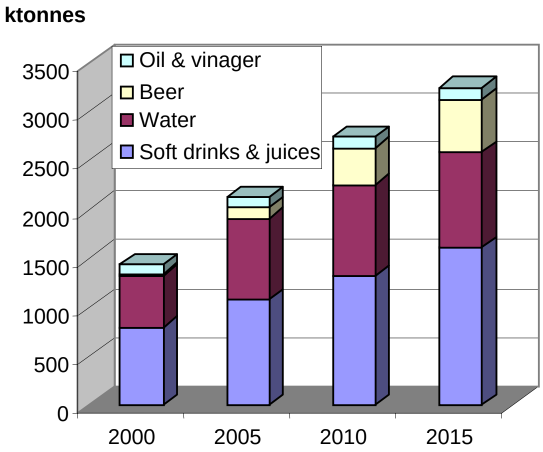
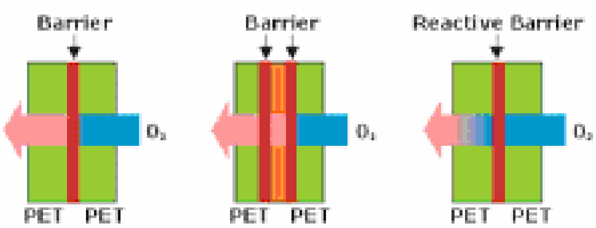


Figure 17. Markets for PET bottles (Source: ANEP[13])

In general, it can be stated that approximately 5% of Europe’s PET consumption is now multilayer bottles with this expected to increase as the level of hot-fill applications rise e.g.: beer and juices . Around 62% of PET barrier bottles worldwide are multilayer while 25% are monolayer and 13% use coatings, according to the mentioned joint research[34].

The wide variety of barrier technologies developed is increasing the concentration on additional materials in the PET bottle flow. The table below illustrates main multi-layer technologies.

Table 10. Barrier technologies in PET packaging

Multilayer technology	Co-extruded or co-injected forms of PET and other polymers.  3 layers (left), 5 layers (centre), multi-layer structure with reactive layer(right)[35]
Barrier coating	Aerosol coating (Bairocade from PPG, spray coat from SIPA, MicroCoating Technologies)
	Deposition by chemical vapour (Actis from Sidel, Plasma Nano Shield from Kirin, Glaskin from Tetra Pak', BestPET from Krones, Vapor Phase Plasma from Dow , HiCoTec from Schott)
Monolayer	PEN and other applications like Blend Amosorb DFC/PET.
Technology combination	Blend Amosorb DFC/PET & coating

On the other hand, as mentioned in section 1.2.2, bottle colour is also a key factor that affects the value of the recycled fraction, and in this sense, the growth of plastic bottles for beer comprise a visible increase of brown coloured bottles. However, coated bottles are not expected to reach more than 12.5% market penetration[36].

The information on the ratio clear/coloured PET bottles varies among countries and end of life schemes, since this information is compiled mainly in the collected flow. In general, it is estimated that PET bottles are about 70 percent clear and 30 percent coloured However, it must also be stated that the growing use of PET barrier in beer packaging will also affect this balance, since usually they are brown/grew coloured bottles. The following table illustrates some data:

Table 11. PET coloured bottle ratio in domestic waste

	Germany 2001[37]	UK 2002[8]	UK [38]
Clear	70	82	71
Colour	30	17	29

Barrier materials are not only used in bottles, but also in other applications, for example as lidding films. Although not so significant in quantitative terms, this is a growing market where PET film and film-based materials are the dominant feature, making aluminium foil lose its historically dominant position in this market. The market for multipack lidding materials is forecast to grow in Europe by 5% a year to 2006. Some 70% of the market is accounted for by paper/metallised PET[18].

Although bottle manufacturing is the main application of PET in packaging, its use in food trays for vegetable, salads, and chilled/frozen food is also relevant. Depending on the purpose, different PET types are currently used, as shown in Table 12.

Table 12. PET in food trays

PET type	Application
A-PET	Salads, Desserts, Fish, Meat
C-PET	Precooked chilled and frozen food: Microwaveable ready meals, Ovenable ready meals

Particularly the market of pre-cooked food shows the widest development, following the evolution of food consumption habits in Europe. The stability of Crystalline PET (C-PET) at high temperatures is consolidating this resin in the pre-cooked frozen and chilled food, as shown in the figure below.

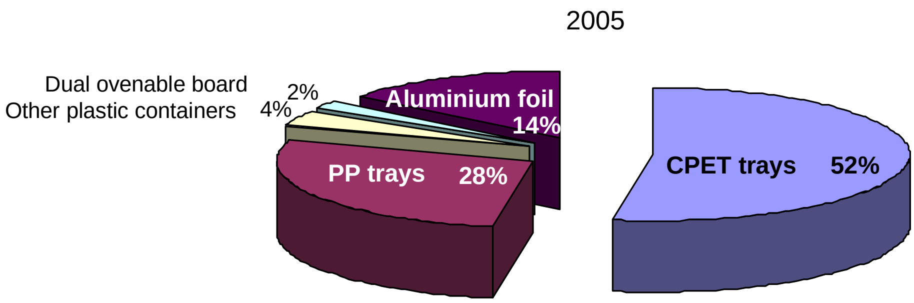


Figure 18. Food trays market share by materials.

Although consumption habits affecting PET packaging are nowadays very different all over Europe, it can be estimated that around 58.5 tonnes of CPET are generated annually.

Regarding the contaminants present in PET bottles, in general it can be seen that the desired properties for packaging applications are attained from the intrinsic properties of PET polymer. Therefore additives such as antioxidants, plasticizers, heat or UV stabilisers are not required. Colorants in low concentrations (usually less than 500 ppm) are used for some PET commercial grades and, like catalysts, become encapsulated or incorporated as part of the polymer chain. They are added at either the resin or pack manufacturing stage and possess extremely low extractability (ILSI, 2000[33]). Therefore, for the purpose of this study, no additive has been considered to pose special hazard or recycling problems.

However, the growing use of multilayer PET is an issue that should be considered specially, because of its end of life implications. Table 14 compile available information about barrier PET shares in several applications.

Table 13. Impacts associated to generated PET packaging waste

		%	TONNES	Total calorific value, GJ/t	Total CO_2 equivalent tonnes	Total Energy content GJ/t
Bottles	Clear bottles	49.35	989.622	45.324.693	4.344.441	76.596.753
	Coloured bottles	21.15	424.124	19.424.869	1.861.903	32.827.180
	Barrier brown bottles	4.10	82.218	3.765.577	360.936	6.363.661
	Other barrier bottles	0.90	18.048	826.590	79.230	1.396.901
CPET + APET trays		7.00	140.372	6.429.035	616.233	10.864.788
Film + barrier film		1.13	22.660	1.037.830	134.827	2.447.284
Other packaging		16.37	328.270	15.034.756	1.441.104	25.408.082

Table 14. Estimated contaminants in PET due to barrier technologies.

Application		Contaminants
Bottles	Clear bottles	
	Coloured bottles	
	Multilayer brown bottles	62% of PET barrier bottles worldwide are multilayer while 25% are monolayer and 13% use coatings.
	Other multilayer bottles	
CPET trays		Usually coloured
APET trays		
Film		Metallised and coated with paper. (0.01% of yoghurt lidding)
Other packaging		

1.2.5. Plastic resins in packaging: PS

For the purpose of the study, a clear division among EPS and other PS has been made, since EPS presents an specific end-of-life scenario with marked differences.

Crystal polystyrene is used as a packaging material where the “crystal clear” properties can be utilised to advantage. These are containers for a variety of foods and as disposable “plastic glasses” for beverages.

Biaxially oriented polystyrene films in thin gauges are used for food packaging carton windows. They have also been used as “breathable” films for over-wrapping fresh produce, such as lettuce. Thicker gauges are used to manufacture clear vending cups, and tubs for desserts and preserves, using the thermoforming process.

HIPS (high impact polyestirene) is used in the form of pots for dairy products, such as yoghurts, as vending cups for beverages such as coffee, tea, chocolate and also soup, and in the form of “clams” for eggs. Some pots and containers have multilayer structures, which often consist of a layer of HIPS sandwiched between layers of crystal polystyrene. The crystal polystyrene layers provide “barrier” properties between the HIPS and the food or beverage, and an attractive “glossy” external appearance. Other multilayer composites contain layers with barrier resins such as ethylene vinyl alcohol (EVOH) and polyesters (PET/PETG).

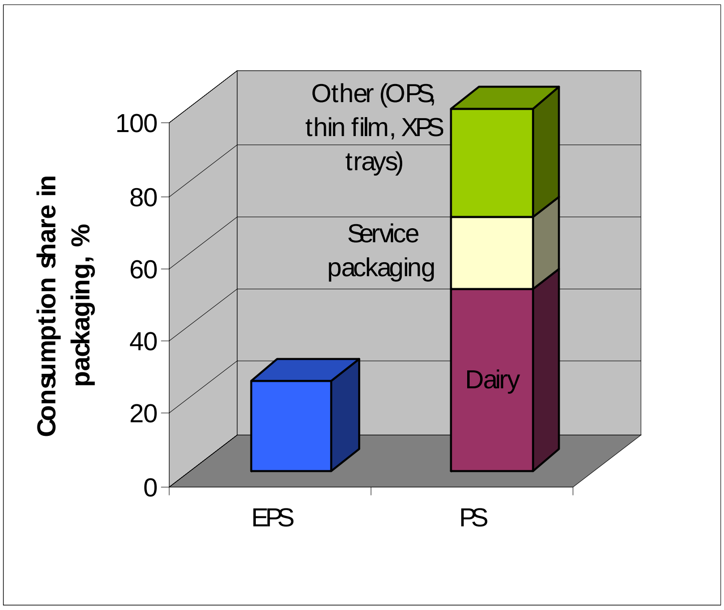


Figure 19. PS consumption in packaging applications (Source: RECOUP[39] , Basf[40] , Sofres 2000[41])

In recent years, polypropylene (PP) plastics have replaced HIPS plastics in some of the above mentioned uses, but for some types of food packaging, the reverse has occurred due to advantages of ease of processing and low shrinkage provided by polystyrene

Expanded polyestirene, 25% of total PS packaging[40, 41], is used for protection packaging for food contact (meat, poultry, fish, fruit and vegetables; “clamshell” containers for eggs, and fast-foods, and disposable cups for beverages). Some foamed polystyrene trays, cups and containers have surface layers of crystal polystyrene which provide a “barrier” layer between the plastic and the foodstuff.

EPS contaminated with organic materials (such as waste fish crates) poses a larger problem in the recycling process, although still technically feasible. Many EPS recyclers co not accept dirty EPS, and in the case of fish crates the process must be adapted to deal with the extra moisture, which can be up to 40 per cent of the total compacted weight[42].

Based on the data from Spanish situation (extrapolated to the EU-25 considering actual consumption patterns) a waste generation of approximately 67,000 tonnes of EPS fish crates can be estimated . Other products may also pose similar problems to the packaging material, but they have not been considered within the study due to the difficulty of estimating global amounts.

Table 15. Impacts associated to generated PS packaging waste

	%	TONNES	Total calorific value, GJ/t	Total CO_2 equivalent tonne	Total Energy content GJ/t

EPS		25.0	285,993	14,299,634	746,441	23,880,388
PS	Dairy	37.5	428,989	21,449,450	1,548,650	36,249,571
	Service packaging	15.0	171,596	8,579,780	791,056	14,671,424
	Other (OPS, thin film, XPS trays)	22.5	257,393	12,869,670	1,443,977	22,264,530

Polystyrene plastics and HIPS are manufactured with various “additives” which include antioxidants, colorants, mould release agents and processing aids. Antioxidants, such as pentaerythritol tetrakis [3-(3,5-di-tert-butyl-4-hydroxphenyl)propionate], are usually present at concentrations well below 1% and are typically at around the 0.1% level. A common mould release agent is zinc stearate, added at the low level of about 0.05%. White mineral oils are used as processing aids and flow promoters with levels ranging from 0.5 to 6% by weight, with an average of about 2%. White mineral oils are not used in foamed polystyrene plastics[43].

For the purpose of this study no toxic additives or additional materials have been considered, since no relevant problems reciclability or hazardousness in the end of life phase have been reported.

1.2.6. Plastic resins in packaging: PVC

PVC has very low representation in packaging applications, and it continues decreasing. Main applications in the packaging sector are films, bottles and sheet. PVC sheet has seen its use decline in this sector but is still widely used in blister packaging for medical, pharmaceutical and non-food applications[44]. In general a decrease of PVC packaging has been clear in all applications: PVC bottles showed a descent of 65% between 1995 and 2001[45]

Table 16. PVC main applications in packaging (Source: ILSI[46])

Product Type	Application/Food Types
Thermoformed sheet and foil	Blister packs/display trays for a wide range of fresh foodstuffs, including meats, vegetables and sandwich containers. Tamper evident packaging.
Bottles	Fruit squash, mineral water and cooking oils.
Cling and stretch film	Supermarket stretch film. Household catering film. Particularly suitable for meats.
Cap seals	Canned and bottled food.
Hose and tubing	Transport of soft drinks and beers, etc.
Closures and can linings	Inner lining to coat metal cans and as seals for a range of foodstuffs.

Table 17. Impacts associated to generated PVC packaging waste

	%	TONNES	Total calorific value, GJ/t	Total CO_2 , equivalent tonne	Total Energy content, GJ/t
PVC films	23	95,959	3,262,604	175,605	5,968,647
PVC bottles	19	79,270	2,695,195	145,065	4,930,621
Closures	3	12,516	425,557	22,905	778,519
Other	55	229,467	7,801,880	419,925	14,272,851

The drop in PVC use in packaging has been strongly associated to the potential effects of chlorine in the end-of-life of the products and mainly to the presence of additives and their possible migration in food-contact applications.

All PVC formulations contain at least the PVC polymer, a stabiliser and a lubricant. Depending on the application aimed at, different other additives are included in the formulation. Such additives could be plasticizers, fillers, pigments, flame and smoke retardants etc.

As an average approximation, the following content in specific additives can be assumed:

- Organotins: 0.1-0.2%4
- Calcium/Zinc compounds: Ca (0.1%) and Zn (<0.1%)

- DEHP (0.2 %) and DOM (0.5%)[47]

2. ANNEX 1.2 – POLYMERS IN ELECTRIC AND ELECTRONIC EQUIPMENT

Little information exists about the actual amount and composition of collected WEEE plastics in Europe as such. Information can be found however about overall polymer consumption in the electronic sector and detailed material composition from specific equipments as provided by manufacturers and, occasionally, recyclers.

From the data reported by the national WEEE collective systems it can be concluded that just three (ICT equipment, large household appliances and consumer electronics) out of the ten WEEE categories covered by the Directive 2002/96/EC account for almost 90% of selectively collected WEEE plastic.

Therefore, main polymers in currently collected WEEE plastic will be PS and ABS from inner shelving and liner of cold appliances; ABS, PC/ABS and HIPS from CE and ICT equipment, such as TV sets and computers (especially monitors) and mobile phones; and PU from large household appliances insulation. Epoxy resins used as substrate in PWB are also another polymer recurrently found in most collected WEEE, although in minor quantities. The PP, highly consumed for small household appliances casings, is regularly lost in the residual MSW stream and only the PP due to parts in washing machines and dishwashers is currently recoverable from separately collected WEEE. Those polymers are in most cases flame retarded or use other additives that may contain substances of special concern in legislation (WEEE and RoHS Directives).

2.1. CONSTRUCTION OF WASTE SCENARIOS

Following this, the hypothetical plastic WEEE scenarios in 2005 and 2015 can be worked out by estimating the evolution in quantities and composition of the electronic plastic waste from the changes in volume and composition of the main items discarded (EOL items responsible for the biggest shares of WEEE plastic on a weight basis), using replacement sales as an indicator of the amount of equipment ready to be disposed of.

In the case of E&E equipment, disposal is likely to be affected by a number of factors, some related to the equipment itself (e.g. length of working life) and some to consumer behaviour.

The average life span for E&E equipment is 8-10 years according to APME data[48], with high variations among equipments within the different electr(on)ic categories: Large household appliances like refrigerators and washing machines can run smoothly for up to 15 years and longer. TV sets and radios for anything between 5 and 15 years. Life span of small household appliances is 5 to 10 years, as fixed network phones and fax machines. IT and communication equipment, like computers or mobile phones, are as a rule obsolete after one to four years[49].

But does exist also consumer's reluctance to dispose of immediately phased out equipment and, thus, old mobile phones, audio equipment, watches and toys are treasured up in the households for years, even if they are no longer working. Having this in mind, the current WEEE plastic scenario might be roughly estimated from the available 1990, 1995 and 2000 polymer consumption data.

In the forecast of 2015 WEEE plastic composition should be firstly contemplated that electronics are a growing part (on unit basis) of the total waste, especially ICT and consumer electronic categories, with their average life span falling below 3 years. The development and obsolescence rate of other electr(on)ic categories constituting major consumers of plastic, such as large household appliances, is not foreseen to boost at the same pace, since they are a saturated market, although there is a general observed trend of decreasing durability, repairability and upgradability of E&E goods, which may explain shorter life spans in the future.

Secondly, changes in composition of existing equipment (substitution of traditional materials —e.g. metals— by plastics, shift to alternative polymers) and polymer composition of new E&E equipments entering the market can explain variations in the WEEE plastic composition between current and future collected stream.

Finally, an influence from recycling legislation can be foreseen, mainly in the substitution of hazardous substances (e.g. BFR in plastics and foaming agents in PU insulation).

Table 18. Estimated year of manufacture of E&E becoming waste in the current and future scenarios

WEEE item	2005 Waste	2015 Waste
LHH appliance (15 years)	1990	2000
SHH appliance (5-7 years)	1998-2000	2008
CE – TV (10 years)	1995	2005
ICT - mobile*	2000-2004	2010-
ICT - PCs*	1998-2000	2010-

** EOL kept stored in households for years before disposal*

Next a region sensitive analysis by main E&E categories in collected WEEE is presented, focusing on the sales volume of typical equipments, the composition evolution over the years and design trends that might affect the polymer recovery from the collected WEEE. Stress on additives has been made. The case studies evaluated have been

- Cold appliances and washing machines (Large household appliances)
- TVs (Consumer electronics)
- Computers and mobile phones (ICT equipment)
- Mixed Small household appliances
- Printed circuit boards (PWBs) present in most E&E discarded equipment

2.1.1. Large household appliances. Cold and washing appliances

50 million large appliances and 200 million small appliances are sold in average in Europe, every year[50]. It is estimated that 188 million large appliances older than 10 years are still in use today in EU-25 European households. The Figure 20 below shows the differences in annual sales volume of various large household appliances in three states of the EU-25 and exemplifies the steady-state models of growth in consumption of most white goods (with typical peak campaigns in refrigeration equipment linked to warmer years).

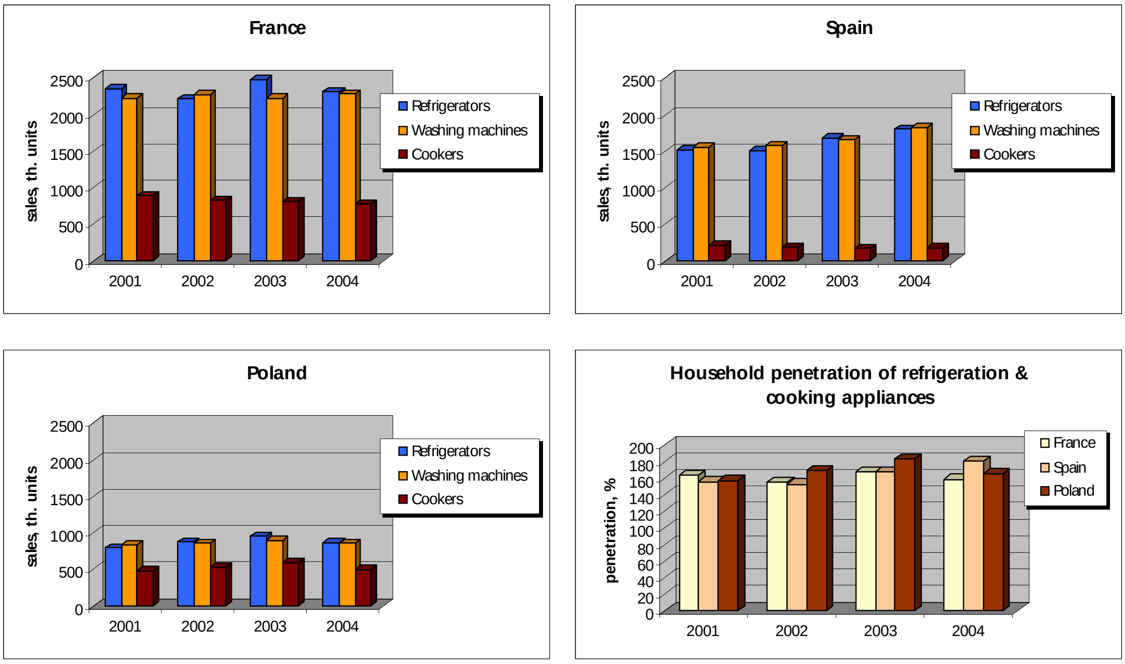


Figure 20. Evolution of annual sales of large household appliances in France, Spain and Poland. (Source: GIFAM[51], ANFEL[52] and GfK[53])

❑ COOLING APPLIANCES

Around 20 million cold appliances (freezers and refrigerators) were sold in the EU last year. The refrigerators market is a saturated market with an ownership rate of 106% for refrigerators, which is assumed to be unchanged in the future, and 52% for freezers in 2005 (48% in 1995), according to CECED Stock Model (see Figure 21). Market penetration level for the main Central Eastern European markets are assumed to be similar to EU-15, as confirmed by some sources that report that 98% of households have refrigerator in Poland, that there are 152.2

refrigerators and freezers per 100 households in Czech Republic and that in Hungary white goods consumption is “replacement” purchases.

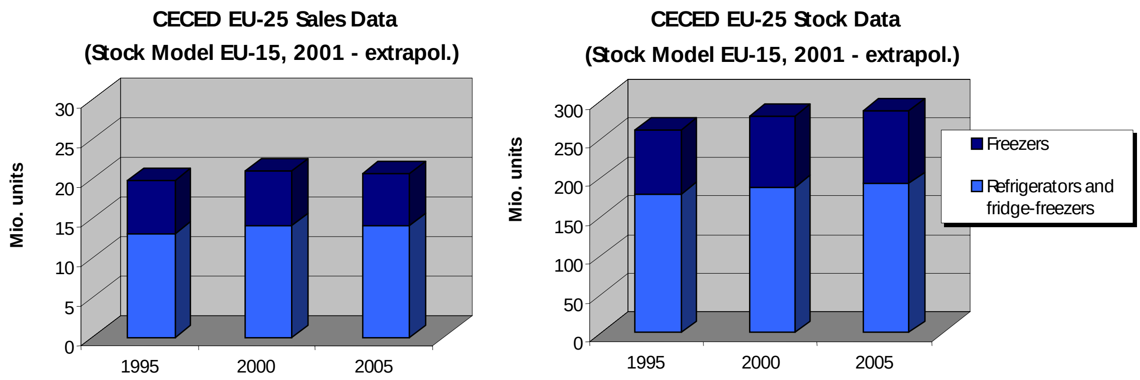


Figure 21. Estimated stock and sales data of refrigerators and freezers in the UE-25 (Source: CECED)

Assuming an average lifespan of 15 years and market saturated conditions, annual sales of refrigeration equipment can be proximated to maximum potential waste (maximum volume of replaced items). Knowing the average equipment weight and the plastic content of the generation of refrigerators discarded, the tonnes of collectable plastic from that source can then be estimated.

Main points in available waste plastic from discarded cooling appliances are the evolution across the years in polymers content and the presence of blowing agents and refrigerants in the foamed insulation materials.

Annex II of Directive WEEE requires certain substances are removed from any separately collected WEEE and treated in a certain way. Among those the following are cited: Chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC). Annex II(2) further explains how to treat the gases mentioned in Annex II: " [...] equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 2037/2000 of the European Parliament and of the Council of 29 June 2000 on substances that deplete the ozone layer."

In the 1990s the chlorinated gases CFC and HCFC were phased out as they were found to be ozone depleting (Regulation 2037/2000). As an alternative, manufacturers moved to use HFC (for instance, R134a) and HC (isobutane, R600a, and propane are used as refrigerants in the cooling circuit; cyclopentane —sometimes in combination with other HCs— is used as blowing agent in the foam for the insulation of the walls of refrigerators and freezers)[54]. The conversion from CFC-11 to cyclopentane foam and the refrigerant type replacement have also meant that lower amounts of the new refrigerant and blowing agents are needed for achieving similar or even higher efficiency[55].

Neither HFC nor HC are gases that deplete the ozone. A relevant ozone depletion potential only occurs when cold appliances including CFCs (i.e. appliances which are manufactured before 1993) are replaced. Ozone-depleting gases such as CFCs and HCFCs (e.g. R11 —or CFC11— and R12) have to be treated in accordance with Regulation 2037/2000 (i.e. these gases have to be extracted and handled properly).

Hydrocarbons used in refrigerators, freezers and air conditioners have a global warming potential below 15. In effect, the specification of the directive Annex II(2) exempts hydrocarbons from the recycling requirements, notably extraction and treatment. HFCs used for refrigerators and freezers need to be extracted and handled properly as their global warming potential is above 15.

Table 19. Composition data of typical cold appliances of 1990's and 2000's. (Source: aggregated data from manufacturers[50, 56, 57, 58])

Typical Cold Appliance	Manuf. Date: 1990	Manuf. Date: 2000
Estimated sales, Mio. units	20	21
Av. Equipment weight, kg	50	60
% PU foam (insulation)	9	10
% other plastics (mainly PS and ABS, 50:50)	12	18
% Foaming agent amount (type)	0.417 (R11)	0.327 (Pentane)

% Refrigerant amount (type)	0.177 (R12)	0.061 (R600a)

- WET APPLIANCES

Washing machines constitute almost a saturated market, whilst dishwashers show still a growing penetration (in fact they are one of the domestic products which have a strongly growing ownership level in the EU market). Nowadays 2 out of 3 sales are dishwasher replacement in the EU-15, where household saturation (over 40%) is twice as much as in the early 90's. The dishwasher household penetration in the new EU member states is still low (under 5%) and their contribution to the total volume of discarded domestic dishwashers is negligible[59]. Washing machines penetration in households from 2003 Accession Countries is closer to the average of EU-15[60]. Annual sales of washing machines (17.8 million units sold in Europe in 1998 according to EU sources[61]) can be roughly considered as replacement sales.

The plastic content in both appliances has grown; in the case of dishwashers from 7% in the early 90's to 24% in 2004 models[59] and it has doubled for washing machines (9% in 1990 models[62] and 18% currently[63]). The rise is due mainly to the replacement of steel parts by reinforced PP. For instance, in the current generation of washing machines in the European appliance market, approximately two-thirds of washing machines produced use plastic (Carboran, PP 20-40% filler) for the washing machine tub, and the number is expected to grow[64].

Table 20. Composition data of typical washing appliances of 1990's and 2000's. (Source: VHK[59], Öko-Institut[63], The Product-Life Institute Geneva[62])

Average Washing Machine	Manuf. Date: 1990	Manuf. Date: 2000
Estimated replacement sales, Mio. units	16	18
Av. Equipment weight, kg	75	75
% PP	1	13*
% other plastics	7 (PS + PVC >3)	5.5 (ABS + EPDM)
Average Dishwasher	**Manuf. Date: 1990**	**Manuf. Date: 2000**
Estimated replacement sales, Mio. units	1.5	3.5
Av. Equipment weight, kg	62	58
% PP	1	15
% other plastics (mainly PVC, (E)PS, ABS)	5.5	8.5

**Carboran (PC) 40% is used instead of PP 20-40% in some segment models as steel substitute.*

2.1.2. Consumer electronics. TVs

The entire market of Consumer Electronics in the EU-25 is in the phase of growth. The growing trend of sales value of Consumer Electronics should persist in the following years and will be generated mainly by expected exchange of CRT TV-sets for LCD TV-sets, of DVD players for new generation DVD players and increased sales of MP3 players.

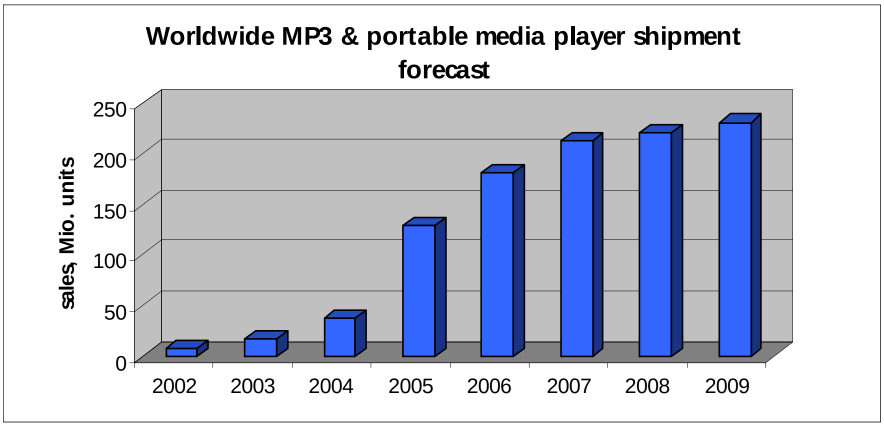


Figure 22. Outlooks for MP3 and portable media player worldwide shipments (Source: iSuppli[65])

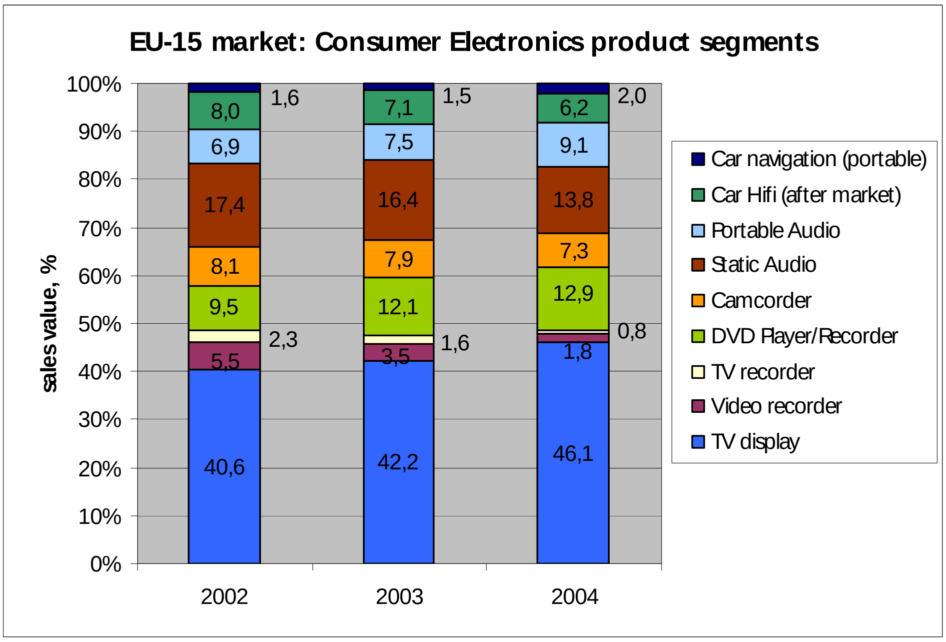


Figure 23. EU-15 Share of Product Segments, value % (Source : GfK[66])

TVs represent the highest share of CE equipment, both in sales value and in tonnes. AEAT estimates the stock of TVs in EU-25 at 270 million units with an ownership rate of 99% (households having at least one TV set) and penetration of 154%[59] (value over 100 indicates percentage of second household TVs). Data from IDATE[67] indicate that during the period 1997-1999 there was an average annual growth of TV households in the EU-15 of 2,327,500 with average annual TV sales of 21,321,930 units. Assuming that the difference between the figures corresponds to discarded units, the annual EOL TVs would account for 89% of annual TV sales on average.

There is a worldwide trend for substitution of traditional CRT display TVs with flat panels (LCD, PDP and others), especially noticeable in Europe. Consumers' taste for bigger size screens is also growing in the last years. The boost in TV sales is closely linked to the promotion of the shift from analogue to HDTV signal transmission within the EU, which also impacts on the type of screen technology and the screen size chosen by consumers. The plasma TV market is dominated by sets with 42/43" screens and in the LCD TV market; sets with 32" screens are becoming more and more popular[68]. These flat screens are consistently based on a 16:9 widescreen format, which has spread from 1995 on, also in CRT TVs.

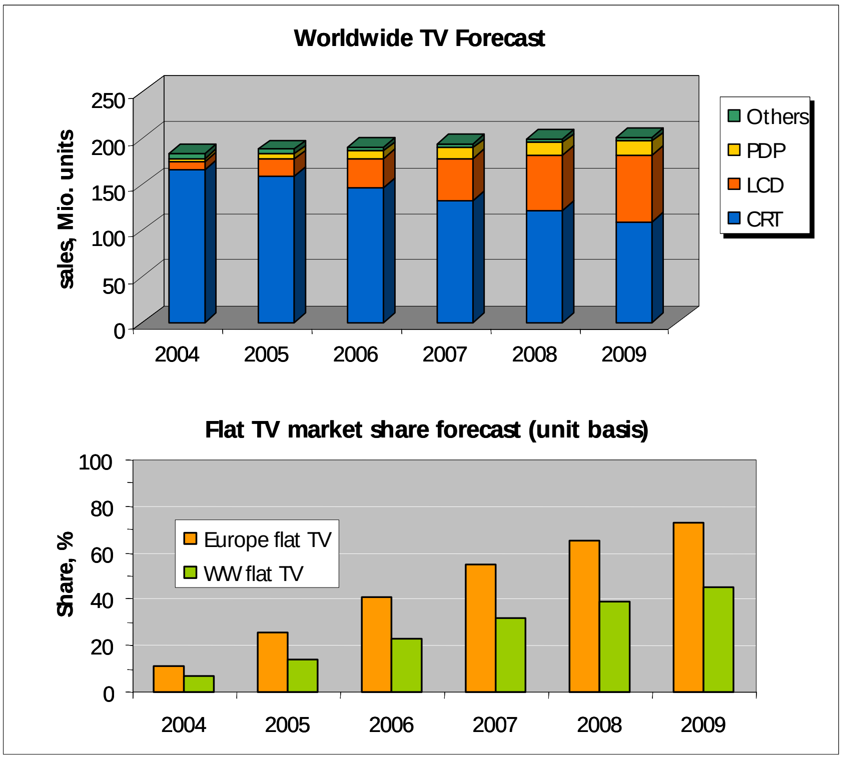


Figure 24. Market share forecast of TV sales by display technologies (Source: DisplaySearch[69])

The flat panel overtaking of CRT and the growing size screens involve a change in the nature of the future waste. Although high impact polystyrene (HIPS, SB) is still predominantly the material of choice for the housings of TV-sets —and, therefore, one of the main plastic portions in this type of electronic equipment—, flat panel TVs introduce new polymers in the waste stream, such as PC, PMMA and PET.

The increasingly higher screen sizes of TVs do not necessarily mean heavier units, as design stress is put on the development of lighter homologous models across the years[70].

Table 21. Characterisation of typical TV sets from years 1995 and 2005. (Source: aggregated data from manufacturers, VHK[59], Gaiker[71, 72], WRAP[73], AEA[74])

Average TV-sets	Manuf. Date: 1995	Manuf. Date: 2005
Estimated replacement sales, Mio. Units	24	28
Estimated ratio of future discarded TV types (CRT:FPD)	100:0	85:15 to 65-35
Design trends	Exterior frame and housing: black. 22'' / 4:3 screen format	Exterior frame and housing: metallised >25'' / 16:9 widescreen format
Av. Equipment weight, kg	28	29.5 to 22.5 **
% Plastic	14	16 to 17 **
% main polymers (HIPS)	11	11 to 8 **
% PWB	4-5	4
% BFR	Deca and Octa-BPE, TBBPA 2% (housing)* + 0.8% (PWB)	TBBPA 0.8% (PWB)

* *Alternatively, 0.3% phosphorous based FR*

** *Estimated percentages according to assumed CRT:FPD ratios*

An important issue when dealing with WEEE plastics from CE is that around 55% of the plastics contained are flame retardant treated[75, 76, 77].

Brominated flame retardants have not been used in TV housings manufactured in Europe since 1993, although they are still used in circuit boards and connectors. However they may still be used in TV housings made outside Europe and will therefore enter the waste stream for many years to come. (*N.B.* In terms of quantities of FR added to plastics, the scientific literature is rather poor and the published data vary significantly from one to another. For the purposes of this study own estimates from data supplied by recyclers and manufacturers and from average literature numbers have been considered).

Apart from the flame retardants in housing and PWB, TV plastics (especially the oldest units) may contain pigments and stabilisers (Cd, Pb, Ni, Cr, Sb, Sn, Ba).

LCDs greater than 100 cm^2, as the ones from TV-sets, are to be separately treated following requirements by the WEEE & RoHS Directives, due to the mercury content in the display back light. In addition, liquid crystals are substances under study in order to determine their potential hazardousness.

2.1.3. ICT equipment. Computers

Phased-out computers are becoming commonplace electronic waste in the EU-25. As data from Eurostat show, the percentage of households with access to personal computers (PC) exceeds 50% in most EU-15 and 30% in 2003 Accession Countries, averaging 55% for the whole EU-25 area.

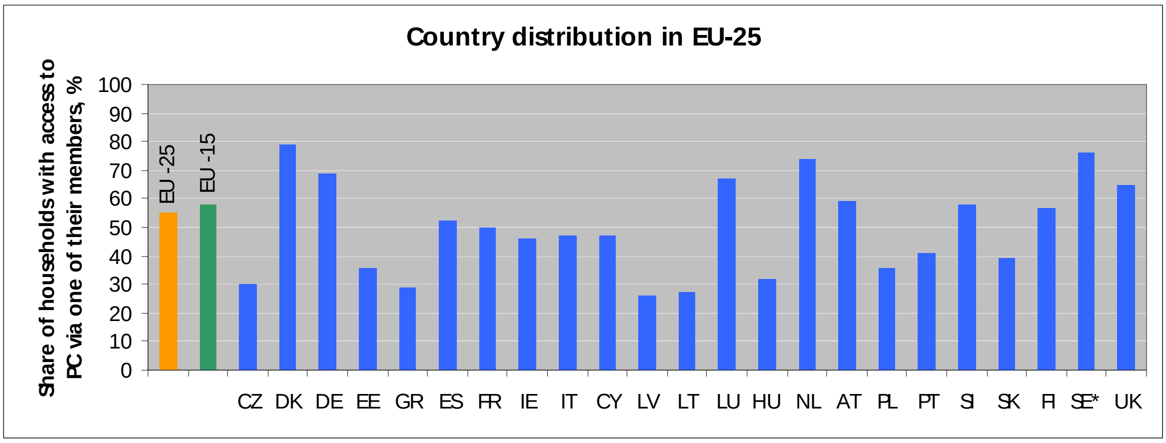


Figure 25. Percentage of households in the EU having access to, via one of its members, a Personal Computer; Year 2004 (Source: Eurostat)

No reliable statistics exist about the actual stock of PCs in EU-25 and the number of them replaced annually. Publicly available studies on PC ownership are very generic, not clearly distinguishing between the different types of computers (servers, workstations, PCs, etc.). Besides, the fact that a desktop computer can be assembled from OEM components —and therefore not marketed as a PC— complicates the sales reckoning. Refurbishment and use of old PCs' components as spare parts make likewise difficult to estimate the volume of PCs disposed of.

The obsolescence rate of computers (CPU) has dropped to 2 years[78], although peripherals (monitors, keyboards) can last longer than CPUs and, for instance, desktop computers are replaced more often than monitors[59, 78]. Replacement of computers is not always immediately followed by disposal of the old units: in some cases, those are stockpiled for some years; in other cases they are addressed to the secondary PC market. It is estimated that one in every 12 PCs in use worldwide is a secondary PC[79]. Demand for refurbished PCs exists primarily in regions such as Eastern Europe, Middle East and Africa, Latin America and parts of Asia/Pacific. More than 25 percent of PCs replaced out of the worldwide installed base in "supply" countries (mature markets such as Western Europe, USA, Japan and Australia) continue to be used. Replacement market is well established in office sector and is recently started in residential sector.

With all those data in mind, VHK[59] has estimated the current stock of PCs in the EU-25 at 170 million units and total PC sales in 2004 at 38 million. Approximately half of the sales and the units in stock correspond to residential use. As the Eurostat reported annual growth in accessible PC per household is over 7% in the EU-25, it can be concluded that replacement sales amount to ca. 25 million units. The number being disposed of is uncertain, as no data about PC reuse flows in the EU external and internal markets are available, neither is the ratio of inactive obsolete PCs accumulated.

As many E&E items, computers are a rapidly changing market in which long-term predictions are difficult to make. Computers are at a crossroads in terms of technologies. One the one hand is the functionality expansion of desktop computers; on the other hand the search for compact and integrated devices. In both cases, there is a clear convergence with other E&E products (CE and other ICT devices, respectively). Notebook sales continue to eat into the desktop PC market and this in turn will impact on sales of associated monitors, although how long the current boom in the notebook market will continue is uncertain. The penetration of LCD displays in PC monitors market started sooner than in the TV markets and is gradually displacing CRT monitors, as shown in the following figures. The German speaking countries have the highest LCD penetration in Europe, at 60% in 2003, whilst only 26% of monitors sold in Central Europe were LCD in 2003[80].

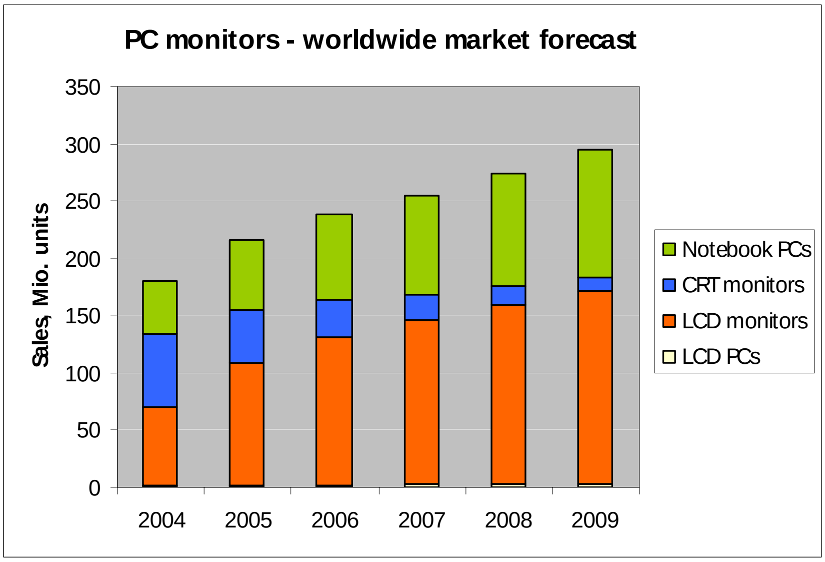
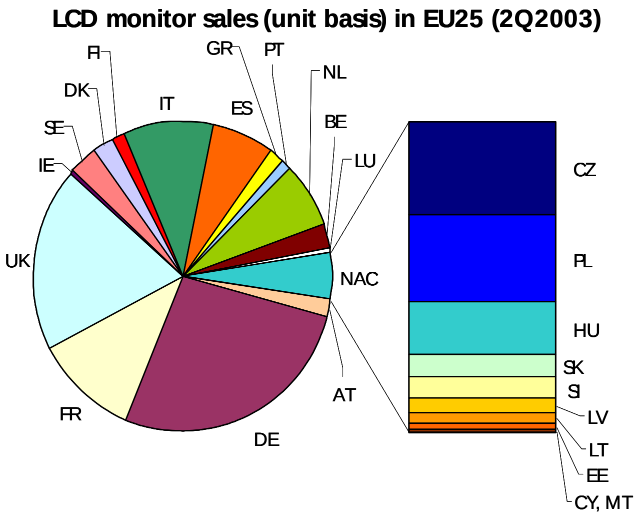


Figure 26. Forecast of PC monitors market share (Source: DisplaySearch[81]



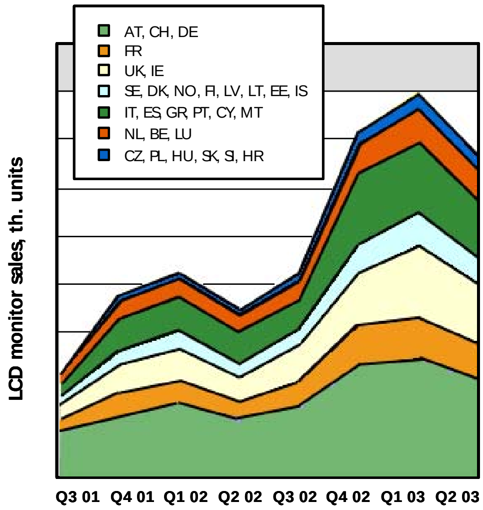


Figure 27. LCD monitor market share by country and regional trends in the EU-25 (Source: Meko Ltd., DisplayCast [82])

Data on material composition of CRT and LCD monitors are more readily available than data on the rest of desktop computer parts (CPU, keyboards) and much more than records on notebook computers' BOM.

As for the plastic content in computers, styrenics hold the biggest share, but unlike TVs and other CE apparatus, HIPS subfamily is not the most prolific, but ABS and the blend PC/ABS of housings of CRT monitor, CPU and peripherals. The enclosure of notebook computers is typically made of PC/ABS (Mg-Al alloy and fibre reinforced PC/ABS in the most recent models). LCD plastic frames are commonly made of PC.

BFRs and heavy metals used as pigments and stabilisers are hazardous substances that may be present, especially in older units. Over 80% of computer ABS tends to be flame retarded. The PWBs and LCDs (greater than 100 cm^2) require separate treatment. The Table 22 shows the approximate plastic composition in computers.

Table 22. Material composition of computers (Source:VHK[59], Gaiker[71, 72, 83], WRAP[84], AEA[85], US EPA[86])

Average TV-sets	Manuf. Date: 1995-2003
Design trends	Exterior frame and housing: light colour→black.→metallised Screen size: 14” → 17”+ Display: CRT → CRT & LCD (50:50) PC type: desktop → desktop & notebook (70:30)
Av. Equipment weight, kg	Average Desktop PC 25 kg *CPU 10 kg* *VDU: CRT 14 kg, LCD 7kg* *Keyboards: 2-0.7 kg* (Notebooks: down to 2.5 kg)

% Plastic	23%
% main polymers	11% ABS & PC/ABS, 7% HIPS
% PWB	14% (20% CPU, 11.5% CRT VDU, 5% LCD VDU)
% BFR	3.5% TBBPA (Deca-BPE)

2.1.4. ICT equipment. Mobile phones

While the size of an individual mobile phone is small their cumulative size is substantial. The total mass of all mobile phones that are produced worldwide is tens of thousands of tonnes per year, and with accessories there are tens of thousands of tonnes more. Eurosource Europe[87] states that 58 million replacement mobiles are bought each year in Europe, with approximately 85 million unused phones lying around in people's homes. So, millions of old phones could potentially be recycled annually, although it is estimated that fewer than 5% are.

The number of subscriptions to mobile telecommunication in the EU-25 countries can give an indication of the regional stocks of mobile phones. The use of mobile phones has grown exponentially, from the first few users in the 1970s. About 11 of the 16 major markets in Western Europe had in 2005 official penetration rates above the 100% mark. The most penetrated at the end of the year were Luxembourg (160%), Italy (119%), Portugal (114%) and Sweden (112%). Others above 100% include Greece, the UK, Spain, Ireland, Finland, Austria, the Netherlands and Denmark.

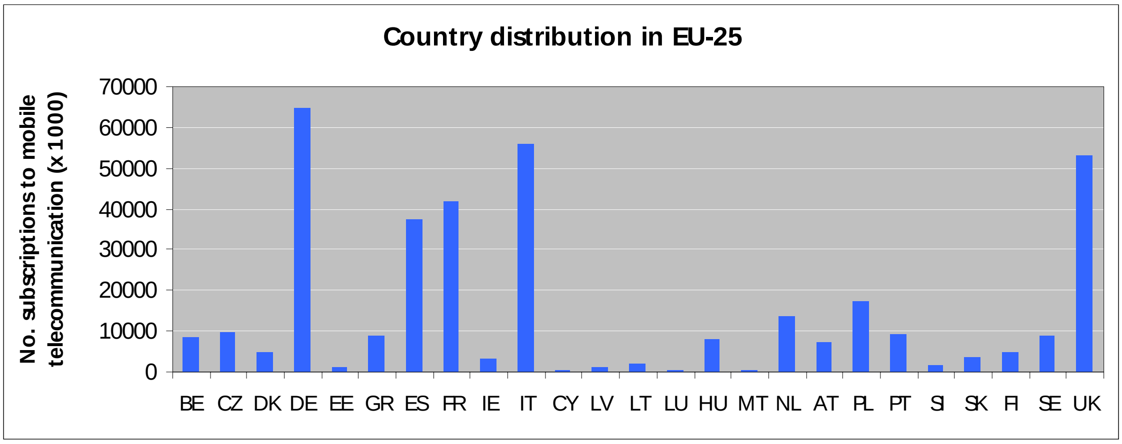


Figure 28. Number of subscriptions to public mobile telecommunication systems using cellular technology in thousands of subscriptions in the EU-25, Year 2003 (*Note: Active pre-paid cards are treated as subscriptions. One person may have more than one subscription*). (Source: Eurostat)

Attention to design of a mobile phone for environmental considerations must begin with recognition of the dramatic evolution of their design over the last three decades. The first and strongest demand has been for greater portability. The first generation of truly portable phones was large and heavy; they contained lead acid batteries and weighed over 4 kg. But these devices progressed steadily to smaller, lighter models in the 1980s, and today mobile phone handsets typically weigh 100 g or less, and are powered by a small battery[88].

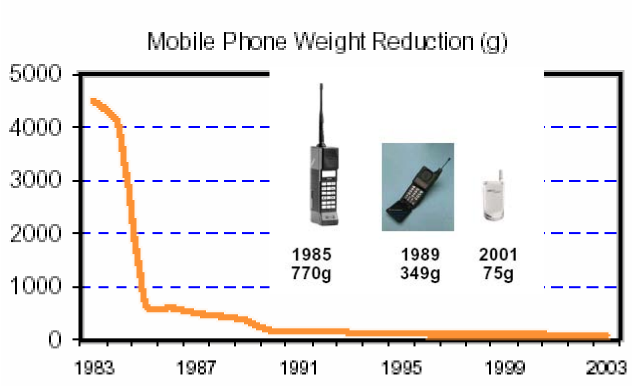


Figure 29. Historical weight evolution of mobile phones (Source: MPPI[88])

On average, about 40% of the weight of a whole mobile phone (including handset, battery and accessories) is plastics nowadays. By mid 90's, the average plastic content in a mobile phone handset due to housing was 55 g; similar to the weight of its PWB.

The case of a mobile phone is typically made of PC/ABS plastic and the case of the charging station is typically made of PC. Plastics are the largest single category of constituent, by weight and volume, of mobile phones and some plastics must be recycled if the WEEE Directive's requirement that 65% of collected end-of-life mobile phones (by weight) must be recycled is to be met. Paints, labels and metal fasteners hurdle the recovery of such plastics.

There are certain substances of potential concern in end-of-life management of mobile phones[88, 89, 90]:

- According to WEEE Directive, PWB of mobile phones are to be separated and properly treated. The display screens in mobile phones use “liquid crystal” (LCD) technology. The old small sized displays weighed about 5 g per device. Novelty models are equipped with bigger TFT displays
- The plastic cases and the PWB are likely to contain bromine in organic compounds used as a fire retardant. Two BFRs are commonly used in current mobile phones; these are TBBPA and Deca-BDE. TBBPA is reacted into the resins used to make the PWB substrates, and either TBBPA or Deca-BDE may be added to a mobile phone’s plastic case. A current design mobile phone will contain approximately 2 g of flame retardant. Antimony trioxide used in flame-retardant formulations may also be present in mobile phone plastic cases.
- Lead may be present as constituent of the tin-lead solder used in almost all mobile phones in their electronics, typically less than 1g per phone.
- Some mobile phones can contain hexavalent chromium plating for decoration and chromate treatment.
- A small percentage of older mobile phones contain a mercury vapour lamp, i.e. a small screen illumination unit using mercury vapour,

typically with about 0.01 g of mercury for each such phone. No current use of mercury in mobile phones is now known.

Following RoHS Directive requirements, manufacturers are searching for efficient substitutes for BFR and for lead in solders (lead-free solders actually introduced) and phasing out Cr (VI) in their latest models.

2.1.5. Small household appliances

According to CECED, about 200 million small appliances are sold on average in Europe, every year. The E&E category of Small Household Appliance (SHA) reveals as more region sensitive than others. The amount and type of the SHA owned per household in the various EU-25 countries (see figures below) may vary significantly.

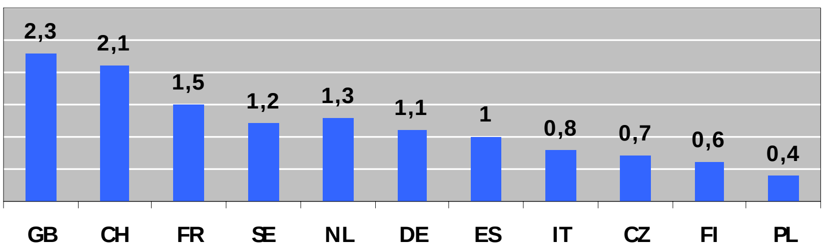


Figure 30. Average number of Small Household Appliances sold per household and year in several EU-25 countries (Source: GfK, GIFAM[91])

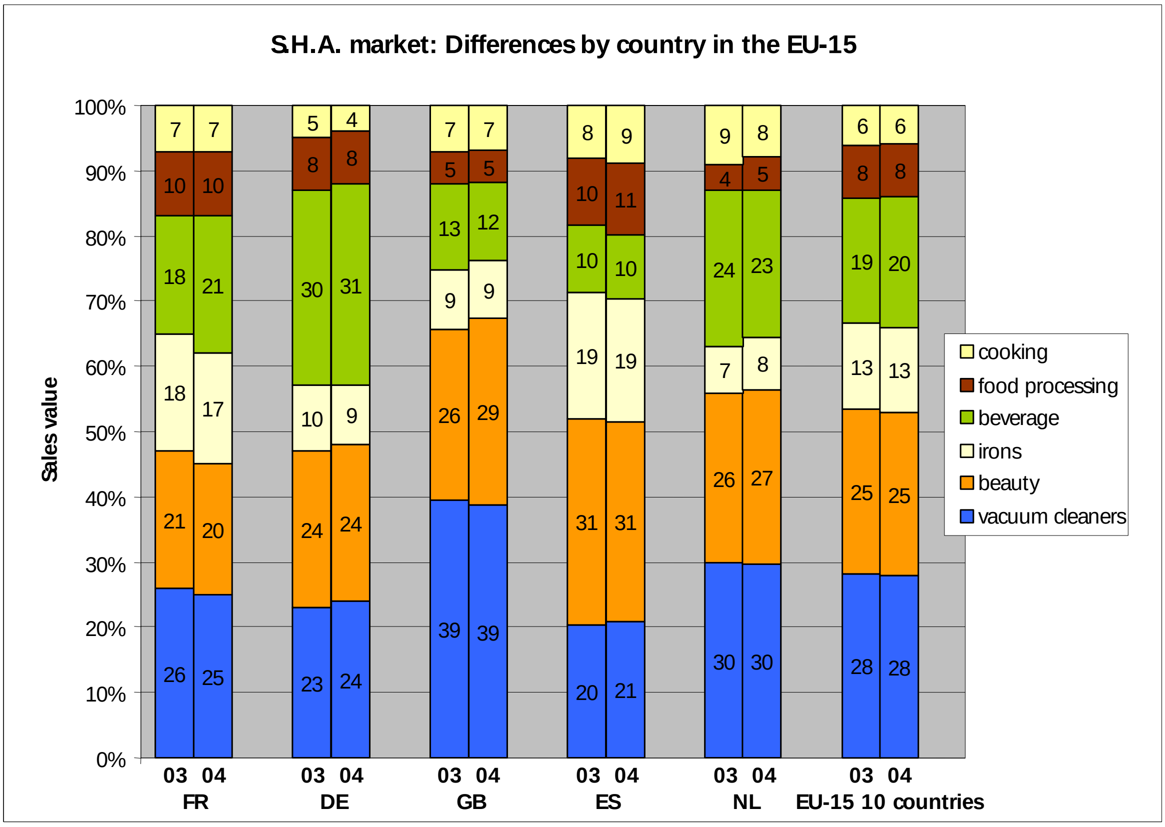


Figure 31. SHA market share by applications in EU-15 countries (Source: GfK, GIFAM[91])

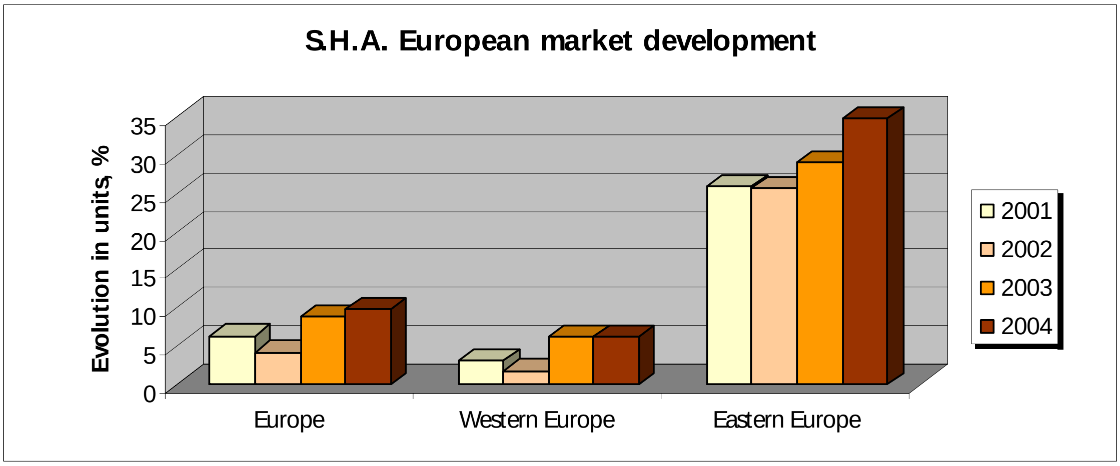


Figure 32. Evolution of SHA market in Europe by region (Source: GfK, GIFAM[91])

PP, styrenics and PC are among the polymers most commonly used in SHA, although the wide range of appliances included in the category makes difficult to establish a standard composition. Within this category, vacuum cleaners account for nearly 60 per cent of the tonnage discarded, assuming an average weight of 8-12 kg per vacuum cleaner. In the case of vacuum cleaners, plastics make up 30-65% of total appliance weight, with a polymer share of 75% PP, 14% ABS, 3% PS and 3% PC[59].

Small appliances (coffee grinders, toasters, irons, hair dryers, vacuum cleaners...) have differing amounts of components with dangerous substances. For instance, in certain cases, batteries/accumulators are not removed which means that Ni-Cd-rechargeable batteries and mercury containing batteries and round cell batteries may be present. Mercury is also a component of some temperature regulators (e.g. in heating and hot water appliances).

Appliances with a high percentage of electronic components, with plastic containing flame retardants (polybrominated diphenylethers up to 15 % by weight) and with heavy metals should also be considered as potentially harmful.

Experience proves that only a small portion of the total SHA waste potential can be collected by waste collection systems. In fact, 75% of waste items in the small household appliance categories weigh 2 kg or less. This is significant because it means that these items are small enough to be disposed of with general household. An investigation carried out in Germany showed that the amount of small E&E, which is disposed of together with municipal waste in the rubbish bin is about 1% by weight. This also includes single parts such as pumps, small motors and components that cannot be assigned to a specific appliance.

2.1.6. Printed Circuit (/Wiring) Boards (PWBs)

Printed wire boards (PWBs), also called printed circuit boards, hold on a laminate (rigid or flexible) microchips and other electronic components used to run electronic devices. Most PWB rigid base laminates are made of either epoxy or phenolic (thermoset) resins. The polymeric substrate is generally reinforced (mostly with fibre glass) and sometimes contains cellulose/paper in the core. Other materials used for the PWB laminates (especially for flexible foils) are polyimide and polyester resins[92].

Exposed to constant heat and electrical current PWB laminates are required to meet certain flammability standards. Commonly, Tetrabromobisphenol A (TBBPA) is used as flame retardant (in over 90%

of PWBs). PBDE was used for some years in PWBs of ICT equipment, CE (TV sets, radios, calculators, etc.) and toys. Mineral based FR (e.g. aluminium and magnesium hydroxides) are also available for non-halogenated solutions. BFR content is in the range 5-1.5 wt% of the total PWB weight.

Another matter of concern dealing with EOL PWBs is the lead-containing solders. According to the Directive 2002/95/CE on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive), as from 1 July 2006 all new E&E goods manufactured and/or marketed in the European Union must be lead-free (with some exceptions). The level of lead within populated PWB waste is generally in the region of 2%. Lead-free soldering technology may reduce PWB's lead content under the admitted 0.1% by RoHS Directive[92, 93].

Scrap PWBs are generally subject to grading into three categories that essentially mirror their inherent precious metal content. These are referred to (from richer to poorer) as High-grade, Medium-grade and Low grade. PWBs from mobile phones are among the highest graded, followed by PWBs from other telecommunication equipment and computers (CPUs). PWBs from monitors and TV-sets are medium-low grade and the poorest are those from SHHA, HiFi and, in general, PWBs prior to 1990.

PWB recycling has tended to be limited to date to operations concerned solely with precious metal recovery (via smelting). That explains that only an estimate 50% of total tonnes of WEEE populated PWBs was recycled in EU-15 in 2002 and that the rest was landfilled[92]. However, from August 2004 on, the WEEE Directive requires the separation of plastics containing BFRs from E&E equipment prior to recycling and also the selective treatment of printed circuit boards for mobile phones and any other PWB of more than 10 cm^2.

The same sources roughly calculate annual waste generation of populated PWBs from WEEE among 180,000 and 258,000 tonnes in that year, increasing to 300,000 in 2006[92]. Other authors[76, 94], estimate that PWBs make up slightly over 3% by weight of average WEEE composition (1995-2000), which cuts the volume of PWB available into collectable WEEE down to 100,000 tonnes. About 40-50% of PWBs weight corresponds to the GF reinforced resins (10% to the glass fibre).

It should be noted that the increasing miniaturization of equipments has pushed components to their physical limits, requiring new materials and processes to be developed to provide ultra-small and ultra-lightweight components. In the case of PWBs that means higher density assemblies and that new materials and laminates are under development for use in thinner, flexible and multilayer PWBs. As a result changes in the nature of the future waste PWBs can be foreseen.

2.2. FLAME RETARDANTS IN E&E PLASTICS

Flame retardants (FR) are added to some plastics in electronic goods to help them meet the strict fire safety standards. The majority of FR are found in housings, connection cables and printed circuit boards in products that are exposed to high internal heat. For example, laser printers, copiers, TVs and microwaves are made with them, whereas FR are rarely added to phones or inkjet printers.

There are three main types of FR: halogenated (mostly bromine, some chlorinated), phosphorous based and mineral (aluminium and magnesium oxides). Brominated Flame Retardants (BFR) are well recognised to be highly effective flame retardants. Different types of brominated flame retardant have been used in E&E plastics:

- Polybrominated diphenilethers family (PBDEs): such as Pentabromodiphenyl ether (Penta-BDE), Octabromodiphenyl ether (Octa-BDE) and Decabromodiphenyl ether (Deca-BDE)

- polybrominated biphenyls family (PBBs): Hexabromobiphenyl, Decabromobiphenyl...
- Tetrabromobisphenol – A (TBBPA)
- Oligomeric brominated flame retardants

Brominated flame retardants are most likely to be present in styrenic plastics (PS, HIPS and ABS) and in ABS/polycarbonate components. They are less likely to be present in polypropylene components, however this is a growing market for BFRs. Plastics such as PC/ABS utilize frequently other category of flame retardants, the phosphate type. BFR categories are accompanied by a synergist (antimony trioxide) which improves the ignition resistant characteristics.

Table 23. Types of FR commonly used with polymers in E&E items[71, 73]

Products	Brown goods, data processing	Office equipment, small domestic appliances, telecommunications
Polymeric Matrix	SB, ABS, PC, PC/ABS, SB/PPE, PP, PVC	SAN, PET, PA, PE, POM, PBT, PMMA
Flame Retardants	DecaBDPE, OctaBDPE, TBBPA, HBBD, Sb_2O_3	PBB-MA, halogenated polyolefines, ammonium polyphosphates, melamine compound, Al and Mg hydroxides

To pass the required fire tests applicable to electronics (UL-94 V-0 or V-2) relatively large amounts of flame retardants must be added to plastics.

Table 24. Content of FR in WEEE polymers[95]

Polymer	Rating	FR type, wt.% in plastic		
		Bromine	Phosphorus	Mineral
Nylons	V-0	10	15	25
	V-2	7-8	10	17
Polyolefins	V-0	17	8-15	25
	V-2	7-8	8-15	20
Styrenes	V-0	8	7	23
	V-2	0-3	0-3	11

Apart from their potential toxicity and health risks, BFRs are suspected to affect adversely the end-of-life management of plastics through formation of brominated dioxins and furans (dibenzodioxin and dibenzofurans, PBDD/F). Nevertheless, several studies have shown that plastics containing specific BFRs can be mechanically recycled without degrading significantly down to PBDD/F species[96] or undergo thermal treatments with energy recovery keeping the PBDD/F concentrations well below regulatory limits[97].

As of August 2004, the WEEE Directive (Directive 2002/96/EC) will require the separation of plastics containing BFRs from E&E equipment prior to recycling. Additionally, the RoHS Directive (Directive 2002/95/EC) stipulates that as from 1 July 2006, new electrical and electronic equipment put on the market does not contain polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) — although a maximum concentration value of 0.1% by weight in homogeneous materials of PBBs and PBDEs will be tolerated. The use of DecaBDE in polymeric applications is currently exempted from those requirements.

Manufacture of PBBs has already stopped and production of Penta-BDE and Octa-BDE has just been discontinued in 2004[95, 98]. The two most commonly used BFRs currently are the Deca-BDE (in the system Deca-BDE/HIPS) and the TBBPA (e.g. combined in PWB with the polymeric matrix).

Deca-BDE is widely used with styrenics (mostly HIPS) in housings. Deca-BDE is still being produced, at a rate of 60,000 Mt/yr (7-8,000 Mt sold in Europe)[95]. TBBPA is the largest volume brominated flame retardant (BFR) in production today to improve fire safety of mainly electrical and electronic equipment, representing over 50% by weight of the year 2000 BFR market. Because the substance is marketed around the world without any legislative restrictions, over 130.000 tons of TBBPA were used worldwide in 2002[99].

The main application of TBBPA is as a reactive flame retardant in laminates (e.g. epoxy resins for PWB). TBBPA is also used as an intermediate in the production of other brominated FR systems, TBBPA derivatives and brominated epoxy oligomers. TBBPA is chemically bound in these applications and has no potential for emissions to the environment.

TBBPA is also used as an additive flame retardant in ABS plastics. In these ways, TBBPA contributes to the fire safety of the vast majority of electrical and electronic equipment, such as consumer electronics (TVs, washing machines etc) and office (computers, printers, copiers etc) and communication equipment (fax machines, mobiles etc).

Several studies demonstrate that TBBPA is fully compatible with integrated waste management concepts (mechanical and feedstock recycling, energy recovery). Because of its chemical structure, TBBPA has very low potential for formation of significant levels of dioxins/furans.

Recycling WEEE polymers faces the problem of treating old WEEE made before the regulated FRs were discontinued, e.g:

- Penta-BDPE in phenolic PWBs
- Octa-BDPE in housings
- PBB in housings made in Europe (older units)

Additional difficulties are the fact that materials may not be uniform and that some FRs may have mutated into other forms or congeners.

Certain ABS/BFR combinations (e.g. brominated epoxies or oligomers) have clear advantages in terms of recyclability due to the stability of those brominated flame retardants in the recycling process. Those recycled ABS/BFR plastics maintain the required flame retardancy level, thus foregoing the need to add more flame retardants after recycling. This provides clear economic as well as environmental benefits[100].

3. ANNEX 1.3 – POLYMERS IN VEHICLES

3.1. ELV COMPOSITION BY POLYMER

In the last decades the vehicles composition has changed considerably. Plastics use has growth reducing vehicle's weight and improving its efficiency. In 1960, the vehicle's plastics content was around 2%, while nowadays it is 9-10% of the car by weight. If the plastic content among European, Japanese and US made automobiles is compared some differences may be noted. For instance, in 1991 new cars in Europe and Japan averaged 23 kg of PP (about twice as much as their American-made counterparts).

Table 25. Automobile composition percentages by weight[101]

<table>
<tr><th rowspan="2">Material</th><th>EU middle class</th><th colspan="2">Japanese cars</th><th colspan="2">US cars</th></tr>
<tr><th>1989</th><th>1973</th><th>1989</th><th>1976</th><th>1992</th></tr>
<tr><td>Steel and iron</td><td>57-76.5</td><td>81.1</td><td>75.7</td><td>74.1</td><td>66.9</td></tr>
<tr><td>Aluminium</td><td>2-10.4</td><td rowspan="2">5</td><td rowspan="2">7.4</td><td>2.3</td><td>5.5</td></tr>
<tr><td>Other non ferrous metals</td><td>2.5-4.7</td><td>2.7</td><td>4</td></tr>
<tr><td>Plastic</td><td>1.2-12.6</td><td>2.9</td><td>7.5</td><td>4.3</td><td>7.7</td></tr>
<tr><td>Glass</td><td rowspan="3">balance</td><td>2.8</td><td>3</td><td>2.3</td><td>2.8</td></tr>
<tr><td>Rubber</td><td rowspan="2">8.2</td><td rowspan="2">6.4</td><td>4.1</td><td>4.2</td></tr>
<tr><td>Other non metal</td><td>10.2</td><td>8.7</td></tr>
</table>

The European vehicle shows an upward trend in plastic content, estimated at 11% in 2000's automobiles (lightweight cars contains up to 20% plastic materials for an average car weight of 1120 kg)[102]. American cars, heavier than European, are also turning to plastics as replacement of metals in many parts and components, as

Table 27 shows in detail.

Table 26. Plastics used in a typical car (*Source: EuPC*[103])

Component	Main types of plastics	Weight in av. car (kg)
Bumper	PP, ABS, PC/PBT	10.0
Seating	PUR, PP, PVC, ABS, PA	13.0
Dash board	PP, ABS, SMA, PPE, PC	7.0
Fuel system	HDPE, POM, PA, PP, PBT	6.0
Body (incl. Panels)	PP, PPE, UP	6.0
Under-bonnet components	PA, PP, PBT	9.0
Interior trim	PP, ABS, PET, POM, PVC	20.0
Electrical components	PP, PE, PBT, PA, PVC	7.0
Exterior trim	ABS, PA, PBT, POM, ASA, PP	4.0
Lighting	PC, PBT, ABS, PMMA, UP	5.0
Upholstery	PVC, PUR, PP, PE	8.0
Liquid containers	PP, PE, PA	1.0
Total Plastics		**105.0**

Table 27. Plastics used in a typical US car (*Source: APC, Automotive Learning Center and www.plastics-car.com*[104]) (I)

Application Area		Principal Polymers
Exteriors	Bumpers + fascia systems	Thermoplastic olefins, polycarbonates, polyesters, polypropylene, polyurethanes, polyamides, composites
	Body panels	Sheet moulding compound (SMC, a thermoset polyester sheet), reaction injection molding (RIM) urethane (thermoset), thermoplastic systems (including polyolefins)
	Lighting systems	Polycarbonate, acrylic
	Trim (door handles, mirror housings, side trim, etc.)	Nylons, polystyrene, polycarbonate, acrylic-styrene-acrylonitrile/poly (acrylonitrile ethylene styrene) (ASA-AES), PVC, polypropylene, polyesters, urethanes
Interiors	Upholstery	Urethane foams (for cushioning), PVC-based fiber (for floorings)
	Instrument panels	Acrylonitrile-butadiene-styrene (ABS), ABS/polycarbonate alloys, polycarbonates, polypropylene, modified polyphenylene ether resin, PVC, styrene maleic anhydride (SMA) resin, urethane resin
	Steering wheels	PVC, RIM-pigmented urethane
	Air ducts	ABS, polypropylene, SMA resin
	Other applications (seat bases, door panels,headliners...)	Glass mat thermoplastic (GMT) composite (polypropylene/fiber glass), ABS, polycarbonate/ABS, PVC

Table 27. Plastics used in a typical US car (Source: APC, Automotive Learning Center and www.plastics-car.com) (II)

Electrical	Component housing	Nylon, styrenics, polypropylene, and polyester
	Switches + sockets	Nylon, polyester, and acetyl resins (for switches); polyphthalamide (PPA), polyphenylene sulfide (PPS), syndiotactic polystyrene (SPS) (for sockets)
	Connectors	Polybutylene terephthalate (PBT), recycled polyethylene terephthalate (PET), nylon
	Lighting systems	Polyetherimide
	Circuit boards + wiring	PVC
Power Train	Transmission	Glass fibre reinforced phenolic resins (stationary transmission parts)
	Bearings	Nylon (for housing bearings)
	CV joints + U joints	Acetyl
Fuel System	Fuel tanks	High density polyethylene (HDPE)
	Fuel lines	Nylon
	Vapour recovery system	Glass reinforced nylon or polypropylene
Chassis	Suspension	Acetyl, nylon, polypropylene (for suspension tubing and links)
	Brakes	Aramid fiber (for brake pads)
Engine	Air-intake systems	Nylon, polypropylene (for air cleaner systems)
	Fuel-intake systems	Nylons (for plastic intake manifolds)
	Cooling systems	Nylon (for radiators); nylon and PPS (for water pumps)

As the tables above show, it is highly complicated to allocate a single polymer for each car component, although in most cases one polymer is clearly predominant over the rest.

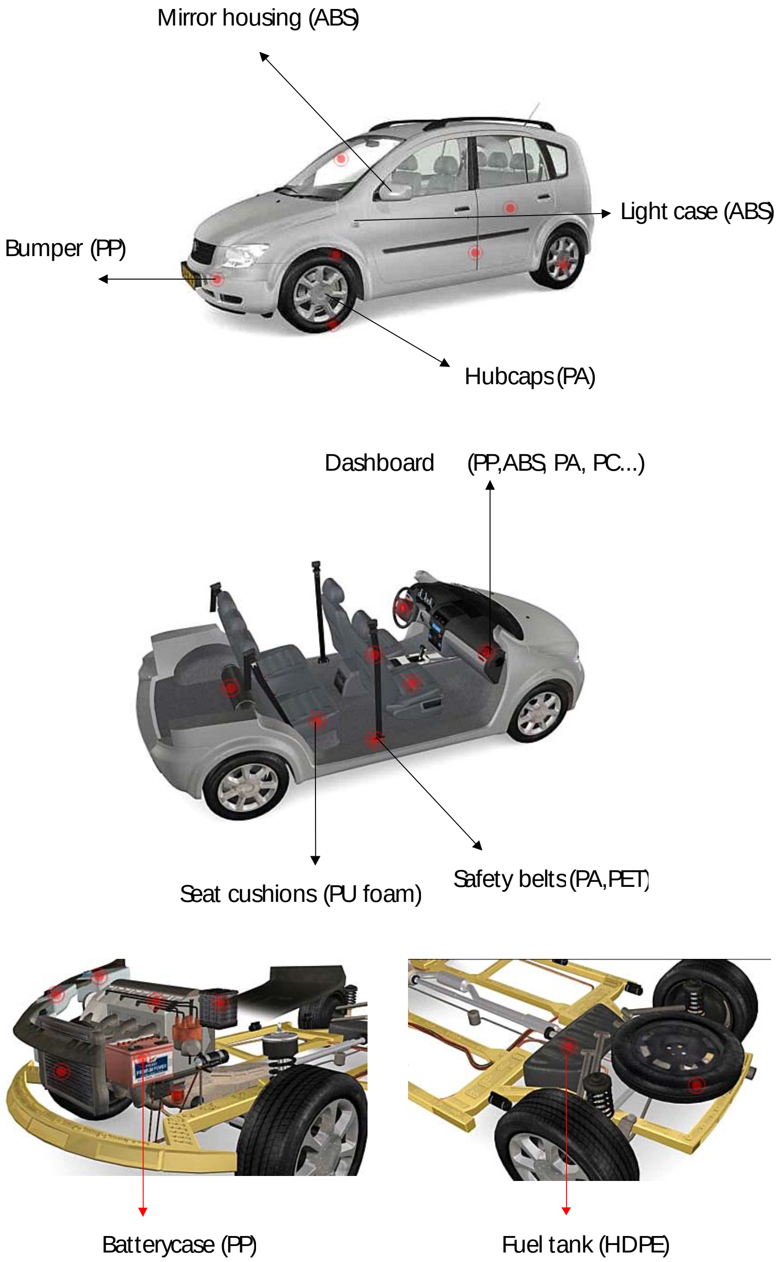


Figure 33. Main plastic parts in vehicles

Thermoplastics account for roughly 90% of plastic used in vehicles. Specific thermoplastics that are most widely used in vehicles are: polypropylene, polyethylene, polyurethane, and polyvinyl chloride.

- PP is most abundantly used, accounting for up to 40% of all car thermoplastics and there is a trend towards an increase in its use[105]. Applications include bumpers, wheel arch liners and dashboards.
- PVC makes up about 6%-12% of the thermoplastic content of an average 1990's European car (Source: *Waste watch Information sheet: car recycling*), however the tendency goes towards a decrease in its use.

The shares by polymer in the plastic content in the average 1990s and 2000s cars, as reported by some sources, are represented in the next figure.

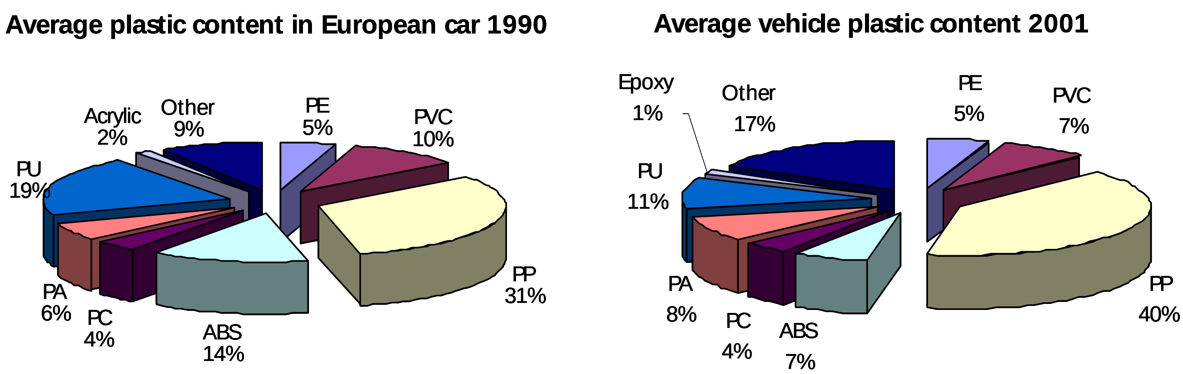


Figure 34. Average composition of plastic content in 1990 and 2000 European Cars (Source: ACORD[106], CEP[107])

In order to elucidate the trends and innovations in car design that can influence the future composition of ELV plastic waste and their potential for recovery, an in-depth analysis of polymers used per application has been carried out. Taking into account the market trends and the top ten vehicles sales by model and segment in the last ten years, it has been possible to estimate composition of plastic waste stream in the sector and the future trends. For each scenario 16 vehicles have been analysed, among them the top ten best selling vehicles. For current waste stream the average composition of a 90´s vehicle is considered and the future waste stream is based upon the composition of a 2000´s vehicle composition. To deal with the problem of accessibility to vehicles plastic content and application the IDIS Database (Version 3.11, April 2004) has been used.

IDIS, the International Dismantling Information System contains data on the material composition on vehicles. The database contains information from all car manufacturers involved in the IDIS project, covering up to 427 models and 875 variants.

Figure 35. IDIS vehicle dismantling database

For the two generations of vehicles, datasheets of plastic parts have been elaborated per vehicle, gathering data on weight and manufacture material of each plastic part.

GOLF 92/97

ID	ITEM	no. parts	part weight, g	total weight, g	material
1. 6	Portaobjectos de puerta	2	230	460	PP-TD30
2. 1a	Embellecedor de rueda, central	4	30	120	PA6/66
2. 1b	Embellecedor de rueda, central	4	28	112	PA6/66
2. 2b	Embellecedor de rueda, anillo	4	62	248	PA66-MD30
2. 3	Spoiler	1	580	580	PP+EPDM
2. 4	Recubrimiento del parachoques	1	3455	3455	PP+EPDM
2. 5	Moldura del parachoques	2	55	110	ABS
2. 6	Protección bajo motor	2	95	190	PP+EPDM
2. 7	Recubrimiento del parachoques	1	4065	4065	PP+EPDM
2. 8	Moldura del parachoques	1	65	65	PP+EPDM
2. 9	Calandra	1	445	445	ASA
2.10	Protección del pasarrueda	2	305	610	PP, PP+EPDM
2.11	Luz trasera	2	410	820	PMMA, PMMA+ABS
2.12	Alojamento de la luz de la matrícula	1	150	150	PA6-GF30
2.13	Depósito de carburante	1	6080	6080	PE-HD
2.15	Capo del faro	2	38	76	PP-TD20
3. 1	Salpicadero	1	2890	2890	PP+EPDM-TD30
3. 2	Moldura de guantera	1	430	430	PP
3. 3	Estante del salpicadero	1	775	775	PP
3. 4	Moldura del salpicadero	1	50	50	PP
3. 5	Moldura del cuadro instrumentos	1	240	240	PPE+PS
3. 6	Tapa de la guantera del salpicadero	1	505	505	PP+EPDM-TD30
3. 7	Guantera del salpicadero	1	540	540	PP-TD30
3. 8	Conducto de ventilación	1	260	260	PPE+PS
3. 9	Moldura del salpicadero	1	90	90	PP
3.10	Conducto aire	1	155	155	PP-TD30
3.11	Conducto de ventilación	1	400	400	PP-TD20
3.12	Conducto de ventilación	1	200	200	PP
3.13	Conducto de ventilación	1	290	290	PP-TD20
3.14	Conducto aire	1	155	155	PP
3.16	Conducto aire	1	70	70	PP
3.17	Caja del calentador	1	590	590	PP-TD20
3.18	Conducto aire	1	190	190	PP
3.19	Caja del calentador	1	800	800	PP-TD20
3.20	Consola central	1	75	75	PP
3.21	Consola central	1	780	780	PP
3.22	Consola central	1	290	290	PP
3.23	Conducto aire	2	20	40	PP
4. 1	Espuma del reposacabeza	2	105	210	PUR-E
4. 2	Espuma del asiento	2	650	1300	PUR-E
4. 3	Espuma del respaldo	2	713	1426	Fibra engomada
4. 4	Espuma del asiento	1	2200	2200	PUR-E
4. 5	Espuma del respaldo	1	1300	1300	PUR-E
4. 6	Cinturon de seguridad	5	44	220	PET
5. 1	Pedal acelerador	1	110	110	PA66-GF30
5. 2	Pedal embrague	1	220	220	PA6-GF30
5. 3	Ebanistería superior	1	190	190	PP+EPDM-TD30
5. 4	Bajo peldaño	2	213	426	PVC
5. 5	Tapa del montante anterior	2	120	240	PP+EPDM-TD30
5. 6	Tapa del montante central	2	90	180	PP+EPDM-TD30
5. 7	Tapa del montante posterior	2	370	740	PP+EPDM-TD30
5. 8	Tapa del montante anterior	2	85	170	PP-TD20
6. 1a	Caja filtro de aire	1	520	520	PP-TD20
6. 1b	Caja filtro de aire	1	1200	1200	PP-TD20
6. 2a	Entrada de aire	1	85	85	PP
6. 4	Ventilador	1	330	330	PA6-GF25
6. 5	Depósito de expansión	1	510	510	PP
6. 6a	Carter de la correa de distribución	1	230	230	PA66-GF20
6. 6b	Carter de la correa de distribución	1	170	170	PP-TD40
6. 7	Carter de la correa auxiliar	1	200	200	PP, PP+EPDM
6. 8	Depósito del líquido limpia cristales	1	420	420	PE-HD
6. 9	Soporte del radiador/ventilador	1	2060	2060	PP-GF30
6.11	Protección agua	1	745	745	PP-TD20
7. 1	Soporte de la sombrerera	2	193	386	PP+EPDM-TD30
7. 3	Caja de herramientas	1	170	170	PP, PP+EPDM

Figure 36. Sample datasheet for VW Golf (90's models) extracted from IDIS database

The assessment of composition of plastic parts of best selling models as reported by manufacturers in the IDIS database has allowed us to calculate the average compositions by polymer in the plastic content in the vehicles of 90's and 00's, as shown in Figure 37.

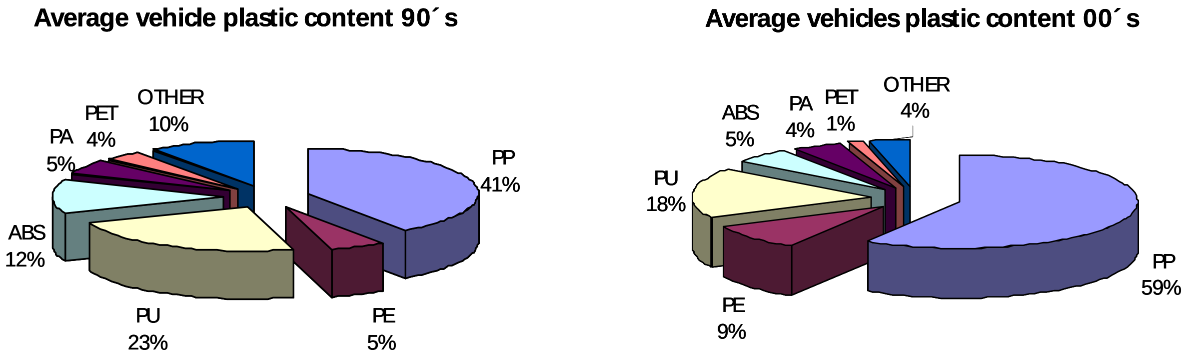


Figure 37. Average composition of plastic content in 90's and 00's car (Source: IDIS [108])

These pie charts depict that the main plastic polymers in use in the automotive sector are PP, PE, ABS, PU, PA and PET. A comparison between both scenarios shows a tendency towards an increase in the use of PP, PE. Also it is known from other sources that the use of PVC is decreasing.

The analysis results for 2 generations of VW Golf are shown to illustrate the evolution in materials used.

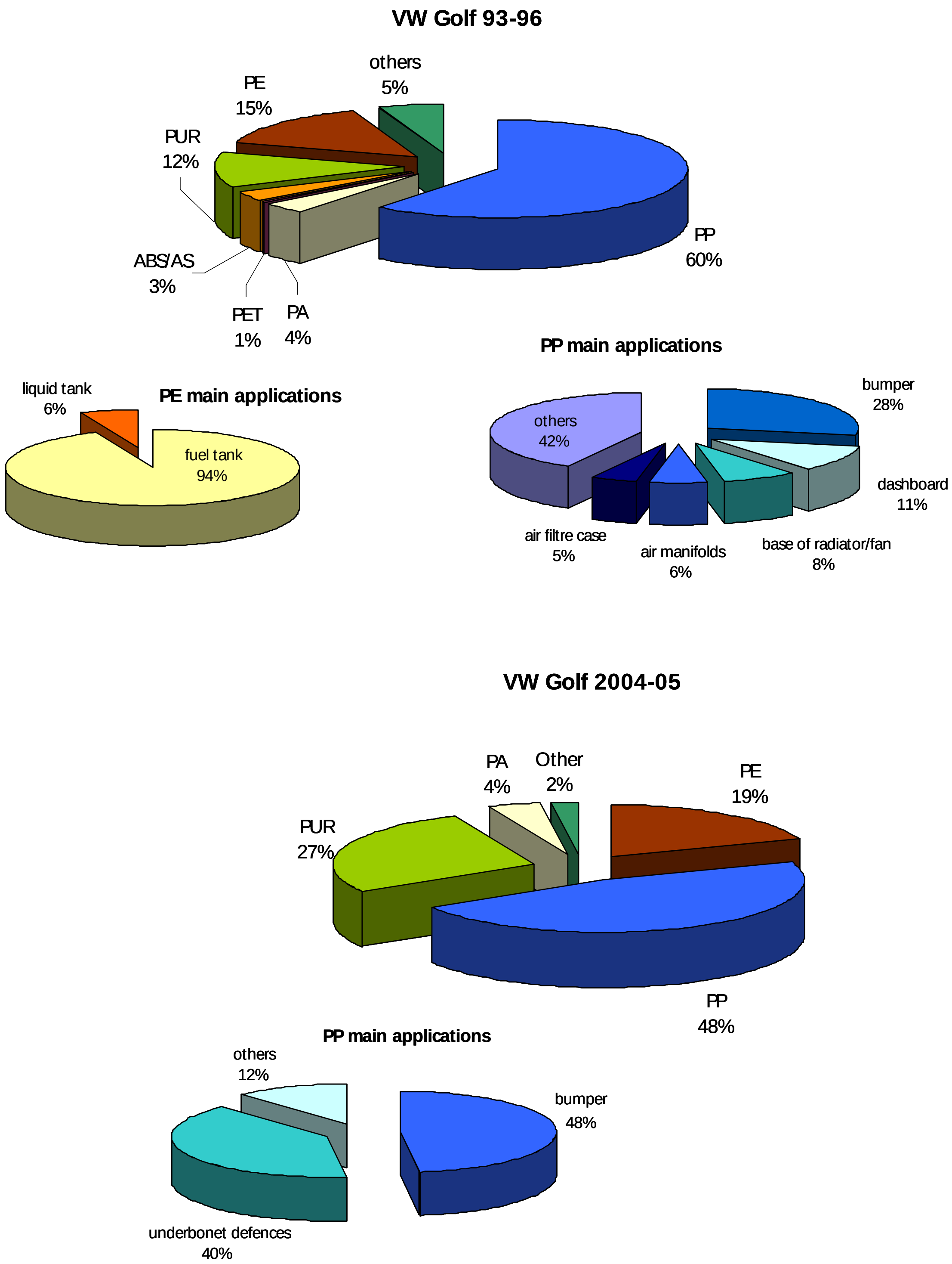


Figure 38. Polymers by application in VW Golf of different manufacture years (Source: IDIS)

3.2. MOST COMMON POLYMERS AND THEIR MAIN APPLICATIONS

3.2.1. Polypropylene

- BATTERY CASES

A car battery is basically made of lead, polypropylene plastic, and electrolyte (a sulfuric acid and water mixture). It weighs a little over 30 pounds (0.454 kg = 1 pound). Lead (including lead compounds) is about 75 percent of this weight. The electrolyte weighs in at 15 percent, and the plastic (mainly PP) is around 5 percent. The remaining 5 percent is silica and other residual materials[109].

- BUMPERS

Bumpers are one of the heaviest plastic parts of the vehicle. The average weight of a bumper is around 5 kg and the predominant materials are PP, PE/ABS or PC/PBT.

Gaiker carried out an analysis of the material composition of automobile bumpers. Different model of vehicles were studied, summing up to a total of 243 samples:

Table 28. ELV passenger car bumpers (Source: GAIKER[110])

Materials	Bumpers	%
PP	210	86
PP+foam	15	6
PC/PBT	8	3
Glass Fibre	10	4
Total	243	100

- AIR DUCTS

Air duct is located in the interior of the car and deliveries air to the passengers. The air duct has many parts, however it is estimated that the 80% of the component it is made of PP and 20% of filler (talc).

Car bumpers, air ducts and instrument panels can be recycled and recovered to produce new car parts. The only drawback is that most recycling grades are black and this limits the applications of PP recyclate. To ensure quality, only 20-30% of old material is used in new car parts. Moreover, by producing single polymer assemblies that do not need dismantling after removal, plastic recovering can become more economical and easier. For example, an all-PP bumper system comprised of a glass mat reinforced beam, an energy absorbing PP particle foam and an PP outer skin is available.

3.2.2. Polyurethane

- SEAT CUSHIONS:

Mainly all of the PU consumed in a vehicle it is used in seat cushions, this component comprises with hardly all the PU used in the vehicle around the 75%. The PU is one of the key plastics used in the automobiles accounting with the 12% more or less of the total, 6.5 kg per car [111]

3.2.3. Polyethylene

- FUEL TANKS

Fuel tanks are mainly made out of plastics, in Europe 92% of them are made of HDPE. An study made by Gaiker Technological Centre shows that the main material use in the production of fuel tanks is HDPE, and the part average weight is 8 kg.

Some of the handicaps that it is possible to come up with are:

- Dust and dirtiness on the surface
- Metallic inserts
- Fuel remains

A project developed by the US Environmental Protection Agency (EPA) in collaboration with the University of Michigan about Fuel Tank Systems concludes that an average US HDPE fuel tank weight is 14.07 kg. The HDPE tank is made of six-layer plastic structure, which consists mainly in HDPE. The six layer of the tank, from outer to inner, include: virgin HDPE mixed with carbon black, a regrind layer with which incorporates flash and scrapped tanks, an adhesive layer, and EVOH copolymer barrier, an adhesive layer, and finally virgin HDPE[112].

3.2.4. Polyamide

- HUB CAPS

Main applications of PA are in hubcaps. Gaiker carried out an analysis of the material composition of the auto hubcaps. Different model of vehicles were studied, a total of 48 samples, with the following results:

Table 29. Analysis of ELV hubcaps samples (Source:GAIKER [110])

MATERIALS	Hubcaps	%
PA66/PA6	34	71
PPE+PA	3	6
SAN	5	2
ABS	3	11
ASA	1	6
PPE+SB	3	2
Unknown	1	2

Total	48	100

Normally hubcaps appear like a blend of materials, the polymer plus fillers and glass fibre. There is an average of 15% of filler and 20% of GF.

Some of the handicaps that it is possible to come up with for recycling are:

- Dust and dirtiness on the surface
- Metallic inserts
- Almost all the hubcaps analysed were painted

4. ANNEX 1.4 – POLYMERS IN CONSTRUCTION SECTOR

Across the UE the consumption of plastics in the B&C sector is very different from one country to another, due to material preferences (wood *vs* plastic & concrete) and building patterns (blocks *vs* (semi-)detached houses, dense *vs* scattered areas..) for housing. In Western Europe the largest plastic consumers in the sector are Germany, France, UK and Italy as shown in the next table:

Table 30. Detail of plastic consumption by country WE 1995[113]

Country	1000 tonnes/year	%
Germany	1299	27
France	891	18
UK	710	15
Italy	552	11
Spain	225	5
The Netherlands	267	5
Total Western Europe	4890	100

4.1. MAIN APPLICATIONS OF POLYMERS IN B&C SECTOR

4.1.1. Pipes and ducts

In terms of plastic consumption, pipes and ducts is the biggest product group within the building sector accounting for the 40%.

PVC is the main plastic used in Western European piping with around 60 wt.% of plastic in this application and accounting for 27% of all PVC products manufactured in Europe[114]. The second largest polymer used is HDPE. Assuming that IAL data are more recent, next table shows a shift from PVC to HDPE pipes.

Table 31. Pipes & Ducts market by polymer

Polymer	% (APME)	% (IAL[115])
PVC	70	56
PP	6	6
HDPE	18	31
LDPE	5	5
ABS	1	2

Normally, pipes are made of monoplastic material which facilitates its identification and separation in the recycling process. In the next figure it is shown an overview of typical PVC pipe composition:

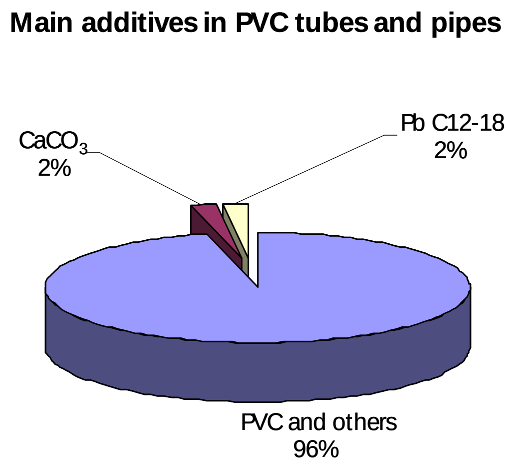


Figure 39. Main additives in PVC pipes (Source: TUHH 1999[116])

Some manufacturers use recycled PVC pipes as a feedstock for new pipes. For example, triple-wall sewer pipes are made using thin outer and inner walls of virgin PVC with a thicker layer of recycled material as the middle layer. The recycled content of these pipes can be as high as 60 per cent by weight.

4.1.2. Windows, profiles and wall and floor coverings

In this category three different applications have been included because of their similarity in the polymers used. It could be said that almost 100% of the plastic content in these applications is PVC.

Some 40% of all European window profiles are made from PVC using about 600,000 tonnes, more than 10 %of Western European PVC production. Consumers choose PVC windows because they are tough and durable, require low maintenance, do not rot, offer design flexibility, are competitive in terms of price, and can be easily processed and fabricated[117].

As pipes & ducts, window profiles and other profiles are made of monoplastic material which facilitates its identification and separation in the recycling process. The next figure shows an overview of typical windows composition:

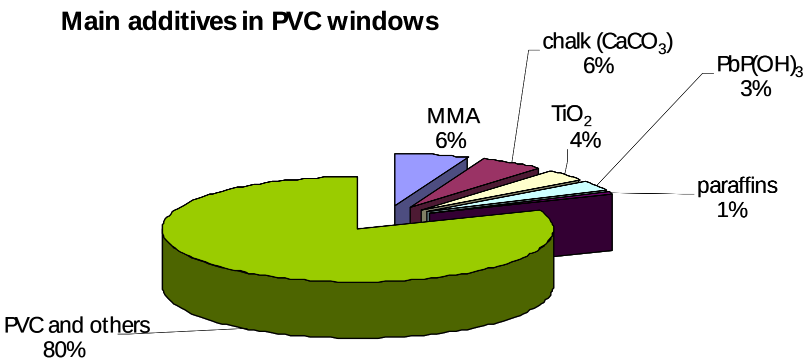


Figure 40. Main additives in PVC windows[118]

In the same way, PVC is also the main plastic used for sheet and tile flooring. Over 800,000 tonnes of PVC flooring were used in Western Europe in 1999.

4.1.3. Insulation panels

Insulation panels are one of the major plastics applications in B&C sector, the second one after piping. The most common polymers used for insulation are EPS, XPS and PU, whose main application is in residential and commercial construction.

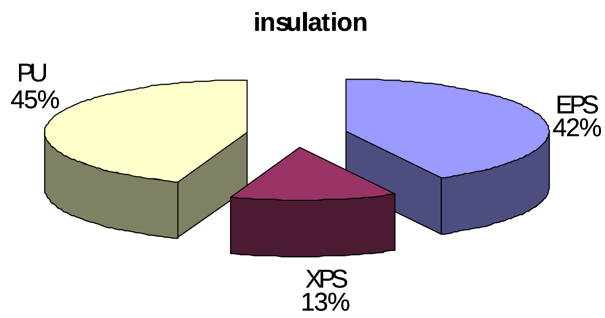


Figure 41. Polymer share in insulation application

- EPS INSULATION PANELS

Expanded polystyrene sheathing is used in new construction as well as remodelling. It is compatible with wood and steel framing, and masonry applications.

Aluminium foil, polyethylene and kraft paper are all used to enhance performance properties and protect it from rough handling and ultraviolet degradation. EPS manufacturers use reflective aluminium foil to increase the resistance of radiant heat absorption[119].

The EPS comprises the following materials[120]:

- STYRENE: Polystyrene has a maximum styrene content of only 0.1% by weight, and since EPS contains only 2% polystyrene by volume (air constitutes the rest), this minute trace of styrene monomer poses no threat to health whatsoever.
- PENTANE: About 6% of pentane is incorporated into the expandable polystyrene granules as a blowing agent. It is a saturated hydrocarbon, not to be confused with (H)CFCs. Pentane is non-toxic and constitutes no threat to the ozone layer.
- FIRE RETARDANT: EPS is available either with or without the fire retardant hexabromocyclododecane (HBCD), which constitutes a weight of maximum 0.5% of the final product. It is a cycloaliphatic fire retardant and not comparable with the aromatic brominated fire retardants (PBBs and PBBOs). HBCD is present in EPS in such a minute quantity that it poses no risks to health whatsoever. Moreover, it remains within the closed cells of EPS and does not dissolve in water.

EPS can be recycled directly into new building products once it comes to the end of its life.

- XPS INSULATION PANELS

Although, the majority of insulation panels are manufactured with Expanded Polystyrene (EPS), Extruded Polystyrene (XPS) panels can also be found, which use a hydrochlorofluorocarbon (HCFC) gas as the expanding agent[121] .

XPS is manufactured from polystyrene resin, which is a thermoplastic material. This means that it can be melted and re-inserted into the manufacturing process to produce new XPS insulation. In fact, XPS manufacturing plants create virtually no 'scrap' or waste material. This is because essentially 100% of the industrial waste XPS boards are recovered, ground-up, re-pelletized back into the polystyrene resin material, and reused in the XPS manufacturing process. Some XPS companies even seek outside sources of scrap polystyrene resin to reuse for this purpose. In addition, post-consumer XPS insulation boards can be reused in many commercial applications—especially re-roofing.

By 2010, XPSA (Extruded Polystyrene Foam Association) member companies will undergo another blowing agent conversion. This is because HCFC blowing agents will no longer be available for use in foam plastic insulation per Montreal Protocol deadlines. There are no immediate technically-feasible replacement materials available for this conversion as was the case during the switch from CFCs to HCFCs in the late 1980's/early 1990's[122].

- PU INSULATION PANELS

Polyurethane is a relatively new product, roughly around 35 years, but has become the most used insulation plastic. Polyurethane foam was produced to replace the shortfalls of expanded polystyrene.

PU insulation contains a blowing agent (an HCFC gas) and throughout the years it may escape as some diffuse emissions [123].

Brominated fire retardants have been used with PUR insulation panels, recently being replaced by phosphor based FR's.

5. ANNEX 1.5 – POLYMERS IN AGRICULTURE

Around 60% of the plastic consumption in the agriculture sector is focused on 2 applications: covers (greenhouse, mulching and tunnel) and silage. The countries with higher consumption on plastic covers are Italy, Spain, France and Belgium, while countries like the Netherlands and Finland silage consumption are the most important agriculture plastic waste source.

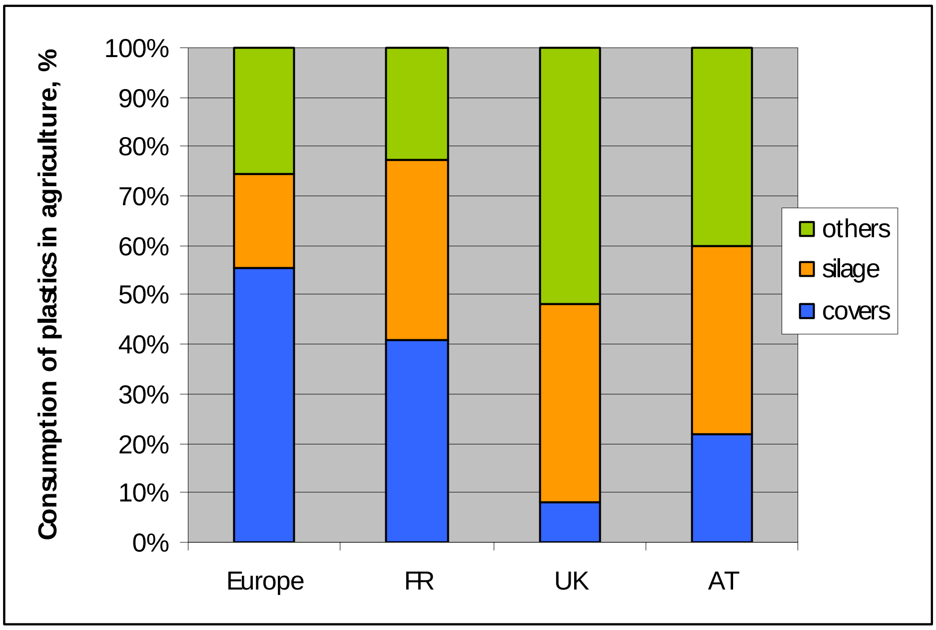


Figure 42. Share of covers and silage in total plastic consumption in agriculture (Source: ADEME[124], EPRO[125], WRAP[126], Umweltbundesamt[127])

5.1. MAIN APPLICATIONS OF POLYMERS IN AGRICULTURE

5.1.1. Films for crop covering

Plastic covering, either framed or floating, is now used worldwide to protect crops from unfavourable growing conditions, such as severe weather and insects and birds. The use of covering techniques started with a simple system such as mulching, then row covers and small tunnels were developed and finally plastic houses. Floating mulch was an exception to this sequence, since it was introduced rather recently.

Table 32. Plastic for crop covering

Greenhouses, Tunnels	Greenhouse and tunnel films are generally made at very high layflats, as high as 65 feet. As a result, bubble stability is very important during production. Greenhouse and tunnel films must: • Resist exposure to UV • Resist fogging due to condensation of interior moisture • Resist environmental contaminants (acid rain, particulate) • Be tough enough to withstand abuse • Allow the transmission of light UV protection and antifogging are typically accomplished using additives. A typical film might be made of a blend of LLDPE and LDPE, with additives. A low MI LDPE (0.2) provides the best stability, but the least favourable clarity. Adding a high MI LDPE (2.0) will give better clarity, but less bubble stability. The choice of LLDPE and LDPE also depends on equipment capabilities. In most countries, greenhouses are made of plastic and glass; the majority are plastic, although, as is well known, almost all greenhouses are glass in the Netherlands where the greenhouse area is over 8,000 Ha. Northern Italy and southern France also constitute a reference for Glass greenhouses. Glasshouses and rigid-plastic houses are longer-life structures, and therefore are mostly located in cold regions where these structures can be used throughout the year[128].
Mulch Films	Mulch films serve a number of different purposes. Transparent mulch film is used to encourage early season plant growth and early cropping, whereas black mulch films are used to control weed growth and white films provide reflected sunlight for the plants. In all cases, a more effective use of the available water is achieved. Most mulch films are 10 to 50 microns in thickness and used in widths up to 3 m.

As stated before, agriculture plastic consumption, and even more plastic for crop covers have very specific geographical distribution, where Italy and Spain are leading countries.

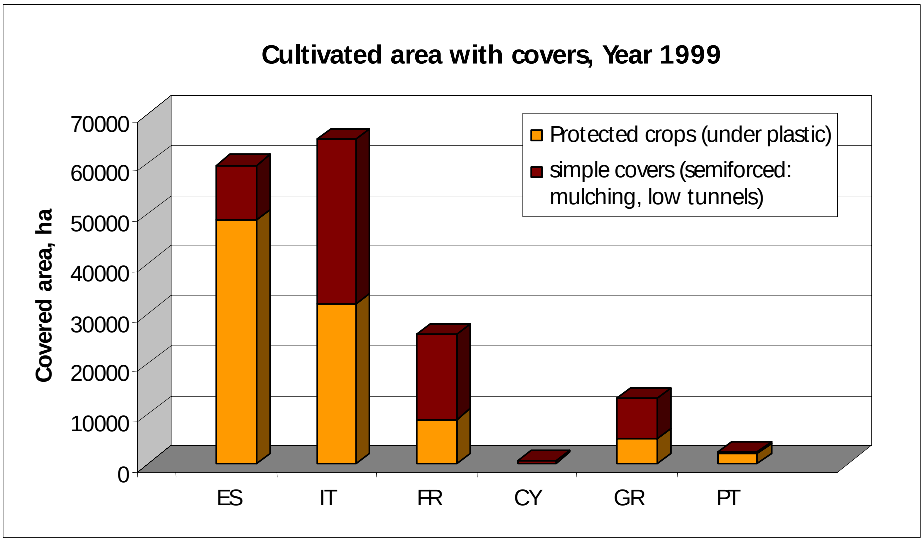


Figure 43. Protected crops (green house and simple covers) in different European countries

As shown in the figure above not only the total area of under-cover cultivation varies across countries, but also the technology chosen. In the last years the use of plastic films for agricultural soils mulching and for low tunnels -in particular based on polyethylene (PE) and ethylene-vinylacetate copolymers (EVA)- has shown an increasing diffusion. In Italy the plastics employed for these purposes cover an area of more than 100.000 hectares in 2005 with an annual consumption of about 65,000 tonnes[129].

The following figure gives more detail on the use of different plastic covers in European countries during 1999.

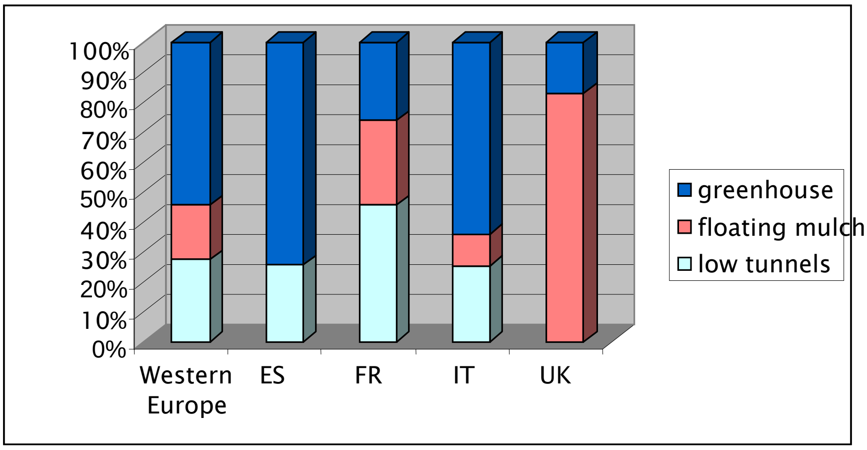


Figure 44. Under-cover technologies used in different countries

Data on plastic consumption for crop covering in European countries is very disperse and shows high variation among sources. The following figure summarises some of the consumption reported for main agriculture plastic consumers:

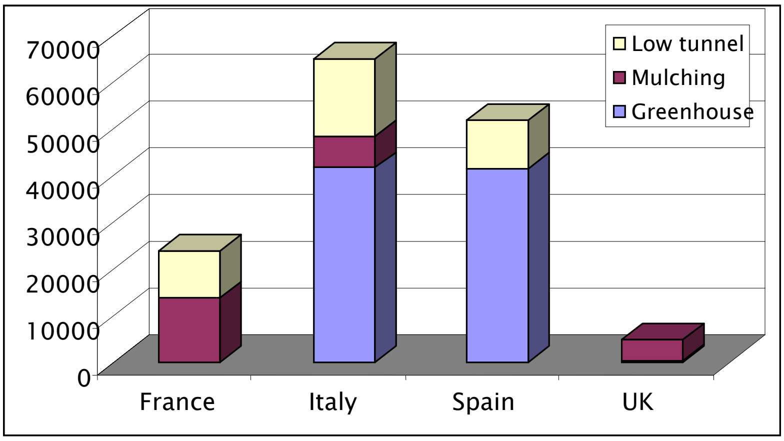


Figure 45. Plastic consumption for under-cover crops in 4 European countries. Data sources: Ademe[124] (France), Picuno & Sica[130] (Italy), Cicloagro[131] (Spain), WRAP[126] (UK).

Considering that these countries amount for 70% of the European under-cover crop area, it can be estimated that the total plastic use for greenhouse, mulching and tunnels rises up to 208.000 tonnes. This estimation is consistent with the data published by EPRO[125].

Another issue to consider is the high content on contamination of plastic covers in agriculture applications, which interferes significantly with the generated waste amount. In fact, the contamination level in mulching rises up to 70%, and 50% in other covers[124]. The following table summarises the plastic waste and the total waste (including other contaminants) generated in different European levels, as well as the estimations for the EU-25 area.

Table 33. Plastic waste amount generated in crop cover applications, with and without contamination considered.

tonnes	PLASTIC WASTE GENERATED				CONTAMINATED WASTE GENERATED			
	Greenh.	Mulching	Tunnel	Total	Greenh.	Mulching	Tunnel	Total
France		14,000	10,000	24,000		17,000	15,000	32,000
Italy	41,737	6,842	16,421	65,000	62,605	27,916	24,632	115,153
Spain	41,531		10,383	51,914	62,297	17,651	15,574	95,522
UK	500	4,500		5,000	750	7,650		8,400
Other countries	119,411	36,125	52,464	208,000	125,652	62,567	55,206	251,075

5.1.2. Silage film

Silage films maintain the nutritional value of forage plants such as corn, vegetables, and grasses that continue to respire after cutting. Silage film exclude the air so lactic acid fermentation can take place, leaving a feed rich in vitamins and carotene. When silage film is used, the feed can keep its nutrients for several months, depending on the amount of air left (the less air, the better). Thus, feed is available for use during periods when forage is not available in sufficient quantities.[132]

The agriculture plastic consumption in silage is another important waste source. There is no specific data on European consumption, but only on determined countries. However, according to the data compiled it can be estimated that silage represents around 32% of plastic consumption in the agriculture sector.

As stated before, contamination in agriculture plastic waste is a key factor that influences strongly the amount generated. Contamination in silage film consists of solid and liquid organics (silage is fermented fodder) as well as sand and soil, and can consist on 50[126]–70%[124] of the generated waste.

Four types of polymers can be found in silages (LLDPE, LDPE, EVA/EBA and PVC.), although LDPE and LLDPE dominates the markets, as shown in Spanish and English[133] data, for example.

Table 34. Plastic use in silage in different countries.(* UK/England & Wales data do not consider pipes and similar structures in the total plastic waste in the agriculture sector)

Silage / total agriculture plastic (tonnes)	Total agriculture plastic	Silage consumption	Contaminated silage waste generated
World consumption	2847000	54000	75.600
France[124]	47.500	27.500	38.500
UK[126]*	37.219	25.000	35.000
England & Wales[133]*	101.369	54.416	76.182
Total Europe (estimated)	900.000	290.542	406.759

5.1.3. Other applications

There is limited and disperse data on other application of plastics in agriculture. Other relevant applications in the sector are mentioned bellow:

- sheets and plates of clear PVC, PMMA, glass reinforced polyester and PC used for lightweight glazing;
- heavy duty sacks for all kinds of agricultural and horticultural supplies (fertilisers, compost, food…);

- Moulded products (horticultural growing pots, boxes, cases and crates, tanks, packaging containers, components for irrigation systems…)
- Non-woven polyolefin fabrics (mainly PP) for flat films;
- extruded pipe and tubing, both flexible and rigid, in PE and PVC;
- extruded PE netting;
- rope and twine

Non-packaging applications amount for 55-59% of the plastic in agricultural waste. In this category pipes and fittings for structural and watering purposes are also considered, but not sacks or agrochemical packages, which represent an important use. On the other hand, the agricultural plastic waste generated in England & Wales report other plastic waste streams[133] that exclude structural material (Table 36).

For the purpose of this study, and considering the average contribution of different applications in the studied countries, the percentages shown in Table 37 have been considered.

Table 35. Percentage of non-packaging applications of plastics in Spain (consumption)*.

Other non packaging agricultural applications		Spain (ANAIP)[10]	Spain (CEP)[134]
Nets and mesh	LDPE	11%	5%
Pots and trays	LDPE	2%	1%
	HDPE	–	3%
Pipes and fittings	PVC	26%	11%
	LDPE	5%	28%
Nets	LDPE	–	5%
	HDPE	3%	1%
Rope, strings, ogher fabrics	PP	7%	6%

(*) *The percentages are calculated without considering packaging in agriculture.*

Table 36. Polymers in other non structural plastic waste from the agriculture sector.

Other non structural plastic waste in agriculture		Austria[127] (*)	England & Wales[133]	UK[126]
Cover plastic	LDPE	22%	23%	8%
Silage plastic	LDPE	31%	54%	40%
Fertiliser bags – liners	PP / PE	22%	4%	20%
Seed bags	PP		1%	2%
Feed bags	LDPE	1%	1%	18%
String / net wrap	PP	1%	12%	
Agrochemical containers	HDPE		2%	4%
Pots	–	1%		
Other packaging (flowers, soil...)	–	9%		

(*) *percentages adapted considering 22% of plastic cover, since this category is not considered in the study at all.*

Table 37. Estimated amount other applications to total plastic waste generation in the agriculture sector.

Application		Tonnes
Fertiliser bags – liners	PP	27,111
	LDPE	26,337
Seed bags	PP	5,286
Feed bags	LDPE	9,838
Agrochemical containers	HDPE	10,579
Nets and mesh	LDPE	44,884
Pots and trays	LDPE	8,365
	HDPE	8,481
Pipes and fittings	PVC	157,371
	LDPE	43,477
Nets and mesh	LDPE	13,327
	HDPE	12,643
Rope, strings	PP	36,301
TOTAL		404,000

5.2. MOST COMMON POLYMERS IN AGRICULTURE

5.2.1. LDPE

LDPE and LLDPE are main materials used in covers (mulching, tunnel and greenhouse. As packaging it is used for the inner liners of fertiliser bags and feed bags. silage clamp plastic is also made of LDPE, as is. LLDPE is used for silage bale wrap and packaging shrink-wrap.

Regarding the recycling possibilities of these films it must be considered that UV light damage and contamination (dirt, sand, grease, grime, vegetation, moisture, pesticide residues or labels, glue, tapes…) limit the recyclable of plastic films. The degree of contamination of agrofilms depends on the type of film application[135, 136]

Table 38. LDPE/LLDPE Waste generated and their environmental implications. The waste amounts reported include contaminants from soil, moisture, chemicals, etc, detailed in next table.

	Total waste	Calorific Value	CO_2 equivalent	Energy
LDPE & LLDPE	Tonnes	GJ	CO_2 tonnes	GJ
Greenhouse	131.205	3.883.664	175.814	7.023.833
Mulching	78.696	1.603.950	72.611	2.900.838
Tunnel	63.326	1.874.461	84.857	3.390.073
Silage	406.759	12.900.065	583.989	23.330.523
Fertiliser bags – liners	26.363	1.169.368	52.938	2.114.870
Feed bags	9.838	436.787	19.773	789.955
Pots and trays	9.706	430.941	19.509	779.383
Pipes and fittings	50.433	2.239.237	101.371	4.049.792
Nets and mesh	15.464	686.600	31.083	1.241.756

Table 39. Contaminants in different LDPE/LLDPE applications

LDPE & LLDPE	Contamination
Greenhouse and tunnel	Possible UV degraded and contaminated by: – moisture – rust from greenhouse structure – metal staples – pesticides residues and sand and soil. Contamination is estimated to be up to 50% of the waste by weight.
Mulching	Can have contamination of up to 50[126]–70%[124] by weight, which makes mulching films difficult to recover. In this also fumigation films are included, which exhibit glue contamination in a proportion (25%) too high for efficient reclaiming. Even a water soluble glue that could be washed could increase the cost of water treatment so as to prohibit the film's recycling.
Silage	Contamination consisting of solid and liquid organics (silage is fermented fodder) as well as sand and soil. The unpleasant odour of cooked silage in reclaimed plastic pellets may be a barrier for recycling. However, the heavy film gauge range (4-9.5 mils) may add enough value to the material to warrant profitable recycling.
Fertiliser bags – liners	The inner liners (LDPE) of fertiliser bags often still have fertiliser residues and are thus not attractive to recyclers. 0.1% of contamination has been estimated, which is the maximum allowed by many European countries for their management as non-hazardous wastes[133].
Nets and mesh	Contamination with soil and organic material (not considered)
Pots and trays	

5.2.2. HDPE

HDPE is an important polymer in the agricultural industry. It is mainly found in the form of plastic containers. These are used to store pesticides, disinfectants and other clearing chemicals. These plastics are usually unattractive to the recycling industry as they are seen to contain hazardous waste. It is true that such plastics are contaminated by materials that in themselves would be hazardous waste. However, the level of contamination on a triple-rinsed container is unlikely to render the plastic hazardous in most situations.

Several European countries have established that containers are only considered as hazardous wastes if they contain more than 0.1% of their original contents, recyclers are still reticent about dealing with these waste streams. It seems there is a perception among recyclers that, if they were to handle large numbers of containers, the hazard would increase significantly.

HDPE is also used ain other applications as pots, trays, nets, etc.

Table 40. HDPE waste generated and their environmental implications. The waste amounts reported include contaminants from soil, moisture, chemicals, etc, detailed in next table

	Total waste	Calorific Value	CO_2 equivalent	Energy
	tonnes	GJ	CO_2 Tonnes	GJ
Agrochemical containers	10,684	446,413	19,147	843,107
Pots and trays	9,841	415,278	17,812	784,304
Nets and mesh	14,670	619,088	26,553	1,169,225

Table 41. Contaminants in different HDPE applications

HDPE	Contamination
Agrochemical containers	0.01% concentration of contaminants in the waste is estimated
Pots and trays	Contamination with soil and organic material (not considered)
Nets and mesh	Can suffer UV degradation

5.2.3. PP

PP is mainly used to make the outer load-bearing cover of bags and string and net wrap.. However, the grades of PP used for these waste streams are quite different in terms of process settings. PP string and netting (a higher grade), and horticultural plastic would need to be carefully segregated from PP bulk bags.

Table 42. PP waste generated and their environmental implications. The waste amounts reported include contaminants from soil, moisture, chemicals, etc, detailed in next table.

	Total waste	Calorific Value	CO_2 equivalent	Energy
	Tonnes	GJ	CO_2 Tonnes	GJ
Fertiliser bags – liners	27.138	1.111.557	52.053	2.087.558
Seed bags	5.286	216.724	10.149	407.018
Rope, strings	42.121	1.726.966	80.873	3.243.327

Table 43. Contaminants in different PP applications

PP	Contaminants
Fertiliser bags – liners	Contamination up to 0.01% has been estimated

5.2.4. PVC

Although there are other applications as hoses, or sheets, the main use of PVC is in pipes and fittings. Since their function is structural, their lifespan differs from other applications. However, for the purpose of this study, waste generation has been assimilated to material consumption.

Table 44. PVC waste generated and their environmental implications. The waste amounts reported include contaminants from soil, moisture, chemicals, etc, detailed in next

PVC	TOTAL WASTE	Calorific Value	CO_2 equivalent	Energy
	Tonnes	GJ	CO_2 tonnes	GJ
Pipes and fittings	182.550	6.206.697	334.066	11.354.605

5.2.5. EVA

Thanks to the good mechanical and spectroradiometrical characteristics of EVA film, it is progressively replacing other polymers traditionally used as cladding material for protected cultivation. EVA is gradually being more used in greenhouse and mulching films. On many occasions it appears as EVA modified polyethylene —or rather PE/EVA and EVA/EBA co-polymers— or as co-extruded layers in films[130, 131].

6. GLOSSARY

ABS: Acrylonitrile Butadiene Styrene

ACEA: European Automobile Manufacturers Association

ACORD: Automotive Consortium on Recycling and Dismantling

ADEME: Agence de l'Environnement et de la Maîtrise de l'Energie

ANAIP: Asociación Nacional de Industrias del Plástico

ANEP: Asociación Nacional del envase del PET

A-PET: Amorphous Polyethylene Therephthalate

APME: Association of Plastics Manufacturers in Europe —now *PlasticsEurope*

ASA: Acrylonitrile Styrene Acrylate

ASR: Auto(motive) Shredder Residue

B&C: Building and Construction

BDP: (Bioplastics and) Biodegradable Polymers

BFR: Brominated Flame Retardant

BOM: Bill of Materials

BW: Bagged Waste

C&D: Construction and Demolition

CE: Consumer Electronics

CEP: Centro Español de Plásticos

CFC: Chlorofluorocarbons

C-PET: Crystalline Polyethylene Therephthalate

CPU: (Computer) Central Processing Unit

CRT: Cathode Ray Tube

DfD: Design for Disassembly

DfR: Design for Recycling

E&E: Electric and Electronics

EBA: Ethylene Butyl Acrylate

EEA: European Environment Agency

ELV: End-of-Life Vehicles

EOL: End-of-Life

EP: Epoxy (resin)

EPRO: European Association of Plastics Recycling and Recovery Organisations

EPS: Expanded Polystyrene

ESTO: European Science and Technology Observatory

ETC/WMF: European Topic Centre on Waste and Material Flows

EuPC: European Plastic Converters

EVA: Ethylene Vinyl Acetate

EVOH: Ethylene Vinyl Alcohol

FDP: Flat Display Panel

FR: Flame Retardant

GDP: Gross Domestic Product

GF: Glass Fibre

GH: Greenhouse

GHG: Greenhouse Gases

HCFC: Hydrochlorofluorocarbons

HDPE: High Density Polyethylene

HDTV: High Definition Television

HHW: Household Waste

HIPS: High Impact Polystyrene

IBC: Intermediate Bulk Containers

ICT: Information and Communication Technologies

IDIS: International Dismantling Information System

IT: Information Technologies

LCD: Liquid Crystal Display

LDPE: Low Density Polyethylene

LHH: Large Household (appliances)

LLDPE: Linear Low Density Polyethylene

Mio. tonnes: Millions of tonnes

MPV: Multi Purpose Vehicle

MSW: Municipal Solid Waste

OEM: Original Equipment Manufacturer

OPP: Oriented Polypropylene

OPS: Oriented Polystyrene

PA: Polyamide

PBB: Polybrominated Biphenyls

PBDE: Polybrominated Diphenyl Ethers

PBT: Polybutylene Terephtalate

PC: Personal Computer / Passenger Car

PC: Polycarbonate

PDA: Personal Digital Assistant

PDP: Plasma Display Panel

PE: Polyethylene

PEN: Polyethylene Naphthalate

PET: Polyethylene Terephthalate

PETG: Glycol modified Polyethylene Teraphthalate

PF: Phenolic (resin)

PLA: Polylactic Acid

PMMA: Polymethyl Methacrylate

POM: Polyacetal (polyoxymethylene)

PP: Polypropylene

PPE: Polyphenylene Ether

PPO: Polyphenylene Oxide

PS: Polystyrene

PU: Polyurethane

PVC: Polyvinyl Chloride

PWB: Printed Wire (/Wiring) Board (also called *Printed Circuit Board*, PCB)

RoHS: Restriction of Hazardous Substances (in electrical and electronic equipment)

SAN: Styrene Acrylonitrile Copolymer

SHH: Small Household (appliances)

SMA: Styrene Maleic Anhydride

SMC: Sheet Moulding Compound

SUV: Sport Utility Vehicle

SWOT: Strength Weakness Opportunities Threats

TBBPA: Tetrabromobisphenol-A

th. Tonnes: thousand tonnes

TNO-STB: TNO-Strategie, Technologie en Beleid (TNO: *Netherlands Organisation for Applied Scientific Research*)

UP: Unsaturated Polyester

UV: Ultraviolet

VDI-TZ: VDI Technologiezentrum GmbH (VDI: *Verein Deutscher Ingenieure*)

VDU: Visual Display Unit

WEEE: Waste Electrical and Electronic Equipment

WRAP: Waste & Resources Action Programme

XPS: Extruded Polystyrene

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ANNEX 2

POLYMER RECOVERY TECNOLOGIES. TECHNOLOGICAL SHEETS

ID no.	WASTE STREAM	POLYMER	RECOVERY OPTION	TECHNOLOGY	PROCESS	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
1	Packaging	PET	Mechanical recycling	Advanced process	Adv - Ultra-clean regranulation Bottle-to-bottle (PET)	Conventional (Adopted and/or diffused in industry)	Post-consumer food packaging PET from separated collection schemes free of other plastic and non-plastic materials. Volatile matter contamination	Post consumer bottle flakes (shredded PET bottles, typically 12 mm screen), sorted and washed.	More than 25 recycling plants equipped with **Vacurema** system (industrial plant) in the EU (Austria, Belgium, France,Germany, Czech Republic, Netherlands, Portugal, Spain, UK) and Switzerland.	Production of upgraded recyclates (close-loop recycling)	Medium: Adoption and diffusions most likely, but maybe difficult
2	Packaging	PET	Mechanical recycling	Advanced process	Adv - Ultra-clean regranulation Bottle-to-bottle (PET)	Conventional (Adopted and/or diffused in industry)	Post-consumer food packaging PET from separated collection schemes free of other plastic and non-plastic materials. Volatile matter contamination admited.	Post consumer bottle washed, sorted and flaked (typically 10-12 mm screen). Washing to clean the surface from impurities and to remove labels and glue. Sorting to separate other plastics and polymer foreign materials from PET and to sort different colours such as clear, green, blue and others	Several processes combining washing & extrusion + SSP: **Bühler Bottle-to-Bottle System**: Amcor-Bühler PET bottle-to-bottle recycling plant in Beaune (France); **STEHNING BottletoBottle process (OHL)**: production unit at PET Kunststoffrecycling GmbH (PKR) in Beselich (Germany); **LEDA; Recostar PET iV+** process **(Starlinger)**	Production of upgraded recyclates (close-loop recycling)	Medium: Adoption and diffusions most likely, but maybe difficult
3	Packaging, ELV, WEEE, C&D	PVC	Mechanical recycling	Advanced process	Adv - Vinyloop	Conventional (Adopted and/or diffused in industry)	Post consumer PVC composites down to 60 wt% PVC content, recommended average PVC concentration of 85%. PVC compound composites containing the following material have been successfully tested in pilot plant: Polyester Fibres, Natural Textiles, Glass Fibres, PP, PE, Rubber, PU, Paper, Metals. Any combination of the above materials is also acceptable.	Post consumer PVC composite waste sorted by source (recommended). Pretreatment may include: a cleaning step (washing, etc.), reducing the size for fast dissolution (by cutting, grinding, milling, etc.) and a homogenization step.	**VINYLOOP** Pilot plant in Brussels, Solvay's Ferrara (Italy) industrial unit for cables. Schedule for further units to be built in Germany, Spain, France: Ferrari (France) industrial unit for architectural tarpaulin and canvas	Mechanical recycling of complex plastic mixtures	Medium: Further development promises added value for recycling
4	C&D, MSW (coated fabrics, e.g. tarpaulins, artificial leather)	PVC	Mechanical recycling	Advanced process	Adv - Vinyloop	In development (Applied research)	Polyester and PVC coated tarpaulins, covers and fabrics: cloth offcuts, returns of old worn -even printed - fabrics, welded advertising messages, etc., provided PVC makes up 2/3 of the weight, polyester 1/3. Not accepted: PU-coated waste products, imitation leather, packaging and accessories (eyelets, straps, cables, zip fasteners, boltropes, snap-rings, etc.), PVC fabrics coated on a PA support.	Material sorted into 3 classes: WHITE FLAME-PROOFED (non printed), COLOURED FLAME-PROOFED (including printed white) and NOT FLAME-PROOFED (all the rest). Material is ground, metal removed and compacted. If tarpaulin is very polluted (earth, mud, leaves or other), it should be rapidly washed then thoroughly rinsed and dried.	Vinyloop based **Texyloop** process by Ferrari & Solvay: industrial plant in Ferrara (Italy)	Mechanical recycling of complex plastic mixtures	Medium: Further development promises added value for recycling
5	ELV	HDPE	Mechanical recycling	Advanced process	Adv - Others	Emerging (Scientific basic research)		shredding and demetalisation of old fuel tanks. Separation of other plastics by sink-float.	RECAFUTA Project (Solvay) for close-loop recycling of discarded fuel tanks. Planned industrial plant in the Netherlands	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	High: Technology potentials are not utilised yet
6	Packaging, C&D, Agriculture	HDPE, LDPE, PP, PET, PVC	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	Conventional (Adopted and/or diffused in industry)	Single-material post consumer waste streams (e.g., window frames, pipes, bottles) of HDPE, PET, PVC… Metal + glass + non-reclaimed polymers < 5%	Cleaning and sorting (by polymer, grade and frequently by colour), removal of impurities, shredding and drying.	Recycling plant for PE & PVC plastic pipes in Wavin (NL), LINPAC recycling plant in Castleford (UK); OEMs: SOREMA turnkey recycling plants, LEDA recycling plants for PET and HDPE bottles…	Others	Low: Existing technology already reached its peak

ID no.	WASTE STREAM	POLYMER	RECOVERY OPTION	TECHNOLOGY	PROCESS	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
7	C&D (roof membranes)	PVC	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	Conventional (Adopted and/or diffused in industry)	PVC post consumer membranes from ROOFCOLLECT® programme: EOL PVC-P and EVA/PVC roofing membranes cleaned and free of remaining particles of glue or bitumen. Fleece-backed and adhered roofing membranes composed of PVC-P and EVA/PVC also admited.	Thermoplastic membranes must be shredded prior to injection moulding into floorings	JUTTA Hoser (Germany) industrial plant	Others	Low: Existing technology already reached its peak
8	C&D (flooring)	PVC	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	Conventional (Adopted and/or diffused in industry)	Sorted post-use PVC floor and wall-coverings and PVC residues. PVC floor on jute, felt or polyester felt is acceptable. Cement or glue residues adhering to the PVC do not present a problem; provided their weight is markedly less than that of the PVC floor-covering. Unable to accept PVC floor-coverings which are contaminated by oil, solvents or other dangerous substances.	The post-use PVC floor-coverings are broken up into chips no larger than 30mm in size. Following the magnetic removal of metals, the chips are freed from concrete and glue residues using a hammer-mill. Afterwards, a sieving machine separates the pieces from these unwanted residues.	AgPR cryogenic recycling plant in Troisdorf (Germany)	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
9	Packaging	PET	Mechanical recycling	Advanced process	Adv - Ultra-clean regranulation Bottle-to-bottle (PET)	Conventional (Adopted and/or diffused in industry)	The process accepts post-consumer, colour sorted PET beverage bottles – either refillable or single-trip. Removal of any coarse contaminants such as stones, metal parts or coloured bottles. Multilayer PET bottles limited: <1% PA	Bottles are wet ground into flakes and the mixture of PET bottle material, label material and caps is subjected to an intensive washing and separation process to remove any surface contamination. It then undergoes float separation and the polyolefin cap materials and label materials are skimmed off.	caustic cleaning and partial depolimerisation (surface layer peel-off) by **URRC process**: Cleanaway Plastic Recycling GmbH plants in Rostock (Germany) and Frauenfeld (Switzerland)	Production of upgraded recyclates (close-loop recycling)	Medium: Adoption and diffusions most likely, but maybe difficult
10	Packaging, WEEE, C&D, ELV	PS (EPS, XPS), ABS/PC and PVB	Mechanical recycling	Advanced process	Adv - Other solvent based physical techniques (i.e: Wietek)	In development (Applied research)	Other plastics or impurities (BFR incl.) accompaning the EPS+XPS do not dissolve and are not a problem.	grinding controlling the static charging before the dissolving step (avoid high fine particles content, dusting)	CreaSolv selective extraction process by CreaCycle GmbH developed in INNONET project (pilot plant and industrial scale-up) for EPS. CreaSolv ABS/PC and Creasolv PVB also offered.	Energy recovery/Recycling of plastics with halogenated flame retardants	High: Further development promises a maximum of added value for recycling
11	ELV	PVC, ABS	Mechanical recycling	Advanced process	Adv - Other solvent based physical techniques (i.e: Wietek)	In development (Applied research)	Copper (of the wire whose PVC is recovered)	No wire chopping.	Process developed by Delphi Automotive Systems in Wuppertal (DE) commercialized by Wietek GmbH (Germany)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Medium: Further development promises added value for recycling
12	C&D, MSW (coated fabrics, e.g. tarpaulins, artificial leather)	PVC	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	Conventional (Adopted and/or diffused in industry)		sorting and shredding	replag® recycling system in industrial plant of Friedola® Gebr. Holzapfel GmbH (Germany)	Others	Low: Existing technology already reached its peak
13	C&D (flooring)	PVC	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	In development (Applied research)		hand sorting to remove non-PVC materials and classify feedstream into calendared flooring and plastisol flooring.	Mechanical recycling ending with melt filtration trials at Techniplasper plant (Barcelona, Spain).	Production of upgraded recyclates (close-loop recycling)	Medium: Further development promises added value for recycling
14	C&D (windows frames)	PVC	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	Conventional (Adopted and/or diffused in industry)	Complete post-consumer windows are delivered, with rubber seals, mortar residues, etc. VEKA system mixes 4:1 post-industrial (pre-use) scrap with post-user material (for maintaining output quality).	Several shredding & milling operations combined with magnetic, Eddy current and pneumatic separation stages.	Mechanical recycling ending with melt filtration and colour separation at VEKA industrial plant in Behringen (DE) and FREI recycling plant in North Rhine-Westfalia (DE)	Production of upgraded recyclates (close-loop recycling)	Medium: Adoption and diffusions most likely, but maybe difficult

ID no.	WASTE STREAM	POLYMER	RECOVERY OPTION	TECHNOLOGY	PROCESS	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
15	MSW	Mixtures (MPW)	Mechanical recycling	Conventional process	Conv - Remelting and Pelletisation	Conventional (Adopted and/or diffused in industry)	total contamination <10% (metals < 3%, glass, sand & dirt < 2%, wood < 2%, paper & cardboard < 3%) Polyolefine content > 70% (in some processes) PVC content limited (in the range: 1-15%)	Removal of metals, mineral contaminants, wood and paper. Shredding, washing (not always) and drying. Adjusting mixture -polymers shares (not always).	J.E.T. recycling systems (OEM of processing machines & turnkey recycling plants for commingled plastics); Ligeplas recycling plant (Spain), Intruplas Ltd. and Lankhorst Recycling UK (UK)	Mechanical recycling of complex plastic mixtures	Low: Existing technology already reached its peak

ID no.	POLYMER	WASTE STREAM	RECOVERY OPTION	TECHNOLOGY	PROCESS	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
1	PET	Packaging	Feedstock recycling	Chemical depolymerisation methods	Other - Others	In development (Applied research)		Scraps	Henkel process	None	Low: Still no economically feasible way to implement the new technology
2	PET	Packaging	Feedstock recycling	Chemical depolymerisation methods	Chem - Methanolysis	In development (Applied research)			Teijin Mitsubishi Eastman Chemical Co.	None	High: Further development promises a maximum of added value for recycling
3	PET	Packaging	Feedstock recycling	Chemical depolymerisation methods	Chem - Glycolysis	Conventional (Adopted and/or diffused in industry)	Without contaminants	Clean scraps	Hoechst Celanese Wellman, Inc Eastman Chemical Co. AIES Company, Ldt. NanYa Plastics Co. Roychem	None	High: Further development promises a maximum of added value for recycling
4	PA 6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Hydrolysis	Emerging (Scientific basic research)	Without fillers	Clean scraps		None	Low: Long time perspective for further development
5	PA 6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Acidic depolymerisation	Conventional (Adopted and/or diffused in industry)		Scraps	BASF Rhône-Poulenc SNIA DSM and Allied Signal Rhodia	None	High: Little technical risk
6	PA 6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Alkaline depolymerisation	In development (Applied research)		Scraps	Laboratory stage	None	Medium: Further development promises added value for recycling
7	PA 6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Aminolysis	Emerging (Scientific basic research)	This process accepts PA 6,6		Laboratory stage	None	Low: Long time perspective for further development
8	PA 6	ELV	Feedstock recycling	Others	Other - Bacterial degradation	Emerging (Scientific basic research)			Laboratory stage	None	Low: Long time perspective for further development
9	PA 6,6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Acidic depolymerisation	Conventional (Adopted and/or diffused in industry)		Scraps	Du Pont	None	High: Little technical risk
10	PA 6,6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Alkaline depolymerisation	Conventional (Adopted and/or diffused in industry)		Scraps	BASF Rhône-Poulenc	None	High: Little technical risk
11	PA 6,6	ELV	Feedstock recycling	Chemical depolymerisation methods	Chem - Aminolysis	Emerging (Scientific basic research)	This process accepts PA 6,6	Scraps		None	Low: Still no economically feasible way to implement the new technology
12	PU	ELV C&D WEEE	Feedstock recycling	Chemical depolymerisation methods	Chem - Hydrolysis	In development (Applied research)	No mixed flexible foams	Scraps	Bayer and General Motors (pilot plant stage)	None	Low: Long time perspective for further development
13	PU	ELV C&D WEEE	Feedstock recycling	Chemical depolymerisation methods	Chem - Glycolysis	In development (Applied research)	Pure PU	Scraps	Regra (Germany), demo plant	None	Low: Long time perspective for further development
14	Mixtures (MPW)	MSW Packaging Agriculture WEEE ELV (ASR) C&D	Feedstock recycling	Gasification and other oxidative methods	Gas - Gasification	Conventional (Adopted and/or diffused in industry)	Free of metals PVC content limited (Cl<5%) Paper content limited	Shredded or chipped (SVZ: pelleted). Dry, residual moisture limited (Texaco: slurried with water, solids>60%). Combined with coal/oil.	Netherlands Refining Co. BV industrial practice (Netherlands); Global Energy, Inc. (former SVZ) BGL industrial practice at Schwarze Pumpe plant (Germany); Texaco process pilot trials; Shell process pilot trials at Nuon Buggenum plant (NL)	Feedstock recycling of complex plastics mixtures	High: Further development promises a maximum of added value for recycling
15	Mixtures (MPW)	MSW Packaging ELV (ASR)	Feedstock recycling	Gasification and other oxidative methods	Gas - Gasification	Conventional (Adopted and/or diffused in industry)		Wastes are press compacted, dried and degassified.	Thermoselect [pyrolysis + gasification] industrial practices in: Fondotoce (IT) -demo plant closed in 1999-, Karlsruhe (DE) -closed down in 2004 by strategic reasons- and Japan (e.g. Chiba plant)	Feedstock recycling of complex plastics mixtures	High: Further development promises a maximum of added value for recycling
16	HDPE, LDPE	MSW Packaging	Feedstock recycling	Gasification and other oxidative methods	Gas - Gasification	Conventional (Adopted and/or diffused in industry)	Aluminium & PE coated packaging waste only. Typical composition: 70 wt% wood fibres and 30 wt% PE.		Corenso United Oy Ltd. Industrial plant in Varkaus (Finland).	Feedstock recycling of complex plastics mixtures	High: Further development promises a maximum of added value for recycling
17	Polyethylene, polypropylene and polystyrene	Packaging and agricultural	Feedstock recycling	Thermal decomposition methods	Therm - Pyrolysis	In development (Applied research)	PVC, Not applicable PUR, Fair, Oil recovery is small Fibre Reinforced Plastics, Fair and Pre-treatment is required to remove fibres	Input feedstock plastics do not require washing or sorting	Liquefaction, pyrolysis and the catalytic breakdown of plastics to diesel (Thermalysis: Nabari plant (JP) & 1 plant under construction in Spain; Thermofuel by Ozmotech: 31 orders in EU)	Others	Medium: Adoption and diffusions most likely, but maybe difficult

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18	Mixtures (MPW)	WEEE ELV C&D Packaging	Feedstock recycling	Thermal decomposition methods	Therm - Pyrolysis	Conventional (Adopted and/or diffused in industry)	Free of non-plastics. BASF process accepts the average PVC content in packaging waste (DSD waste), which is 4-5% (i.e. maximum Cl content 2.5%.)	Ground & agglomerated. BASF: plastic is melted and dehalogenised	BASF conversion process: pilot plant (Germany) closed	Feedstock recycling of complex plastics mixtures	Medium: Technology potentials are not clear by all means
19	Mixtures (MPW)	WEEE ELV C&D Packaging	Feedstock recycling	Thermal decomposition methods	Thermal cracking	Conventional (Adopted and/or diffused in industry)	Free of non-plastics PVC content limited Metal content limited	Ground Residual moisture limited	Innovene (former BP Chemicals) Polymer Cracking Process (Grangemouth pilot plant)	Feedstock recycling of complex plastics mixtures	Medium: Further development promises added value for recycling
20	Mixtures (MPW)	WEEE ELV C&D Packaging	Feedstock recycling	Thermal decomposition methods	Thermal coprocessing with coal in coke ovens	In development (Applied research)	Free metals Free PVC	Ground Agglomerated	Nippon Steel (Nagoya and Kimitsu pilot plant)	Feedstock recycling of complex plastics mixtures	Medium: Further development promises added value for recycling
21	Mixtures (MPW)	WEEE ELV C&D Packaging	Feedstock recycling	Catalytic methods	Catalytic cracking	Emerging (Scientific basic research)	Free non-plastics PVC content limited	Ground Agglomerated	Kurata Process	Feedstock recycling of complex plastics mixtures	Low: Still no economically feasible way to implement the new technology
22	Mixtures (MPW)	WEEE ELV C&D Packaging	Feedstock recycling	Catalytic methods	Cat - Catalytic hydrogenation (Hydrocracking)	Conventional (Adopted and/or diffused in industry)	Plastics content > 90 wt% PVC content limited (< 4% or < 2 wt% chlorine) Metal content < 1 wt% Inerts < 4,5 wt%	MPW Ground (< 1 cm) and Agglomerated (bulk density > 300 kg/m^3) Residual moisture limited (water < 1 wt%)	Veba Combi Cracking process at KAB (Germany) -industrial practice closed down	Feedstock recycling of complex plastics mixtures	High: Further development promises a maximum of added value for recycling
23	Mixtures (MPW)		Feedstock recycling	Others	Other - Reducing agent in blast furnace	In development (Applied research)	Free PVC Free metals Free fibres	Ground	NKK Corp. British Steel (UK) Stahlwerke Bremen (Germany)	Feedstock recycling of complex plastics mixtures	High: Little technical risk
24	Mixtures (MPW)	MSW	Feedstock recycling	Others	Other - Reducing agent in blast furnace	In development (Applied research)	Cl = 0.5-5.0 wt% (MPW in MSW) Cl < 0.15 wt% (MPW after dechlor.) Low content of impurities	Dechlorination of MPW water slurry in a stirred reactor. Filtering & washing of the mixed plastic granules (fuel pellets).	DSM Research REDOP project bench scale and trials in CORUS commercial blast furnace in Ijmuiden (NL)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	High: Further development promises a maximum of added value for recycling
25	PVC	all types of PVC waste (C&D)	Feedstock recycling	Others	Other - Others	In development (Applied research)	Can accept pure PVC waste streams (does not need dilution with other waste materials)	Sorting and granulation. 1st stage: PVC dechlorination by hydrolisis. 2nd stage: pyrolisis	Combined hydrolisis-pyrolisis RGS-90 process: full-scale plant near Skælskør (DK) -on hold	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Medium: Adoption and diffusions most likely, but maybe difficult
26	PVC		Feedstock recycling	Gasification and other oxidative methods	Gas - Gasification	In development (Applied research)	All types of PVC admited. Iron and heavy metals separated from waste.	Shredding and screening of waste to the required particle size. Removal of metals after crushing (by magnet & gravity sifter).	Linde KCA slag bath gasification process: pilot plant in Solvay's Tavaux plant (France) -industrial plant discarded	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Low: Technical risks are too high
27	PVC	WEEE, C&D.	Feedstock recycling	Thermal decomposition methods	Therm - Pyrolysis	In development (Applied research)	Initially only PVC cable sheathings admitted. Pilot trials also with flooring materials, cable trays, artificial leather, binders, mixed German building waste and mixed Danish building waste. No restrictions on the chlorine content of the incoming materials. PVC-rich waste streams may contain other synthetics (rubber, light plastics, PTFF, etc.), metals, wood and sand.	In the pretreatment light plastics such as PE, PP, wood and the like are sorted out. Also, sand, iron, steel, brass, copper and other metallic pollutants are separated from the PVC. The PVC cable waste is separated (generally, by sink-float) into a metal fraction, a polyethylene (PE) residue (containing some PVC traces) and a PVC-rich waste fraction. PVC-rich waste fraction is dried after sink-float separation stage.	NKT-Watech two-step pyrolysis: pilot plant (Denmark) no funding for scaling-up	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Low: Still no economically feasible way to implement the new technology
28	PVC	C&D, WEEE, Packaging and their mixture	Feedstock recycling	Gasification and other oxidative methods	Gas - Gasification	In development (Applied research)	Trials have been carried out with a waste stream consisting of pure PVC waste but also with a mixture of PVC, PE, other polymers, rests of Cu, Al, chalk, cement and fibres.		Batelle/FERCO process in Akzo Nobel steam gasification pilot plant (The Netherlands) - large scale plant building plans stopped	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Low: Long time perspective for further development
29	PVC		Feedstock recycling	Chemical depolymerisation methods	Chem - Other chemolysis	Emerging (Scientific basic research)		A pretreatment method separates the plasticizer from pulverized feed material (soft PVC) in a subcritical aqueous environment.	Nikkiso two-stage PVC supercritical conversion into raw materials (Japan)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	High: Technology potentials are not utilised yet

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30	Mixtures (MPW)	ELV (ASR)	Feedstock recycling	Thermal decomposition methods	Gas - Other oxidative methods	Conventional (Adopted and/or diffused in industry)	ASR of wide composition range	No preatreatment needed for ASR	Ebara TwinRec (gasification combined with combustion) plants in Japan UBE Process and ICFG	Feedstock recycling of complex plastics mixtures	High: Adoption or diffusion is most likely
31	Mixtures (MPW)		Feedstock recycling	Catalytic methods	Cat - Catalytic coliquefaction	Emerging (Scientific basic research)			Laboratory stage (Greece)		Medium: Technology potentials are not clear by all means
32	Mixtures (MPW)	MSW, ELV (ASR)	Feedstock recycling	Thermal decomposition methods	Therm - Pyrolysis	In development (Applied research)		No MSW pretreatment in original Siemens process. Shredding in upgraded processes (Mitsui R21 & Takuma)	Siemens Schwel-Brenn process (combination of pyrolysis and combustion) 3 plants for MSW in Germany (one in Fürth); trials with ASR at the Ulm-Wiblingen plant (DE) -process no longer in operation due to economic reasons. Licensed in Japan: Mitsui-Babcock (focus on MSW) and Takuma Tech (Kanemura plant for ASR)	Others	Low: Still no economically feasible way to implement the new technology

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1	Agriculture Packaging ELV WEEE	Mixtures (MPW)	Energy recovery	Use as alternative/secondary fuel	Alt - Cement kilns (coal substitution)	Conventional (Adopted and/or diffused in industry)	PVC content limited	Chipped or shredded	Cementos Lemona (Spain, pilot plant) Lafarge Perlmooser (Retznei cement plant, Austria)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	High: Further development promises a maximum of added value for recycling
2	MSW	Mixtures (MPW)	Energy recovery	Energy production (Mono-combustion)	Mono - Incineration	In development (Applied research)	PVC content limited Heat Value between 9-13MJ/kg Metal content limited	Grounded	NEUTREC process (Dalmine - Bergamo, Italy)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	High: Little technical risk
3	MSW	Mixtures (MPW)	Energy recovery	Energy production (Mono-combustion)	Mono - RDF burning dedicated boiler	Conventional (Adopted and/or diffused in industry)	Free of metals Free of non combustible materials	Briquettes or pellets	Kobe Steel RDF plant (Japan)	Others	High: Little technical risk
4	MSW	Mixtures (MPW)	Energy recovery	Energy production (Mono-combustion)	Mono - Incineration	Conventional (Adopted and/or diffused in industry)	Free of metals Free of non combustible materials		ASM Brescia (IT), Wien - Meinel (AT), IMOG Harlebeke (BE), Brno (CZ), I/S Kara Roskilde (DK), SICDOM Rouen (FR), TEV Neumünster (DE), Envikraft Debrchen (HU), Högdalen Stockholm (SE)…	Others	Low: Existing technology already reached its peak
5	MSW + C&D (flooring, roofing, cables…) + Agriculture	Mixtures (MPW)	Energy recovery	Energy production (Co-combustion)	Co - Co-Incineration with other wastes	In development (Applied research)	Cl content not critical (>50% acceptable)	Mix of high-chlorinated wastes with HV control (by mixing with other wastes of lower HV). Shredding: particle size 10 x 10 x 10 cm	BSL/DOW rotary kiln plant with HCl recovery in Schkopau (DE)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Medium: Further development promises added value for recycling
6	MSW, MSW + C&D, MSW + ELV (fluff ASR), MSW + Packaging	Mixtures (MPW)	Energy recovery	Energy production (Co-combustion)	Co - Co-Incineration with other wastes	Conventional (Adopted and/or diffused in industry)	PVC content limited: additional PVC content to MSW's standard (av. 0.7%) < 2%	Size reduction (chipped or shredded) Mix of plastic wastes with MSW for HV control.	Incineration plants with HCl rectification: MVR Hamburg, SM Herten 3/4, SBA Fürth, RZR Herten, RVA Böhlen, RMVA Köln, RMHKW Böblingen, MHKW Kiel& Kempten, etc.(Germany); Kristinehedverket Halmstad (Sweden)	Energy recovery/Recycling of halogenated plastic waste (ie: PVC)	Medium: Adoption and diffusions most likely, but maybe difficult
7	MSW, Packaging	Mixtures (MPW)	Energy recovery	Energy production (Co-combustion)	Co - RDF burning multi-fuel boiler (with oil or coal)	In development (Applied research)	Metal and glass removed. 22 wt% water in PPF separated fraction to be converted in pellets	Pre-separated domestic waste as a 'Plastic-Paper Fraction' (PPF), which contains 36 wt.% plastic, 32.5% cellulose (wood, paper and textile) + 22% water converted into pellets (10-20 mm long). Subcoal pellets are pulverized onsite and mixed with coal at a pellet fraction of 0.5-1%	Subcoal project test run at plastic at the E.ON Maasvlakte power station (NL)	Others	Low: Still no economically feasible way to implement the new technology
8	MSW, Packaging, ELV (ASR)	Mixtures (MPW)	Energy recovery	Others	Other - Others	Conventional (Adopted and/or diffused in industry)	In the ASR treatment plants: ASR of wide composition range	No preatreatment needed for ASR	Ebara TwinRec (gasification combined with combustion) plants in Japan	Others	High: Adoption or diffusion is most likely
9	MSW, Packaging, ELV (ASR)	Mixtures (MPW)	Energy recovery	Others	Other - Others	Conventional (Adopted and/or diffused in industry)	High moisture content, low calorific value MSW MSW may have been previously sorted for removal of recyclable plastics (Mitsui R21, Compact Power...)	MSW shredded (e.g. to 200 mm in Mitsui R21 and 75 mm in Compact Power)	Pyrolysis + combustion processes: Mitsui R21(Japan), Von Roll RCP (DE), Pyropleq (DE), Compact Power (UK)...	Others	High: Adoption or diffusion is most likely

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1	MSW, Packaging, Agriculture	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Polymeric matrix recognition	IDSORT/POLY - MIR Spectroscopy	Conventional (Adopted and/or diffused in industry)	It is able to identify black plastics	Needs of surface preparation, Coatings have to be removed	Industrial practice (Bruker Optics)	Fast recognition and identification of plastics	Medium: Technology potentials are not clear by all means
2	WEEE,ELV,C&D (Streams that contain black plastics)	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Polymeric matrix recognition	IDSORT/POLY - MIR Spectroscopy	In development (Applied research)	It is able to identify black plastics	Needs of surface preparation, Coatings have to be removed	Bench Scale & Demo plants (European projects such as COMBIDENT & RECYCOMB)	Fast recognition and identification of plastics	High: Further development promises a maximum of added value for recycling
3	MSW, Packaging, Agriculture	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Polymeric matrix recognition	IDSORT/POLY - NIR Spectroscopy	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Industrial practice (LLA Instruments, Pellenc, RTT Systemtechnik)	Fast recognition and identification of plastics	Low: Long time perspective for further development
4	WEEE,ELV,C&D (Streams that contain black plastics)	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Polymeric matrix recognition	IDSORT/POLY - NIR Spectroscopy	In development (Applied research)	No aplicable	Coatings have to be removed	Bench Scale & Demo plants (European projects such as COMBIDENT & RECYCOMB)	Fast recognition and identification of plastics	Medium: Further development promises added value for recycling
5	MSW, Packaging, Agriculture	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Polymeric matrix recognition	IDSORT/POLY - Raman Spectroscopy	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Bench Scale & Demo plants (Spectracode: Industrial Raman RTP-1)	Fast recognition and identification of plastics	High: Further development promises a maximum of added value for recycling
6	WEEE,ELV,C&D (Streams that contain black plastics)	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Polymeric matrix recognition	IDSORT/POLY - Raman Spectroscopy	Emerging (Scientific basic research)	No aplicable	Coatings have to be removed	Laboratory Scale (Bruker Optics)	Fast recognition and identification of plastics	High: Further development promises a maximum of added value for recycling
7	MSW, Packaging, Agriculture, WEEE, ELV, C&D	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Element recognition	IDSORT/ELEM - Laser Induced Plasma Spectroscopy	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Industrial practice (LLA Instruments: Lipan 3002 Unit)	Fast recognition and identification of plastics	Low: Still no economically feasible way to implement the new technology
8	MSW, Packaging, Agriculture, WEEE, ELV, C&D	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Element recognition	IDSORT/ELEM - X-ray Fluorescence Spectroscopy	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Industrial practice (Niton Co: Niton XRF Portable Series; Horiba Jobin Ybon: XGT-1000WR, XGT-5000 Series)	Fast recognition and identification of plastics	Low: Long time perspective for further development
9	MSW, Packaging, Agriculture, WEEE, ELV, C&D	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Element recognition	IDSORT/ELEM - Sliding Spark Spectroscopy	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Industrial practice (IoSys: Slide Spec-S2)	Fast recognition and identification of plastics	Medium: Further development promises added value for recycling
10	MSW, Packaging, Agriculture	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Hybrid sensors	IDSORT/HYBRID - NIR & SS	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Industrial practice (IoSys: mIRoSpark)	Fast recognition and identification of plastics	Medium: Further development promises added value for recycling
11	WEEE, ELV, C&D (Streams that contain black plastics)	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Hybrid sensors	IDSORT/HYBRID - NIR & SS	In development (Applied research)	No aplicable	Coatings have to be removed	Bench Scale & Demo plants (IoSys)	Fast recognition and identification of plastics	High: Further development promises a maximum of added value for recycling
12	MSW, Packaging, Agriculture	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Hybrid sensors	IDSORT/HYBRID - Colour recognition & NIR	Conventional (Adopted and/or diffused in industry)	No aplicable	Coatings have to be removed	Industrial practice (Titech Vision Sort: PolySort)	Fast recognition and identification of plastics	Low: Long time perspective for further development
13	WEEE, ELV, C&D (Streams that contain black plastics)	Any (all types of plastics)	Identification & sorting	IDSORT - Automatic identification based technologies: Hybrid sensors	IDSORT/HYBRID - Colour recognition & NIR	Emerging (Scientific basic research)	No aplicable	Coatings have to be removed	Laboratory Scale (Titech Vision sort developments)	Fast recognition and identification of plastics	High: Further development promises a maximum of added value for recycling
14	WEEE, Packaging, MSW	Any (all types of plastics)	Separation & Sorting	SEP - Density based (dry)	SEP/DDRY - Air classifying	Conventional (Adopted and/or diffused in industry)	No specified	Plastics have to be ground (i.e. Flake shape).	General industrial practise for removing residual paper labels , dust, aluminum foils or light particles in general from ground plastic flakes (i.e. Bottles, some WEEE). It can be aslo used for separation of a Cu/PVC scrap cable mixture.	Separation of single materials	Low: Existing technology already reached its peak

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15	WEEE	PVC	Separation & Sorting	SEP - Density based (dry)	SEP/DDRY - Vibrating table	Conventional (Adopted and/or diffused in industry)	No specified	Firstly, grinding of scrap cables to obtain granulates and later separation of most of PVC by air classifying technologies	Industrial practice in cable recycling process: the objective is to purify the Cu stream removing mainly the PVC residue and other materials. This technology is used more for metals recovery than for plastics.	Separation of single materials	Low: Existing technology already reached its peak
16	C&D	PVC	Separation & Sorting	SEP - Density based (dry)	SEP/DDRY - Vibrating table	Conventional (Adopted and/or diffused in industry)	No specified	Shredding, size classification and metal separation	PVC window frame recycling process (industrial practise, Veka AG): vibrating tables used to separate glass and wood from PVC	Separation of single materials	Low: Existing technology already reached its peak
17	MSW, Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Density based (dry)	SEP/DDRY - Ballistic classification	Conventional (Adopted and/or diffused in industry)	No specified	No special requirement	The ballistic separator is a sorting device which uses the fact that the trajectories of substances impacting on reaction plates differ depending on the density, shape, hardness, size. It is possible to separate plastic film, rigid plastics, stone, wood, paper, cardboard. Ballistic separation was included in a recycling process for packaging plastics from municipal waste, previous to energy recovery in blast furnaces in place of coke (NKK Keihin and Fukuyama Facilities, Japan).	Separation of material families	Low: Existing technology already reached its peak
18	WEEE, Packaging	Any (all types of plastics)	Separation & Sorting	SEP - Density based (dry)	SEP/DDRY - Centrifuging (e.g. Result)	Conventional (Adopted and/or diffused in industry)	No specified	Shredding	Result process allows to separate multilayered materials: cables, printed circuit boards, electronic scraps, tubes (plastic-Al film laminates), aluminium compounds. The centrifugal force desintegrates and separates the compound materials into their constituent parts according to the physical properties (Result Technology AG).	Separation of single materials	Low: Existing technology already reached its peak
19	Packaging	HDPE, LDPE, PP, PVC	Separation & Sorting	SEP - Density based (wet)	SEP/DWET - Sink/float separation	Conventional (Adopted and/or diffused in industry)	No specified	Granulating: homogenous size and shape flakes required	Sink-float method is widely used to separate mainly polyolefins (HDPE, PP) from other heavier polymers and materials (PVC, PET, metallic particles). A modified process can be also used to separate PVC from other polymers during the recycling of PVC film.	Separation of material families	Low: Existing technology already reached its peak
20	WEEE	PVC	Separation & Sorting	SEP - Density based (wet)	SEP/DWET - (Wilfley concentrating) Shacking table	Conventional (Adopted and/or diffused in industry)	No specified	Material previously chopped	This technology is normally applied to concentrate precious metals or minerals, not plastics, but it can be also used to separate PVC/Cu mixtures from chopped cables in which copper is the target material.	Separation of single materials	Low: Existing technology already reached its peak

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21	Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Density based (wet)	SEP/DWET - Centrifuging and hydrocycloning	Conventional (Adopted and/or diffused in industry)	No specified	Inlet stream must be previously grounded in flake shape (size < 10 mm)	Industrial practise: to enrich polyolefins (overflow) removing other polymers (PET, PVC) or impurities (i.e. metallic particles) in underflow. More efficent than sink-float methods.	Separation of material families	Low: Existing technology already reached its peak
22	WEEE	Styrenics (ABS, PS, etc)	Separation & Sorting	SEP - Density based (wet)	SEP/DWET - Centrifuging and hydrocycloning	In development (Applied research)	No specified	Inlet stream must be previously grounded in flake shape (size < 10 mm) and most of metals removed	To enrich styrenic plastic fraction obtained in WEEE treatment, removing other heavier polymers (PVC, PA…), metallic particles and impurities.	Separation of material families	Medium: Further development promises added value for recycling
23	Packaging, WEEE, ELV	Any (all types of plastics)	Separation & Sorting	SEP - Density based (wet)	SEP/DWET - Centrifuging and hydrocycloning	Conventional (Adopted and/or diffused in industry)	No specified	Grinding (10-20 mm) and metals separation	Censor sorting centrifuge developed by KHD Humboldt Wedag AG is an advanced form of the hydrocyclone and can distinguish between plastics that differ in density by as little as 0.005 g/cc (i.e. HDPE from PP, polyolefins from PVC with less than 20 ppm PVC contamination) with a purity of >99.5%. This sytem has been used in Germany by DSD to separate packaging plastics.	Separation of single materials	Low: Existing technology already reached its peak
24	MSW, Packaging, WEEE, ELV	Any (all types of plastics)	Separation & Sorting	SEP - Density based (wet)	SEP/DWET - Jigging	In development (Applied research)	No specified	Particle size: 2-10 mm; particle thickness: approx. >0.2 mm; min. density between components: approx. 100 kg/m3	DeltexProJig (a spin-off company of the TU-Delf) is advanced separation of shredded plastic mixtures. It separates the input material intro 3 concentrate fractions (float fraction, light sink fraction, heavy sink fraction), performing density separation in the range of 1.0-1.5 g/cc in water as a medium.	Separation of material families	Low: Existing technology already reached its peak
25	MSW, Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Size and shaped based technologies	SEP/SIZE - Screening	Conventional (Adopted and/or diffused in industry)	No aplicable	No special requirement	Rotary screens (trommel) are used to pre-classify packaging (bottles, containers, tips, caps) and other no reclaimed materials according to shape and size at classification facilities.	Others	Low: Existing technology already reached its peak
26	Packaging, WEEE, ELV	Thermoplastics	Separation & Sorting	SEP - Surface properties based technologies	SEP/SURF - Flotation	In development (Applied research)	No specified	Previous removal of metals, non reclaimed polymers and other materials. Granulation: flake shape	Froth flotation can be to apply to separate polymers of equivalent densities from each other: PVC/PET, ABS/HIPS, HDPE/PP. The process has been operated at a pilot-demonstration scale by Argonne National Laboratory (U.S. Patent Nº. 5,653,867; issued 1997)	Separation of single materials	Low: Still no economically feasible way to implement the new technology
27	MSW, Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Chemical behaviour based technologies	SEP/CHEM - Selective dissolution	In development (Applied research)	No metals, paper and other contaminants.	Metals separation and washing/drying of the plastics mixture	A selective dissolution batch process (pilot scale) for recycled plastics has been developed by the Rensselaer Polytechnic Institute (Troy, NY). Separation of LDPE, HDPE, PP, PET, PVC and PS is achieved using mainly xylene as the solvent and by raising the solvent temperature.	Separation of single materials	Medium: Technology potentials are not clear by all means

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28	WEEE	ABS	Separation & Sorting	SEP - Chemical behaviour based technologies	SEP/CHEM - Selective dissolution	Emerging (Scientific basic research)	Only ABS from different WEEE	Shredding and previous separation of metals, polymers and other materials	The process is under development by the Mondragón University (Spain). The objetive is to get good quality ABS removing additives by means of solution.	Separation of single materials	High: Time perspective is short
29	MSW	Others	Separation & Sorting	SEP - Chemical behaviour based technologies	SEP/CHEM - Chemical stripping	Conventional (Adopted and/or diffused in industry)	No aplicable	Granulation: flakes 5-10 mm	Bayer have a CD recycling plant in Dormagen (Germany), which demetallizes CDs using a chemical bath and regrinds the stripped PC	Specific treatments for emerging residues: Active packaging, Liquid cristal and plasma displays, data storage media waste, etc	Medium: Further development promises added value for recycling
30	MSW, Packaging, WEEE, ELV	Any (all types of plastics)	Separation & Sorting	SEP - Electromagnetic properties based technologies	SEP/ELEC - Magnetic separation	Conventional (Adopted and/or diffused in industry)	No specified	Shredding	Industrial practise at recycling facilities: magnetic metals recovery and separation from plastics and other materials	Separation of material families	Low: Existing technology already reached its peak
31	MSW, Packaging, WEEE, ELV	Any (all types of plastics)	Separation & Sorting	SEP - Electromagnetic properties based technologies	SEP/ELEC - Eddy current separation	Conventional (Adopted and/or diffused in industry)	No specified: avoid magnetic metals	Shredding and magnetic separation	Industrial practise at recycling facilities to separate non-ferrous metals (Al) from plastics and other materials	Separation of material families	Low: Existing technology already reached its peak
32	Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Electromagnetic properties based technologies	SEP/ELEC - Electrostatic separation	Conventional (Adopted and/or diffused in industry)	No metals, no reclaimed polymers, low moisture content	Granulation (flakes 2-10 mm), screening, magnetic separation (if required), washing, drying, air humidity control	Industrial equipment available to separate mixture of plastics (PVC/PET or HDPE/PP).	Separation of single materials	Low: Existing technology already reached its peak
33	WEEE	Thermoplastics	Separation & Sorting	SEP - Electromagnetic properties based technologies	SEP/ELEC - Electrostatic separation	Conventional (Adopted and/or diffused in industry)	No specified	Granulation: particle size 2 mm	Industrial equipment available for the recuperation of finest metal particles from different conductor / non-conductor mixtures obtained in WEEE or scrap cables recycling processes	Separation of single materials	Low: Existing technology already reached its peak
34	Packaging, WEEE, ELV	Thermoplastics	Separation & Sorting	SEP - Softening temperature based technologies	SEP/SOFT - Softening temperature fractionation	In development (Applied research)	No specified	Shredding, removal of labels adnd metallic particles	It is not clear the industrial implementation of this separation method. There are some references : Refakt (Germany), Resource Energy Ventures (USA), Salyp ELV (Belgium)	Separation of single materials	Medium: Technology potentials are not clear by all means
35	Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Others	SEP/OTH - Near-critical and super-critical fluids	Emerging (Scientific basic research)	No specified	No metals and other no reclaimed materials. Plastics mixtures granulated (flakes)	Basic research done by University of Pittsburgh, Department of Chemical and Petroleum Engineering (USA)	Separation of single materials	Medium: Technology potentials are not clear by all means
36	Packaging	HDPE, LDPE, PP, PET, PVC	Separation & Sorting	SEP - Automatic sorting based technologies	SEP/AUTO - Colour recognition	Conventional (Adopted and/or diffused in industry)	No specified	Granulation (flakes >10mm), screening, magnetic separation, washing, drying (if required)	There are a number of commercially available systems for optical colour or transparency sorting: coulored recycled HDPE and PP caps from natural recycled HDPE flake, PVC from PET flake, green PET flake from clear PET flake. There are also systems to separate bottles or containers without granulating.	Separation of single materials	Low: Existing technology already reached its peak
37	Packaging	PET	Separation & Sorting	SEP - Others	SEP/OTH - Others	In development (Applied research)	No specified	Mixtures of PVC/PET (bottles and flakes)	Research done but not put in the market.	Separation of single materials	Low: Existing technology already reached its peak

ID no.	WASTE STREAM	POLYMER	OPERATION	TECHNOLOGY	TYPE	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
1	MSW	Mixtures (MPW)	Auxiliary & Conditioning Operations	AUX - Material feeding	AUX/MF- Material feeding	Conventional (Adopted and/or diffused in industry)	No aplicable	No aplicable	Industrial practice		Low: Existing technology already reached its peak
2	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Material feeding	AUX/MF- Material feeding	Conventional (Adopted and/or diffused in industry)	No aplicable	No aplicable	Industrial practice		Low: Existing technology already reached its peak
3	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Material feeding	AUX/MF- Material feeding	Conventional (Adopted and/or diffused in industry)	No aplicable	No aplicable	Industrial practice		Low: Existing technology already reached its peak
4	WEEE	Any (all types of plastics)	Auxiliary & Conditioning Operations	AUX - Material feeding	AUX/MF- Material feeding	Conventional (Adopted and/or diffused in industry)	No aplicable	No aplicable	Industrial practice		Low: Existing technology already reached its peak
5	ELV	Any (all types of plastics)	Auxiliary & Conditioning Operations	AUX - Material feeding	AUX/MF- Material feeding	Conventional (Adopted and/or diffused in industry)	No aplicable	No aplicable	Industrial practice		Low: Existing technology already reached its peak
6	C&D	PVC	Auxiliary & Conditioning Operations	AUX - Material feeding	AUX/MF- Material feeding	Conventional (Adopted and/or diffused in industry)	No aplicable	No aplicable	Industrial practice		Low: Existing technology already reached its peak
7	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Shredding	Conventional (Adopted and/or diffused in industry)	No specified	Previous separation of non-reclaimed polymers	Industrial practice	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
8	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Shredding	Conventional (Adopted and/or diffused in industry)	No specified	No aplicable	Industrial practice		
9	WEEE	Styrenics (ABS, PS, etc)	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Shredding	Conventional (Adopted and/or diffused in industry)	No specified	Previous separation of big plastic parts (i.e. housings) according to the content in forbidden additives by RoHS Directive	Industrial practice		Low: Existing technology already reached its peak
10	ELV	PP	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Shredding	Conventional (Adopted and/or diffused in industry)	No specified	Bumpers: No aplicable	Industrial practice		Low: Existing technology already reached its peak
11	ELV	HDPE	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Shredding	Conventional (Adopted and/or diffused in industry)	No specified	Fuel tanks: Previous removal of big metallic parts, other elements and fuel residue	Industrial practice		Low: Existing technology already reached its peak
12	ELV	PA	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Shredding	Conventional (Adopted and/or diffused in industry)	No specified	Plastic wheel covers: previous removal of metellic parts (i.e. fixing ring)	Industrial practice		Low: Existing technology already reached its peak
13	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Separation of possible metallic parts and non-reclaimed polymers. A primary size reduction required for big plastic containers	Industrial practice	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
14	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Previous coarse shredding	Industrial practice		Low: Existing technology already reached its peak
15	WEEE	Styrenics (ABS, PS, etc)	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Separation of metallic parts (i.e. Inserts) mixed with the plastic stream previously shredded (40 mm aprox.)	Industrial practice		Low: Existing technology already reached its peak
16	WEEE	Others	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Separation of metallic parts (i.e. Inserts)	Industrial practice		Low: Existing technology already reached its peak
17	ELV	PP	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Separation of metallic parts (i.e. Inserts) mixed with the plastic stream previously shredded (40 mm aprox.)	Industrial practice		Low: Existing technology already reached its peak
18	ELV	HDPE	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Bumpers: Separation of metallic parts mixed with the shredded plastic (40 mm aprox.)	Industrial practice		Low: Existing technology already reached its peak
19	ELV	PA	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Plastic wheel covers: removal of small metallic particles	Industrial practice		Low: Existing technology already reached its peak

ID no.	WASTE STREAM	POLYMER	OPERATION	TECHNOLOGY	TYPE	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
20	ELV	PU	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	In development (Applied research)	No specified	PU foam seats: metallic parts separation from pre-ground seats	Car Seat Recyling Plant (project conducted by PolyUrethanes Recycle & Recovery Council)	Separation of single materials	Medium: Further development promises added value for recycling
21	C&D	PVC	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Granulating	Conventional (Adopted and/or diffused in industry)	No specified	Pipes and windows profiles: previous separation of non-reclaimed polymers	Industrial practice	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
22	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Grinding (micronization)	Conventional (Adopted and/or diffused in industry)	No specified	Maximum particle size: 6-8 mm (granulate form). Metallic particles are not accepted	Industrial practice but only for specific recycling processes in which it would be necessary to reduce plastic scraps to powder		Low: Existing technology already reached its peak
23	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Grinding (micronization)	Conventional (Adopted and/or diffused in industry)	No specified	Maximum particle size: 6-8 mm. Previous removal of earth and vegetables residues	Industrial practice but only for specific recycling processes in which it would be necessary to reduce plastic scraps to powder		Low: Existing technology already reached its peak
24	WEEE	Epoxy	Auxiliary & Conditioning Operations	AUX - Size reduction	AUX/SR - Grinding (micronization)	In development (Applied research)	No specified	Printed circuit board: previous removal of electronic components from laminates	NEC has developed the Ecoseparation System to recycle printed circuit board. This system includes removal of electronic components and micronization-electrostatic separation for unpopulated laminates to separate epoxy resin-glass fibre and copper	Production of upgraded recyclates (close-loop recycling)	Medium: Adoption and diffusions most likely, but maybe difficult
25	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Washing	AUX/WSH - Washing	Conventional (Adopted and/or diffused in industry)	Paper and plastic labels and small metal parts (no specified maximum content)	Previous classification according to the polymer, magnetic separation and granulating (flake shapes, 8-12 mm)	Industrial practice	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Low: Existing technology already reached its peak
26	Packaging	LDPE	Auxiliary & Conditioning Operations	AUX - Washing	AUX/WSH - Washing	In development (Applied research)					
27	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Washing	AUX/WSH - Washing	Conventional (Adopted and/or diffused in industry)	Earth and vegetables	Previous shredding	Industrial practice	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Low: Existing technology already reached its peak
28	ELV	HDPE	Auxiliary & Conditioning Operations	AUX - Washing	AUX/WSH - Washing	Conventional (Adopted and/or diffused in industry)	Avoid metals and non-reclaimed plastics	Previous disassembly of metallic / other polymers pieces and removal of fuel residues in case of fuel tanks (HDPE) and shredding	Industrial practice	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Low: Existing technology already reached its peak
29	Agriculture	HDPE, LDPE, PVC	Auxiliary & Conditioning Operations	AUX - Cleaning (mechanical friction and abrasion for cleaning)	AUX/CL -Cleaning (mechanical friction and abrasion for cleaning)	In development (Applied research)	No specified	No specified	Cleaning Separator is a new technology to clean and to separate agricultural plastics residues without using waster, developed by Ein Technical Center in cooperation with the Japan Agricultural Cooperative. It is also suitable for HDPE or PET oil bottles, ELV multiple layered plastics and WEEE plastics.	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Medium: Technology potentials are not clear by all means
30	Packaging	HDPE, LDPE, PET	Auxiliary & Conditioning Operations	AUX - Aspiration and de-dusting	AUX/ASP -Aspiration and de-dusting	Conventional (Adopted and/or diffused in industry)	No specified	In the recycling process of packaging waste from a selective collection scheme, LDPE bags can be separated by aspiration after being cut open and emptied over. Aspiration is also used after plastics granulating (mainly PET, HDPE) to remove labels and fines	Industrial practice	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Low: Existing technology already reached its peak
31	WEEE	Styrenics (ABS, PS, etc)	Auxiliary & Conditioning Operations	AUX - Aspiration and de-dusting	AUX/ASP -Aspiration and de-dusting	Conventional (Adopted and/or diffused in industry)	No specified	Removal of Al foils and other light materials (foams, paper) mixed with WEEE granulated plastic streams	Industrial practice	Separation of non metallic materials from plastic streams	Low: Existing technology already reached its peak

ID no.	WASTE STREAM	POLYMER	OPERATION	TECHNOLOGY	TYPE	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
32	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Drying	AUX/DR - Drying	Conventional (Adopted and/or diffused in industry)	No metallic particles	Previous classification according to the polymer (PET, HDPE and plastic mixture), magnetic separation, granulating (flake shapes, 8-12 mm) , washing	Industrial practice	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Low: Existing technology already reached its peak
33	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Drying	AUX/DR - Drying	Conventional (Adopted and/or diffused in industry)	No specified	Granulating and washing	Industrial practice	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Low: Existing technology already reached its peak
34	Packaging	HDPE, LDPE	Auxiliary & Conditioning Operations	AUX - Washing	AUX/WSH - Washing	In development (Applied research)	No specified	Previous separation of non - reclaimed polymers	NOREC PROCESS (cleaning and extraction process): Removal of flexographic and gravure priting inks from fims surface using chemical solvents. Industrial practice no clear. According to bibliography, legal protection has been sought in the USA and Canada and cooperation contracts for explotation of the know-how and legal property agreed with plant manufacturers.	Plastic decontamination (Removal of paints, oils and/or pesticides residues)	Medium: Technology potentials are not clear by all means
35	Packaging	HDPE, LDPE, PP, PET, PVC	Auxiliary & Conditioning Operations	AUX - Filtration and melt-filtration	AUX/OTH- Others	Conventional (Adopted and/or diffused in industry)	No specified	Previous conditioning and separation of non-reclaimed polymers, metals so on before mechanical reclicling by extrusion.	Industrial practice: filtration of contaminant materials: dirt, cellulosic material, Al foil, metal fragments, fibres, glass, incompatible polymers of higher melting temperature.	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
36	WEEE	Styrenics (ABS, PS, etc)	Auxiliary & Conditioning Operations	AUX - Filtration and melt-filtration	AUX/OTH- Others	Conventional (Adopted and/or diffused in industry)	No specified	Previous conditioning and separation of non-reclaimed polymers, metals so on before mechanical reclicling by extrusion.	Industrial practice: filtration of contaminant materials: dirt, cellulosic material, Al foil, metal fragments, fibres, glass, incompatible polymers of higher melting temperature.	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
37	ELV	Any	Auxiliary & Conditioning Operations	AUX - Filtration and melt-filtration	AUX/OTH- Others	Conventional (Adopted and/or diffused in industry)	No specified	Previous conditioning and separation of non-reclaimed polymers, metals so on before mechanical reclicling by extrusion.	Industrial practice: filtration of contaminant materials: dirt, cellulosic material, Al foil, metal fragments, fibres, glass, incompatible polymers of higher melting temperature.	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
38	Packaging	LDPE	Auxiliary & Conditioning Operations	AUX - Agglomeration and bricketting	AUX/AGG - Agglomeration and bricketting	Conventional (Adopted and/or diffused in industry)	No specified	Previous separation of metallic particles and non-reclaimed polymers and granulating	Industrial practice: commercial equipment available (several suppliers) . Plastic waste based on packaging film, textile fibres and foam is extremely voluminous in nature and needs to be agglomerated or densified in order to convert it into free-flowing granules.	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
39	Packaging	Others	Auxiliary & Conditioning Operations	AUX - Agglomeration and bricketting	AUX/AGG - Agglomeration and bricketting	Conventional (Adopted and/or diffused in industry)	No specified	Previous separation of metallic particles and non-reclaimed polymers and granulating	Industrial practice (packaging foams): commercial equipment available (several suppliers) . Plastic waste based on packaging film, textile fibres and foam is extremely voluminous in nature and needs to be agglomerated or densified in order to convert it into free-flowing granules.	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak

ID no.	WASTE STREAM	POLYMER	OPERATION	TECHNOLOGY	TYPE	STATUS OF THE TECHNOLOGY	ADMISSIBLE IMPURITIES	INLET REQUIREMENTS (pretreatments)	EXPERIENCES OF ITS USAGE	SUITABILITY FOR SOLVING TECHNICAL PROBLEMS	NEED FOR FURTHER DEVELOPMENT
40	Agriculture	LDPE	Auxiliary & Conditioning Operations	AUX - Agglomeration and bricketting	AUX/AGG - Agglomeration and bricketting	Conventional (Adopted and/or diffused in industry)	No specified	Previous separation of soil and organic waste and granulating	Industrial practice (packaging foams): commercial equipment available (several suppliers) . Plastic waste based on packaging film, textile fibres and foam is extremely voluminous in nature and needs to be agglomerated or densified in order to convert it into free-flowing granules.	Production of upgraded recyclates (close-loop recycling)	Low: Existing technology already reached its peak
41	ELV	PU	Auxiliary & Conditioning Operations	AUX - Agglomeration and bricketting	AUX/AGG - Agglomeration and bricketting	Conventional (Adopted and/or diffused in industry)	No specified	Previous granulating	Commercial equipment available	Specific treatment of shredded materials coming from ELV	Low: Existing technology already reached its peak

ANNEX 3

ENVIRONMENTAL EVALUATION. COMPLEMENTARY INFORMATION

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1. THERMOSELECT-PROCESS

The Thermoselect-Process is a new integrated high-temperature technology, which combines pyrolysis and gasification with oxygen. Compressed waste enters a gasification reactor (reductive zone, 600 ºC). In a subsequent step, pure oxygen is added so that organic compounds are oxidized to CO and CO_2 (temperatures reach up to 2000ºC in the gas phase). The inorganic compounds melt and flow into a homogenization reactor, where pure oxygen is added and which a gas-oxygen burner heats. The internally produced synthetic gas can be used for the heating of the pyrolysis canal and for electricity production. Some of the advantages of this technology are the production of recyclable products and the vitrification of slag (reusable "mineral output") with a high quality. Unlike other thermal processes, there are no ashes, slag or filter dusts[1].

The process is being used for processing MSW, although different trials with ASR have been carried out with very positive results.

1.1. ENERGY

Most sources report that 65% of the total energy input to the reactor is transformed into syngas. The following table summarizes data reported by different sources:

Table 1. Rates of energy transformed into syngas in Thermoselect process

	Ademe[2]	Fondotoce[3]	Thermoselect[4]
Energy into syngas	65%	65%	64,9%

The characteristics of the syngas produced are summarized in the following table:

Table 2. Composition of syngas produced in Thermoselect process

Characteristics of syngas (%)	Average[1]	Chiba plant [5]
H_2	25-42	30.7
CO	25-42	32.5
CO_2	10-25	33.8
N		2.3

The produced syngas can be used for methanol or hydrogen production. In fact, in order to use this gas for methanol or ammonia production further processing would be needed, since the required H_2/CO ratio is higher than 2. Other alternative energy recovery options imply to use it as a replacement for fossil fuels in existing power stations, and so it substitutes valuable resources[6], or in cases where a Thermoselect process plant is sited at a steel works or similar energy-consuming facility, it is possible to use the purified synthesis gas in the works (as happens in Chiba Plant, Japan, where it supplies part of the fuel for the combined-cycle power plant[5]).

The European installations for the Thermoselect process have been oriented towards electricity production (Fondotoce and Karlsruhe). There are several options for electricity production. The gas turbine and fuel cell are considered the most efficient ones

The following figure summarizes the average energy flow in the Thermoselect process.

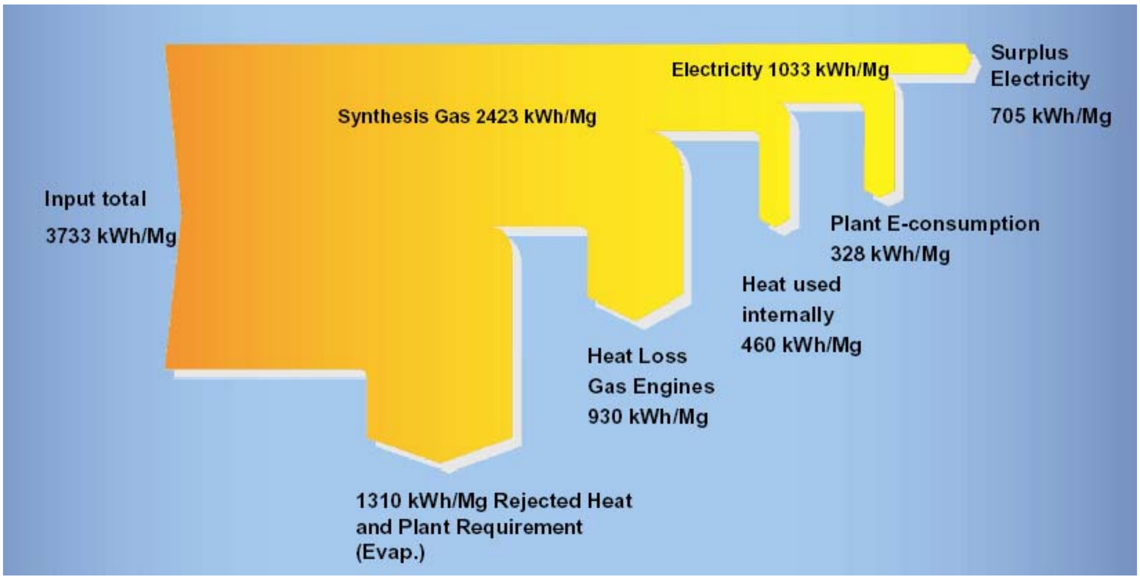

Figure 1. Energy flow in Thermoselect process (Source: Thermoselect website[4])

Although this data can be considered the most reliable information, the variability of different bibliographic sources must also be considered.

Data on the efficiency of electricity production also shows relative consistency, as shown in the following table.

Table 3. Efficiency rates for electricity production in Thermoselect process

Data source	Before internal use	After internal use
Thermoselect[4]	42%	29%
Fondotoce[3] Gas turbine	32%	26%
Chiba (Japan) Gas Turbine[5]	37%	–

There is some disparity on information on the additional energy used within the plant, as energy added to the reactor and electricity consumed in the whole installation.

Table 4. Energy consumption in Thermoselect process

Data source	Natural gas	Syngas
Thermoselect 4	1738 MJ/ton	
Ademe2	–	368 MJ/ton
Hellweg3	1900 MJ/ton	600 MJ/ton
Juniper Report7	1032 MJ/ton	
Data source	**Electricity**	
Thermoselect 4	1180 MJ/ton (from plant production)	
Hellweg3	500 MJ/ton	

1.2. ATMOSPHERIC EMISSIONS

The fate of specific contaminants depends on the feedstock, the process temperature, and the type of pollution control equipment used. The average atmospheric emission cleaning process is detailed in the following figure:

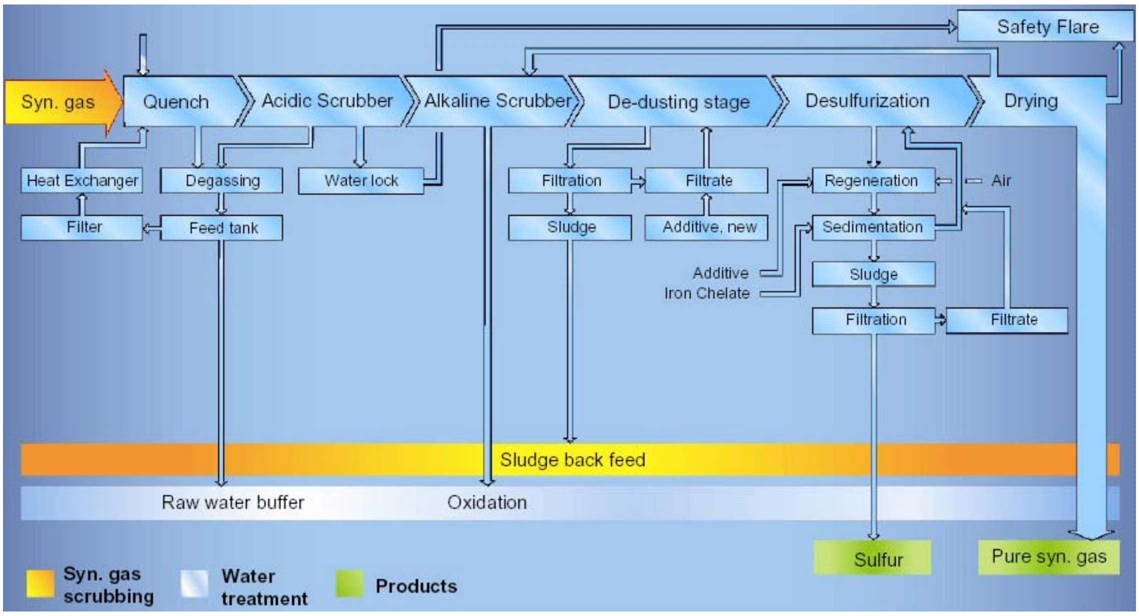

Figure 2. Syngas cleaning system[4]

Table 5. Atmospheric emissions in Thermoselect process

Substances		Chiba MSW	Karlsruhe ASR test[4]	Karlsruhe MSW[1]
NO_x	mg/m³	14	52,3	44,960
SO_2	mg/m³		3,5	1,305
Dust	mg/m³	0,2	0,31	0,403
Dioxins/Furans	mg/m³	0,0072	2,1	3,040
Total C	mg/m³	0,82		0,704
CO	mg/m³		3,24	4,845
HCl	mg/m³	<5	0,05	0,432
HF	mg/m³			0,103
Heavy metals	mg/m³		0,0087	0,015
Hg	mg/m³		0,0023	0,008
Cd/Tl	mg/m³		0,000014	<0,001

1.3. MATERIAL OUTPUTS

The composition of the metals fractions and mineral aggregates recovered are graphically summarised bellow:

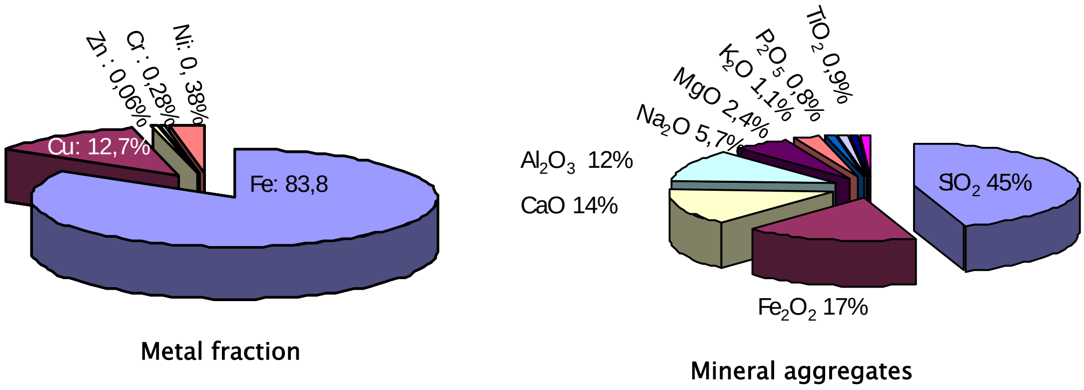

Figure 3. Composition of metal and mineral fractions recovered

2. TWINREC

In 2000, EBARA introduced TwinRec for SR treatment, which is based on fluidised bed gasification in combination with ash melting. The following description is focused on the core components of the TwinRec system: the fluidised bed gasifier and the cyclonic combustion chamber.

Shredder residues are fed to the gasifier without any additional preparation, just as delivered from the shredder plant. A variety of wastes is treated by the Twinrec process in Japan, from waste plastics, SR, sludges, industrial waste, WEEE and slags to MSW[8].

The gasifier is a proprietary internally circulating fluidised bed of compact dimensions, operated at temperatures between 500 - 600°C. Together with the resulting flue gas, fine particles are entrained into the gas flow leaving the gasifier. The low gasification temperature in the fluidised bed leads to easily controllable process conditions.

The gasifier's main function is separation of the combustible portion and the dust from the inert and metallic particles of the SR. Metals like aluminium, copper and iron can be recycled as valuable products from the bottom off-stream of the gasifier as they are neither oxidised nor sintered with other ash components. Together with these metals, larger inert particles are removed, which after separation is ground and fed back to the ash melting furnace[8]. Smaller inerts are returned to the gasifier where they serve as bed material. The fine inerts are blown out of the gasifier to enter the next stage.

Fuel gas and carbonaceous particles, both produced in the gasifier, are burnt together in the cyclonic combustion chamber at temperatures between 1350 and 1450°C by addition of secondary air. Here, the fine particles are collected on the walls, where they are vitrified and proceed slowly through the furnace.

The molten slag is quenched in a water bath to form a granulate with excellent leaching resistance, meeting safely all common regulations for recycling in construction.

Gasifier and ash melting furnace operate at atmospheric conditions, without consumption of fossil fuels (except for start-up) and oxygen. Due to the low excess air ratio, only a compact sized steam generator and an air pollution control unit are required [9].

The energy content of the waste is converted into electricity and/or district heat with high net efficiency [10]. The energy efficiency of TwinRec is better than in thermal waste treatment processes, which require oxygen and consume therefore a good part of the energy internally. Also, the ash melting furnace is integrated into the water steam cycle, making use of the highest temperature level for steam production [8].

In the Aomori (JP) plant the waste (shredded) is fed without pre-treatment[8] .

2.1. MATERIAL CONSUMPTION

Table 6 summarises the reported material consumptions in TwinRec process.

Table 6. Raw materials consumption in TwinRec process

kg/t	Juniper 2000[17]	Afval Overleg Orgaan 2002[11]	DTI 2002 [12]
CaO	28,3		50
Active Carbon	0.3	2	
NH_3	6.7	5	
CaOH		2	
NaOH		35	
Oil			12,92

2.2. ENERGY

Energy is recovered in different forms: The main output of the TwinRec plants in Japan is electricity, although the plant in Kurobe (one of the 4 operating plants described by documentation from Ebara) uses the energy to melt copper containing residues [13]. On the other hand, the plant in Kawaguchi also uses the steam recovered within the process for district heating and internal use.

Ebara provides the following information regarding the electricity production:

Table 7. Ratio electricity produced /energy entering the process

	Before internal consumption	After internal consumption
Average	25%[14]	
	22,8% [11]	19,2%[11]
	20-23% [15]	17 -20%[15]
Aomori (Japan)	23%[13]	
Kawaguchi (Japan)	19%[13]-17%[9]	9%[9]

Efficiency range of the process is estimated to be around 20-25% (17-19.2% after internal consumption). Data from Kawaguchi has not been considered in this calculation, since, as stated before, this plant also produces 1,82 t steam/t waste treated, used in the recycling facility and district heating, and treats 1.5 kg of bottom ash from external source, which is vitrified within the process[9].

Regarding the energy consumption, the gasifier and ash melting furnace operate without consumption of fossil fuels (except for start-up) and oxygen. However, the plant in Kawaguchi presents some specific conditions, due to its application in the vitrification of external ashes fed into the process. Although the low calorific value of waste treated is enough to run the process, the combustion air is mixed with oxygen enriched air to reduce the cooling effect of the Nitrogen. The Oxygen enriched air (ca 75% O_2) is produced by pressure swing absorption which is easy in operation and requires only little maintenance work[9].

In general, only heat and electricity consumption is considered in the process. The internal electricity consumptions reported by different authors are rather consistent, as shown in the following table:

Table 8. Internal energy consumption in TwinRec process

Energy consumption per tonne waste treated:	
Kawaguchi	675 MJ/ton (8337 kJ/kg)[9]
Average	572 MJ/ton[16]

2.3. ATMOSPHERIC EMISSIONS

The typical atmospheric emission control in this installation consists on bagfilters, wet or semidry scrubber and SCR/SNCR DeNOx installation. In the Kawaguchi plant, heavy metals like mercury have been reduced to very low concentrations by adding chelate agent to the adsorbent. Some authors also mention the potential use of active carbon for the reduction of metal emissions.

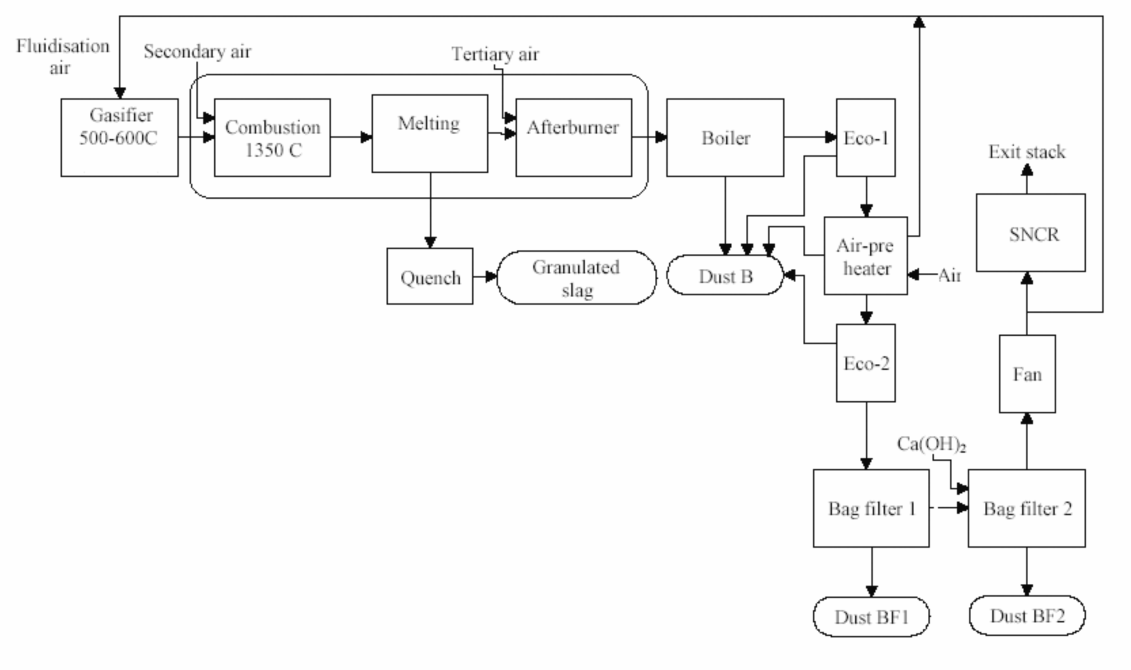

Figure 4. Wet scrubbers (HCl, SO_x) opt, Kawaguchi[9]: addition of chelate agent to the adsorbent (opt). Heavy metals and Hg, Kawaguchi (Extracted from Theunis et al. 2003[15]).

Table 9. Emission levels in TwinRec installations

Substances		KAWAGUCHI[8, 9]			AOMORI[15]
		Line A	Line B	Line C	
Dust	mg/Nm³	<1	<1	<1	
HCl	mg/Nm³	16.1	16.1	16.1	90
NOx	mg/Nm³	43.05	65.6	73.8	178
SOx	mg/Nm³	3.57	3.57	3.57	16
CO	mg/Nm³	2.5	3.75	2.5	8
Dioxins	ng I-TEQ/Nm³	<0.000005	<0.000005	<0.000005	0.016
Total Hg	mg/Nm³	<0.005	<0.005	<0.005	

Based on these values, and assuming a gas flow of 1.26 Nm^3 per waste kg entering the process (reported by Kawaguchi for processing high quality plastic waste[10]), the following emissions by kg of waste treated can be estimated.

Table 10. Estimated emissions per kg of waste treated in TwinRec process

Substances		Best case	Worst case
Dust:	mg/kg waste	1.26	
HCl	mg/kg waste	20.29	113.40
NOx	mg/kg waste	54.24	224.28
SOx	mg/kg waste	4.50	20.16
CO	mg/kg waste	3.15	10.08
Dioxins	ng TEQ/kg waste	0.000006	0.02
Total Hg	mg/kg waste	0.006300	

Regarding the metal flows to atmospheric emissions, the bibliographic references only allow to estimate the parameters shown in the following figure.

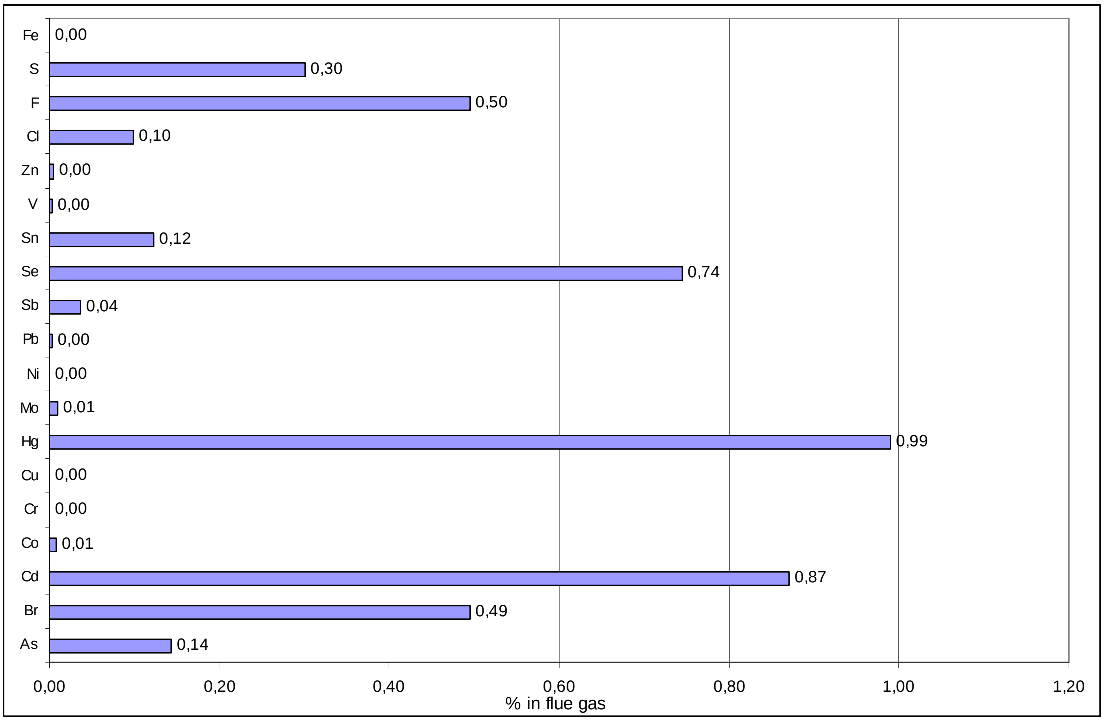

Figure 5. TwinRec: Metal contents in atmospheric emissions (Source: Afval Overleg Orgaan[11])

2.4. WASTEWATER

The potential source of wastewater is the atmospheric emission control installation, in case of using semi-dry scrubber. For the purpose of this study a dry scrubber has been considered, with no wastewater emission. The quench water is circulated internally[16].

2.5. MATERIAL OUTPUTS

The material outputs reported by various bibliographic sources show some differences as illustrated in the table.

Table 11. Outputs of TwinRec process

Material outputs (kg/ton treated)		Juniper[17]	Twinrec[14]	EBARA	DTI[12]	OKOPOL[18]	Average[16]
Waste treated		ASR	MSWI/ industrial	ASR	ASR	ASR Light fraction	ASR
Gasifier	Bottom ash	97	20	70	140	56	125
	Ferrous & NFerrous metals	113,6	20	80		80	
n Chamber / Ash melting	Glass granulate	204	50	200	200	248	285
Boiler	Boiler and filter ash	85.6	22 (Fly ash + lime)	50	135,5	73	372
	APC residues					20	

The outputs of the process are clearly associated to the material treated in each case (e.g. first tests with SR in Aomori showed that the amount of ash generated was higher than expected and the process required some modifications to accommodate to those conditions[9]). According to preliminary approximations performed by some authors, the different contribution of metals in the waste stream to the final outpus of Twinrec process can be estimated as described in Figure 6.

These estimations are consistent with the main outputs reported by the technology supplier, as detailed in subsequent paragraphs, and give valuable information on the composition of different material outputs.

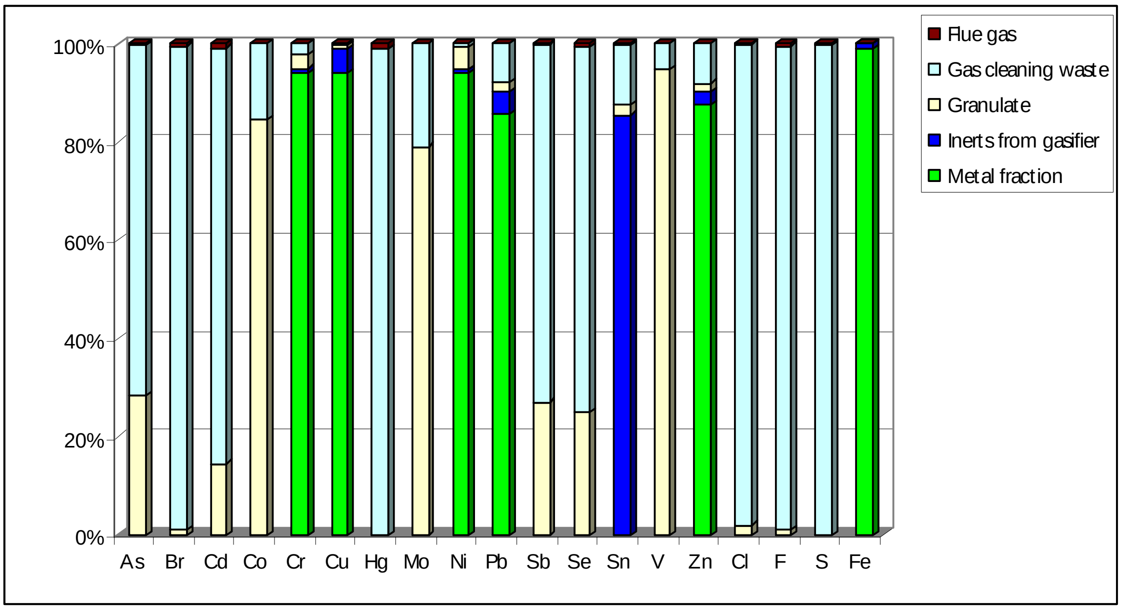

Figure 6. Contents of substances of concern in the output flows of TwinRec process.

- Ferrous and non ferrous metals: Metals are separated in the TwinRec plant[10]. The gasifier separates the combustible portion and the dust from the inert and metallic particles. The bottom off-stream of the gasifier contains metals (which are not oxidised nor sintered with other ash components) together with larger inert particles, which after separation is ground and fed back to the ash melting furnace[8]. The Figure 7 depicts the usual metal separation processes.

Ferrous metals are usually derived to a shredder and later recycled in the metal industry. Non ferrous metals consists mainly copper and aluminium, but also stainless steel.

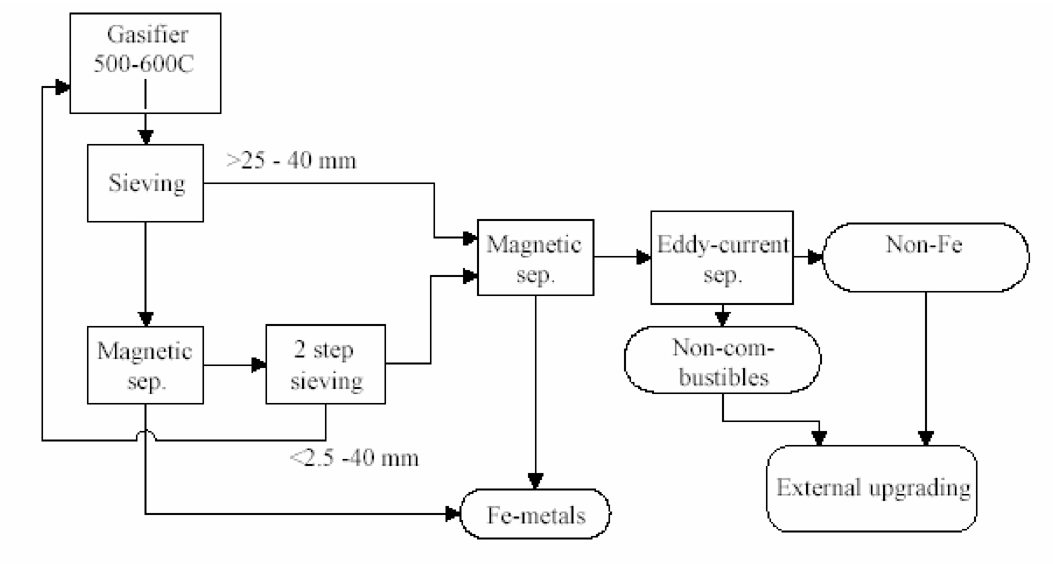

Figure 7. Metal separation at TwinRec process (Source: VITO[16])

- Glass granulate is the largest fraction for recycling. For a successful application in the construction industry it must satisfy technical criteria and pass the respective environmental certification. Technically, the granulate qualifies for various applications, replacing cullet, gravel or sand. It can be applied as loose bulk material, or as filler in combination with inorganic or organic binders. In Japan, the granulate is used as filler in asphalt[8].

- Combustion of waste at a low excess air ratio produces minimal exhaust gas. Minimal volume of exhaust gas enables plants to be reduced in scales[14].
- Boiler and filter ash: only one of the four plants described by Ebara[13] (The Aomori plant) recycles Zn, Pb and Cu in fly ash. However, since this best practice is feasible, for the purpose of this study a plant including this process has been considered.

3. SVZ – THE SEKUNDÄRROHSTOFF VERWERTUNGS ZENTRUM "SCHWARZE PUMPE" GASIFICATION PROCESS

SVZ has converted some of the existing former East German era coal gasifiers in Schwarze Pumpe Germany, to convert biomass, coals, and wastes into clean fuel gas and synthesis gas.

The SVZ plant is a first-of-a-kind integrated gasification, methanol and combined-cycle electricity production plant that converts contaminated and difficult to handle waste materials to clean, value-added products. The high gasification temperatures of up to 1,800°C are high enough to significantly reduce contaminants in the product gas or gas scrubbing effluent streams. The vitrified slag, the only gasifier waste product, safely encloses any residual pollutants and can be used as construction material[19].

The plant gasifies a wide variety of waste materials along with low-rank coals. The waste materials include demolition wood, used plastics, sewage sludge, auto-fluff, MSW, contaminated waste oil, paint and varnish sludge, mixed solvents, tars, and on-site process waste streams. SVZ has developed an effective feed handling and feed preparation system that combines heterogeneous feed materials to prepare a nearly uniform gasifier feed[19].

SVZ in Germany has ten gasifiers for 3 different gasification technologies[20]:

- 7 *Pressurised Solid-Bed Gasifier*: Pressurised solid-bed gasification is used for processing solid waste. The waste is mixed with coal and enters the reactor through an airlock system. The reactors operate at a pressure of 25 bar, using steam and oxygen as gasification agents.

  Gasification is carried out at a temperature of 800 – 1300°C. The remaining solid residues, in the form of slag, comply with the requirements of the waste dump Class 1 of the German garbage disposal laws.

- 2 *Entrained Flow Gasifiers*: Entrained flow gasification is used for the processing of liquid waste. The contaminated oils, tars and slurries are driven by steam over a burner system in the reactor and converted at temperatures of 1600 – 1800 °C into synthesis gas in the process. At these high temperatures, all organic pollutants are reliably destroyed. The subsequent shock cooling of the gas prevents undesired subsequent reactions. Heavy metals are locked into the vitrified slag and cannot be eluted.

- 1 *BGL Gasifier*: After more than two years of full commercial operation of the gasification-methanol-power complex, a the BGL (British Gas – Lurgi) gasifier was brought on line, increasing the waste feed rate by about 75-80%, and the overall efficiency.

The mixture of waste and coal enters the reactor via a double airlock system. The processing capacity of the gasifier is about 30 tonnes per hour. Gasification takes pace at a temperature of 1600°C and a pressure of 25 bar. Steam and oxygen are used as the gasification agents. The slag is removed in the form of a liquid and is then shock cooled to form a vitrified, granular slag in which all pollutants are sealed and cannot be eluted.

The BGL Gasifier presents several advantages[21]

- High conversion efficiency
- Low oxygen consumption
- Low steam/water usage
- Low CO_2 content in syngas
- Medium Btu syngas

The plastic wastes enter the process pelletised. The extrusion plant for waste plastics in SVZ plant, with a capacity of 25,000 tpy, consists of several steps, as shown in Figure 8. For the purpose of this study, consumptions of the pre-treatment have been considered to be included within the general SVZ consumptions.

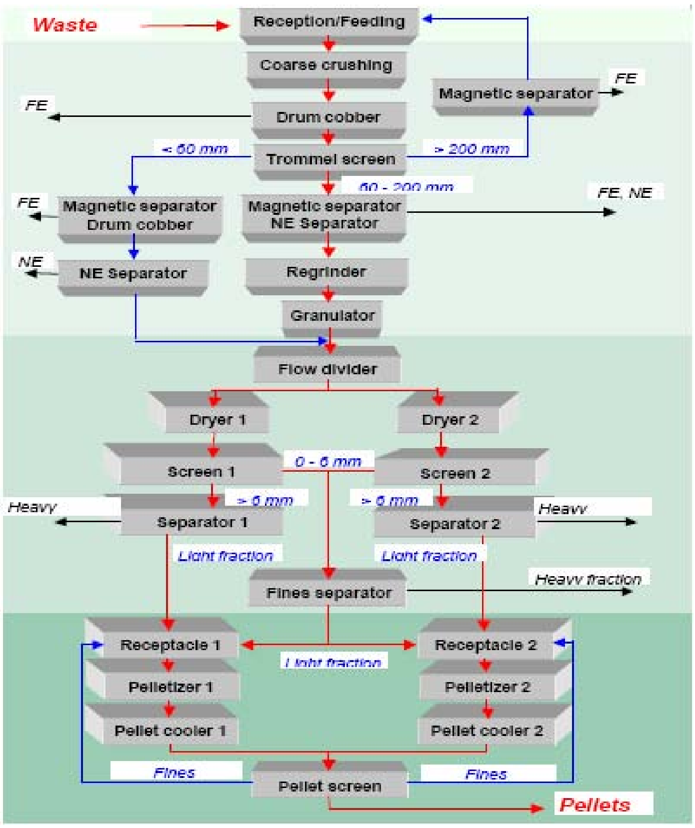

Figure 8. Plastic waste conditioning prior to SVZ process[22]

3.1. MATERIAL CONSUMPTION

Oxygen and steam are used as gasification media, and are supplied in counter flow with the input materials[23]. According to literature, gasification with air instead of oxygen is also possible, having lower working costs, but leads to higher Nitrogen content and a poorer gas phase: syngas of 4-8 MJ/Nm³ when gasifying with air, and 10-15 MJ/Nm³ syngas with oxygen.

The use of other materials (mainly for cleaning systems) is also reported by different sources.

Table 12 displays raw material consumption values for SVZ process found in literature.

Table 12. SVZ process material inputs

Input	Tecnopol [24]	VITO[16]	Thenuis et al.[15]
Wastes	0.625 SR/MSW /0.375 MPW pellets	1 ton waste	1 ton RDF
Oxygen	183 m^3 (262kg)	209 m^3 (300 kg)	337 m^3 (235 kg)
Steam	0.228 ton/ton	0,233 kg	310 kg/
CaO		57.35 kg	1.94 kg
NaOH		4.7 kg	

3.2. ENERGY

The SVZ process was designed starting from the technology to produce methanol and energy from coal. At the moment a ratio of 75-80% waste with 20% coal is being introduced in the gasifier. The thermal efficiency of the BGL gasification is close to the 80%.

Table 13. Energy (fuel) inputs to SVZ process

Input	Tecnopol[24] (BGL)	VITO[16] (BGL)	Thenuis et al.[15]
Waste	1 ton SR/MSW & MPW	1 ton	1 ton
	14400 MJ	16000 MJ/ton	-
Coal	0.16 ton	0.177 ton	-
	4160 MJ	4602 MJ	-
Steam	0.228 ton	0.391 ton	0.310 ton
Natural gas	-	2.5 m^3 (86 MJ)	-

Input	Tecnopol[24] (BGL)	VITO[16] (BGL)	Thenuis et al.[15]
Electricity	-	757 MJ	648 MJ

The gasification produces the following chemical reactions:

$$2C + O_2 \Leftrightarrow 2CO_2$$
$$H_2O + C \Leftrightarrow CO + H_2$$
$$2H_2O + C \Leftrightarrow CO_2 + 2H_2$$
$$C + 2H_2 \Leftrightarrow CH_4$$

The first output of the gasifier is a product gas (consisting principally of hydrogen, carbon monoxide and methane). It has only 2% of the volume of the corresponding quantity of incinerator effluent at their respective operating conditions. It can, therefore, be meticulously scrubbed free of all air-polluting contaminants.

Table 14. SVZ syngas characteristics[22]

	Av. Value	Unit
Heating value	12-15	MJ/Nm^3
H_2	64,1	Vol.%
CO	19,6	Vol.%
CO_2	6,3	Vol.%
CH_4	8,4	Vol.%
N_2	1,4	Vol.%
O_2	0,06	Vol.%
C_nH_m	0,12	Vol.%

Data on syngas production and its efficiency is rather limited. Literature reports around 1085-1725 m^3/ton waste processed. The amount of syngas produced is related to the waste processed.

Regarding the energy balance in the gasification processes, the theoretical efficiency of the BGL gasification is around 80%. However, efficiency around 75% can be estimated from literature on trials with ASR/MSW. Equally, the calorific value of the obtained syngas also varies depending on the energy fed to the gasifier (LHV reported[16, 15, 25]: 11,8 MJ/Nm^3, 14 MJ/Nm^3 and 13 MJ/Nm^3, respectively).

The clean synthesis gas is used for various purposes. It can serve as a synthesis gas for the production of methanol, super clean diesel fuel and high-octane gasoline or even hydrogen for use in fuel cells[26].

Nowadays the main part, is used for the production of methanol, while another part goes for electricity production (around 70/20% is used for methanol/electricity).

Steam is also recovered, mainly for internal use, according to SVZ; however, other sources mention the district heating application.

Electricity produced is partly used to cover internal needs and partly exported. The internal energy uses are reported by different authors, as summarised in Table 13.

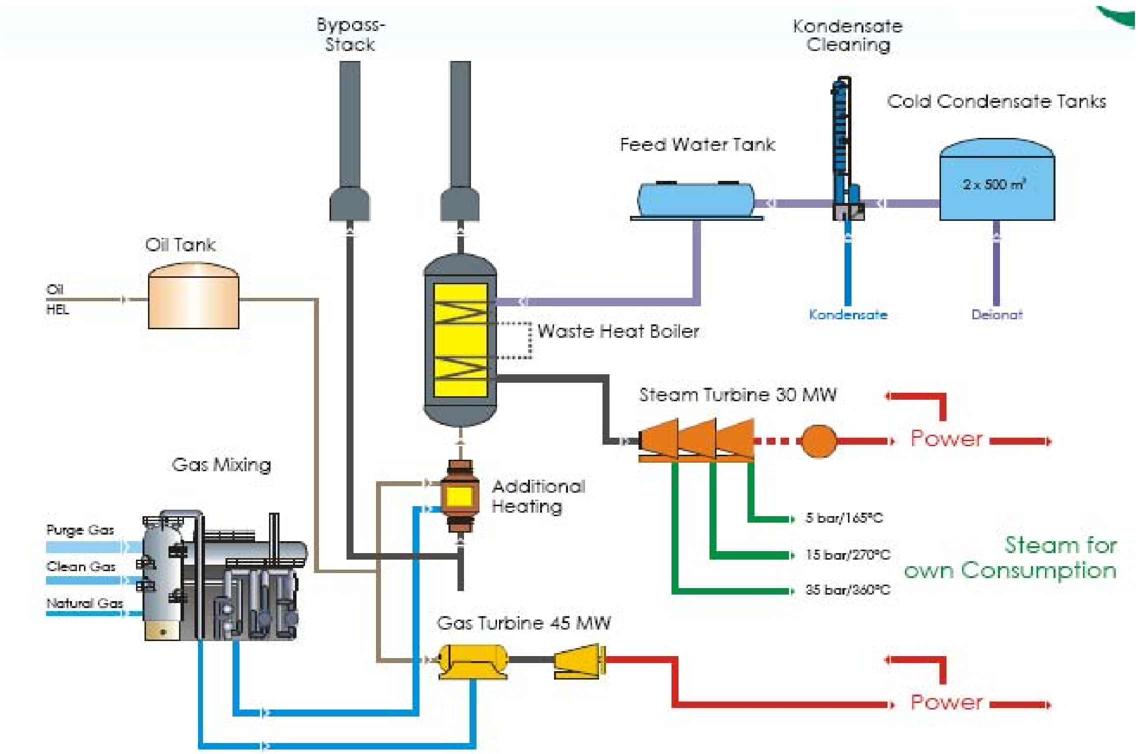

Figure 9. Flow scheme of power station[22]

The methanol is synthesised following the reactions detailed bellow:

$$2H_2 + CO \Leftrightarrow CH_3OH$$
$$3H_2 + CO_2 \Leftrightarrow CH_3OH + H_2O$$

Currently methanol becomes used in different applications[15]:

- as a feedstock for bulk organic chemicals (mainly formaldehyde)
- as additive for fuel

- for direct use as a solvent in this only a moderate growth potential sit.

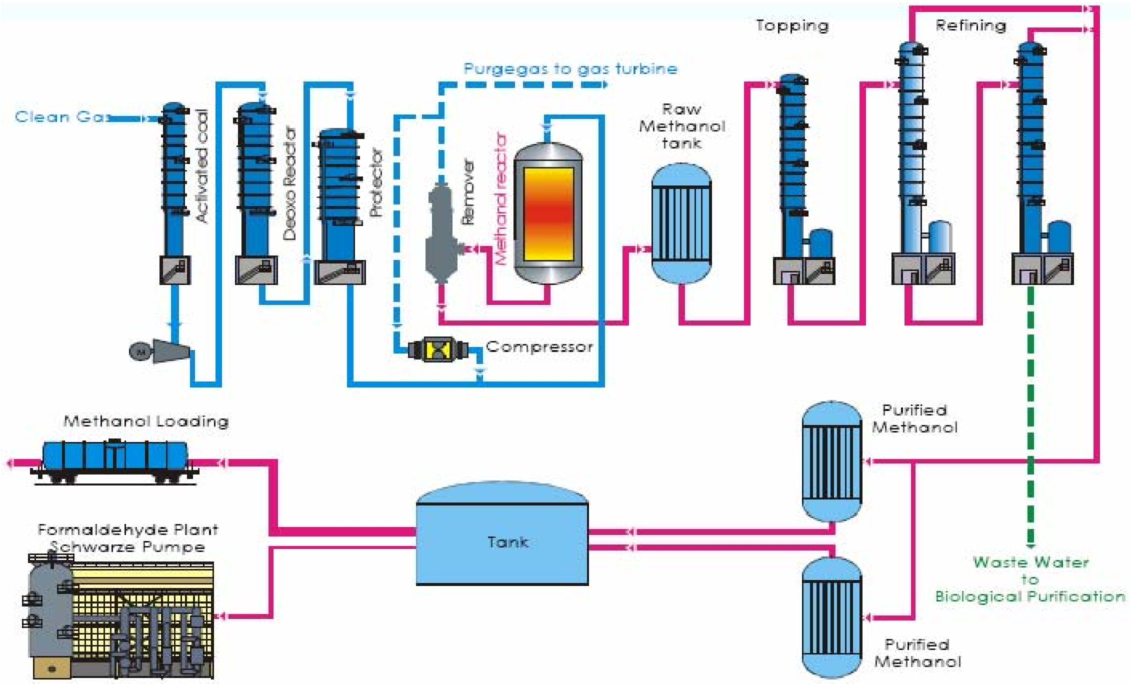

Figure 10. Flow scheme of methanol plant[22].

3.3. ATMOSPHERIC EMISSIONS

There is no information available on the atmospheric emissions from the SVZ process.

3.4. MATERIAL OUTPUTS

The main material output of the process is the clean synthesis gas, which is used for production of methanol and electricity. However, there are other outputs in the SVZ process, such as:

- Slag: Non combustible mineral components of the material feed remain as part of the slag. Hazardous substances are vitrified in the gassified slag, not prone to be leached out.
- NaCl: Chlorine is separated as NaCl in the outputs of the gasifier.
- Wastewater: There is no information regarding the wastewater composition However, certain bibliographic sources state already that this impact is negligible in comparison with the rest of the installation.
- Gypsum: the discharge gas of the of the gas purification system is lead to a desulphuration plant, where gypsum is produced (as well as steam). The gypsum amount is proportional to the sulphur in the input.

4. THERMALYSIS (THERMOFUEL)

The process is based on the liquefaction of plastics for the production of a distillate which consists in a fuel that can be used as fuel for diesel burners, trucks and generators, as well as co-generators[27, 28, 29].

As a result of R&D undertaking, several waste recycling plants have been working throughout the last years (the first one in Japan for more than 8 years), having proven to be successful and economically viable, with virtually uninterrupted operation. As a consequence, their transfer, implementation and running in Spain and other European countries it's worth the effort.

The system uses liquefaction, pyrolysis and the catalytic breakdown of plastics, a process whereby scrap and waste plastic are converted into liquid hydrocarbons that can be used as fuels.

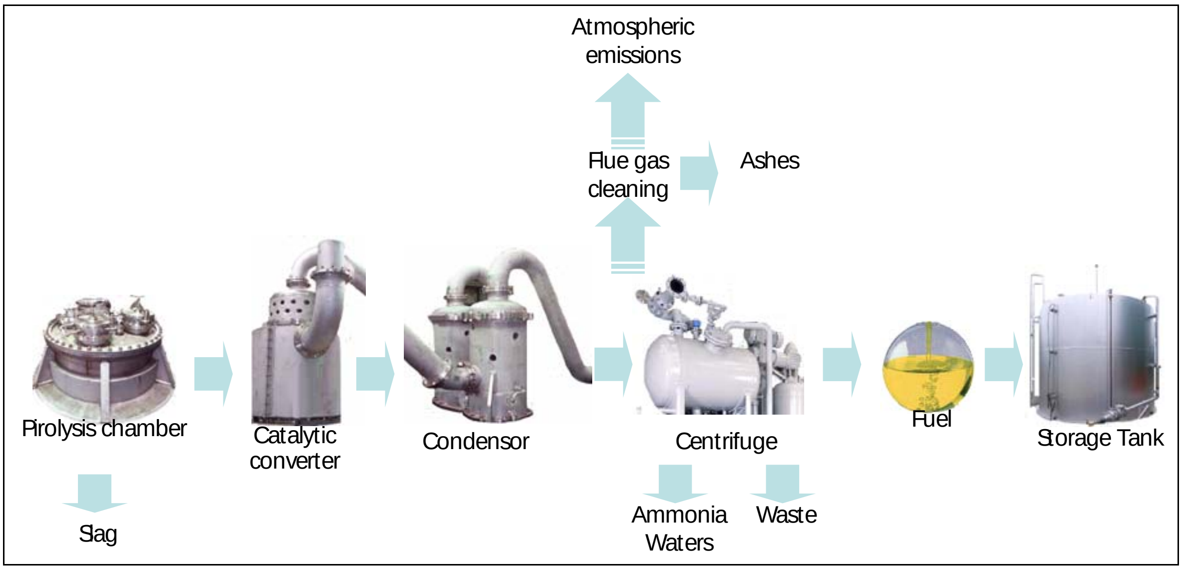

Figure 11. Flow diagram of Thermalysis (/Thermofuel) process

Pyrolysis is a process of degradation in the absence of oxygen. Plastic waste is continuously treated in a cylindrical chamber and the pyrolytic gases condensed in a specially-designed condenser system to yield a hydrocarbon distillate comprising straight and branched chain aliphatics, cyclic aliphatics and aromatic hydrocarbons. The resulting mixture is essentially equivalent to petroleum distillate.

The density of the distilled fuels obtained in the process (named Green Fuel by the technology providers) is close to that of regular diesel, as well as its other characteristics. The "Green Fuel" contains the same energy content as conventional diesels, but with significantly reduced emissions levels for environmentally sound operation. Existing diesel engines can run fully effectively on these fuels with no engine modification.

During the pyrolysis process, non-plastic materials fall to the bottom of the chamber and will be eliminated later. The char residue produced is about 5% of the output for relatively clean polyolefin feedstocks and up to 8-10% for PET-rich feedstocks. Since the char passes acid leaching tests it can simply be landfilled.

This patented technology utilises the embodied energy content of plastics producing a highly usable commodity that, due to its cleaner burning characteristics, is in itself more environmentally friendly than conventional distillate.

Table 15. Plastic suitability for treatment

Resin	Specific gravity	Thermofuel system suitability
Polyethylene (PE)	0.918	Very good
Polypropylene (PP)	0.90	Very good
Polystyrene (PS)	1.04	Very good
ABS resin (ABS)	1.03-1.07	Good. Requires off-gas counter measure
Polyvinylchloride (PVC)	1.23-1.45	Not applicable
Polyurethane (PUR)	1.2	Fair. Oil recovery is small.
Fibre Reinforced Plastics (FRP)	1.65-1.8	Fair. Pre-treatment required to remove fibres

Foreign matter such as soil, sand or papers are often adhered to waste plastics. The system is designed to cope with these foreign materials up to approximately 7% by weight or volume.

Waste plastics are loaded into pyrolysis chamber. The chamber can generally be filled within 30 minutes. When the chamber temperature is raised, the plastics begin to melt and agitation commences to even the temperature. Pyrolysis then commences.

The gas goes through the patented catalytic converter and is converted into the distillate fraction by the catalytic cracking process. The distillate then passes into the recovery tank after cooling in the condenser. From the recovery tank, the product is sent to a centrifuge to remove contaminants such as water or carbon.

The cleaned distillate is then pumped to the reserve tank where a small quantity is drawn off as fuel for the system itself. The remaining product is pumped to the storage tanks.

4.1. MATERIAL CONSUMPTION

The only auxiliary material reported is related to the air and water emission treatment, but no quantitative information is available. However, these inputs are expected to be very low, consisting of ammonia and NaOH.

4.2. ATMOSPHERIC EMISSIONS

The flue gas exiting from the second condenser (12 % w/w of the input) consists mainly composed by non condensable hydrocarbons (methane, ethane, propane, butane, etc). a small quantity (< 1% w/w) of inert (non volatile) materials like earth, sand, dust, metals, inks, plastic charges, etc. may also be carried in the flue gas.

These gases are cleaned in a wet alkaline (NaOH) scrubber to remove the remaining ashes and other eventual pollutants.

The cleaned flue gas is then taken to a combustion chamber where is oxidised at a temperature of about 800ºC and released to the atmosphere. The ammoniated water from centrifuge is a small liquid stream which will be disposed of as a hazardous waste, but is not related to air emissions.

4.3. WASTEWATER

Water is used for refrigeration and is circulated within the system. Since there is no waste water discharge from the system, no environmental risks to neighbouring groundwater or rivers exist.

4.4. MATERIAL OUTPUTS

The fuel recovered shows very similar characteristics to Diesel A. In fact, a comparison of the distillate produced from a plastic mix with regular diesel has been conducted by gas chromatography, showing good similarity between fuels; however, the distillate shows cleaner burning characteristics and contains no chemical elements other than those which can be found in the plastic waste. Existing diesel engines can run fully effectively on these fuels with no engine modification.

A white spirit (solvent and degreaser uses) is obtained as by-product in the process from the condensation of the light fraction of distillate.

Table 16. Recovered materials by plastic waste tonne treated

Product	Unit	Amount
Ecodiesel (Green Fuel)	kg	600
Solvent "white spirit"	kg	200

5. BLAST FURNACE

Iron ore processed nowadays contains a large content of hematite (Fe_2O_3) and sometimes small amounts of magnetite (Fe_3O_4). In the blast furnace, these components become increasingly reduced, producing iron oxide (FeO) then a partially reduced and carburised form of solid iron.

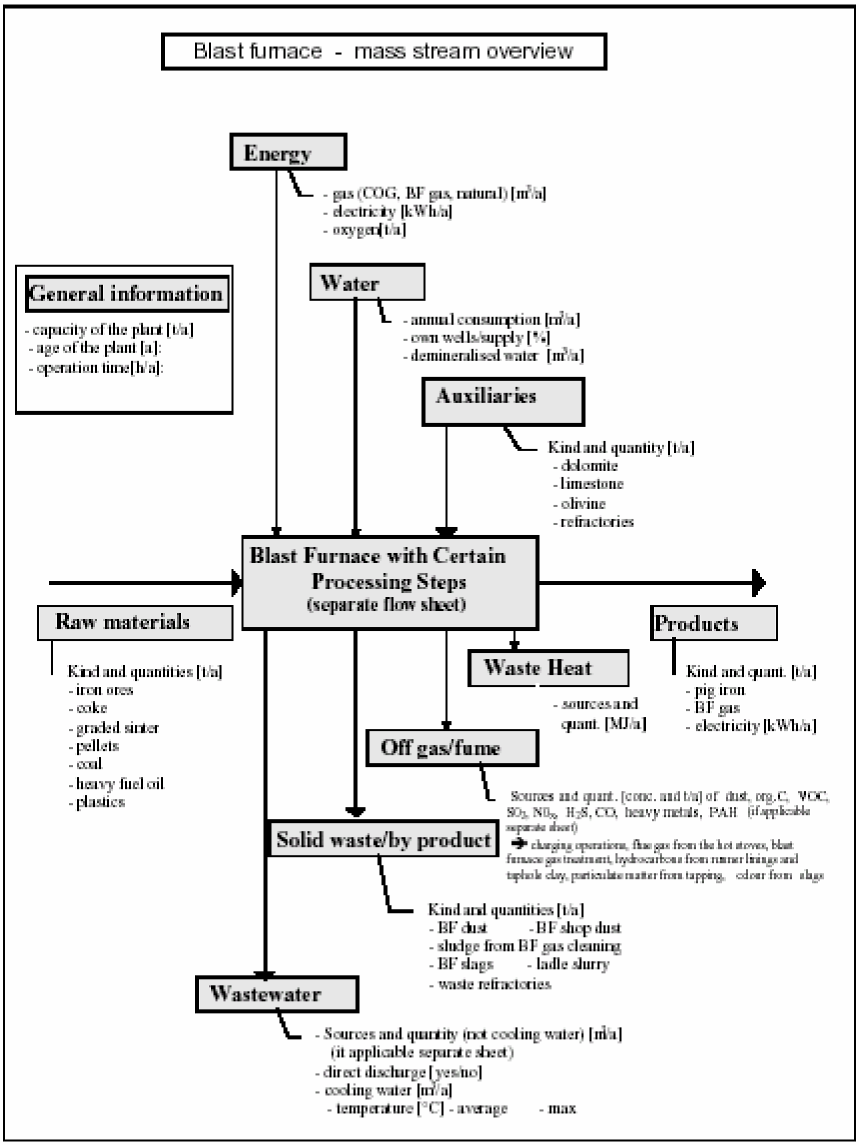

Figure 12. Blast furnace flow chart (Source: BREF on production of iron and steel[30])

Various reducing agents are available. Carbon/hydrocarbons in the form of coke, coal, oil, natural gas, are used. However, the choice between several reducing agents is not determined by costs alone. Apart from being a reducing agent, coke also serves as a carrier of the bulk column in the blast furnace. Without this carrying capacity, blast furnace operation would not be possible.

Most blast furnace installations inject reducing agents into the furnace at the tuyère level. This partially replaces coke in the top charge. This practice enables the operator to optimise on the use of reducing agents. Other advantages are increased output and a reduction in the cokemaking requirements, thereby decreasing the specific coke oven emissions per tonne of steel produced.

As stated before, in addition to reducing and melting the iron ore, coke also functions as a spacer to ensure this movement of gases, liquids, and solids within the blast furnace. Plastic and pulverized coal are unable to function in this manner, and substitution of coke with plastic is therefore limited.

The maximum injection rate depends amongst others on the shape and size of the blast furnace. The maximum injection rate possible is considered to be about 40-45% of the energy and feedstock required by the blast furnace is injected in the form of pulverised coal, the remainder being mainly coke[21].

Coal injection results in energy savings at coke making. Per tonne of coke that is replaced about 1.08 tonne of coal is required. The energy saved is on average 3.5 GJ/tonne coke replaced (the energy requirement for coke making minus the energy content of the extra coal required) [31].

Apart from the fuel savings achieved, coal injection has a positive environmental effect because less coke is consumed and so emissions from coke oven plants are avoided. At a coal injection rate of 180 kg/t pig iron, which is achieved at many places already, approximately 30% less coke is consumed. It is expected that the coal injection rate will continue to increase over the coming years [30].

Another option is the use of plastic waste as a reducing agent instead of coal (or fuel oil). This practise is getting extended in different countries, for example:

- In Europe, although other companies like British Steel (UK) have done trials as well, see Figure 13, German blast furnaces are the only plants in Europe known to use plastics waste in this way[23]. The best-known pioneer in this field is Stahlwerke Bremen, a large German steel manufacturer which operates two blast furnaces to produce over 7000 t/day, or some 3 Million tpa pig iron. In 1993 Stahlwerke Bremen decided to examine the injection of solid plastic material in the blast furnace and carried out a one year test operation with a pilot plant.

Stahlwerke Bremen used plastic waste as a substitute for fuel oil. From a silo or big bags the plastics are filled on a screen where the fraction >18 mm is separated. Also, no fibres or metal particles like wires or nails are allowed in the plastic waste. The smaller plastic waste particles (<18 mm) go to the injection vessel where the injection pressure of about 5 bar is built up. The discharge and dosing work works pneumatically without mechanical support. For continuous operation, it was found that a minimum value for the bulk density of 0.3 t/m^3 should be set[23]. Plastics can substitute heavy oil used in blast furnaces in a 1:1 to 1:1.1 ratio.

The first experiments started in February 1994 with a capacity of 50 t/day of plastic waste. Operation of a large size system started in July–August 1995 with a capacity of 75,000 t/yr, using agglomerated DSD waste. Several developments made it possible to increase the capacity of the plant. In 1998 some 162,500 ton of MPW was used in German blast furnaces, forming some 25% of the amount of MPW recycled in Germany (DSD, 1999)[23].

- In Japan, Nikon Steel introduces plastic instead of the pulverised coal in the tuyeres (this, one originally substituting part of the coal used). As detailed in the figure below, film-type plastics, bottles and other solid plastics are separated by a sorter. The former are pelletized, and the latter are pulverized to the specified particle size and used in raw material for the blast furnace, to be blown from the tuyeres at the blast furnace bottom. Plastics blown from the tuyeres at the blast furnace bottom are gasified and used in the iron ore reduction. The pre-treatment of plastics include the separation of PVC, in order not to incorporate it to the blast furnace. In addition, the company has also started operation of a pilot-scale dechlorination system (annual treatment capacity: 5000 ton scale) for use of vinyl chloride as a blast furnace feed raw material[32], [33].

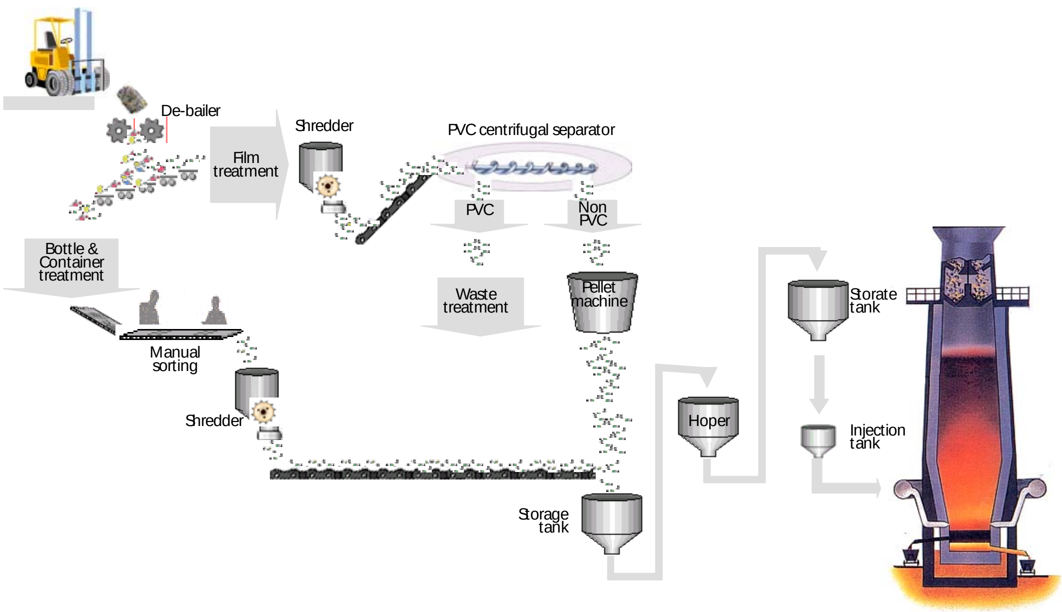

Figure 13. Operation scheme of use of plastic waste as reducing agent in Nikon Steel's blast furnace

5.1. ATMOSPHERIC EMISSIONS

There is very limited information regarding the emission in the blast furnace referred to the use of plastic waste.

The average emissions for a plant by tonne of combustible processed would be as follows:

Table 17. Emissions by tonne of combustible in the furnace[30]

Substance	Min.	Max	unit
dust	0,02	0,09	g/t
Mn	2,01E-05	0,000236	g/t
Ni	2,01E-05	3,59E-05	g/t
Pb	2,01E-05	0,000219	g/t
SOx	0,03	0,41	g/t
NOx	0,06	0,22	g/t
H2S	0,0003	0,0364	g/t
CO	1,50	3,18	g/t
CO2	0,54	0,91	kg/t
PCDD/F	1,83E-06	6,84E-06	µg I-TEQ/t

Regarding CO_2 emissions in the blast furnace, a reduction is expected derived from the use of plastic wastes. As explained by Ogaki et al[31], pulverized coal or coke is burnt rapidly in the first stage of the raceway, consuming oxygen and generating CO_2 at temperatures in excess of 2000ºC.

As all oxygen has been consumed by the last stage of the raceway, CO is produced by reaction with the coke:

$$C + 2CO \rightarrow C_2O \ (coke, pulverisedcoal)$$

In the same conditions, plastic is broken down into CO and H_2 (the following example uses polyethylene as an example):

$$\tfrac{1}{2}C_2H_4 + CO_2 \rightarrow 2CO + H_2$$

The CO and H_2 generated rise within the furnace, reducing and smelting the iron ore. The pig iron produced is removed from the base of the blast furnace. The products of the reduction process differ in case of using plastic, as shown bellow:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$
$$Fe_2O_3 + 2CO + H_2 \rightarrow 2Fe + 2CO_2 + H_2O$$

Therefore, when plastic is used the hydrogen contributes to the reduction reaction, thus reducing the amount of CO_2 generated. Some authors expect a reduction of 30% in the amount of CO_2 emitted.

A reduction in SOx emissions are also expected, since (unlike oil and coal) plastics contain no sulphur. In the same way, no metal emissions are expected from the use of plastics as reducing agent.

Concern has been expressed about the possible formation of dioxins and furans. However, measurements during experiments indicated that the emissions of dioxins and furans were not significantly elevated. Dioxin emissions with or without plastic input appeared to be about a factor of 100 below the standard of 0.1 ng/Nm^3 TEQ TCCD (toxicity equivalent in relation to the toxic dioxin TCCD). This might be to the benefit of the strongly reducing atmosphere and the high temperature of 2100ºC.

As for other potential atmospheric emissions, there is no information on their variation depending on the materials fed to the furnace.

5.2. WASTEWATER

There is no information available on the influence of the substitution of conventional reducing agents by wastes plastics, although no major changes are expected.

0.1-3.5 m^3 wastewater are expected to be produced by pig iron tonne, therefore, the blast furnace with 1 ton of waste plastic would lead to the production of 0,2-7 m^3. The usual wastewater streams from pig iron production are detailed below[30]:

- Overflow water from Blast Furnace (BF) gas treatment: Water from BF gas scrubbing is normally treated, cooled and recycled to the scrubber. Treatment usually takes place in circular settling tanks. The overflow of the circuit is normally 0.1 – 3.5 m^3/t pig iron depending on raw material quality/specification and water availability, which influences the measures taken to optimise water recycling. Especially high salt content raw materials can require significant higher volumes of wash water.

- Wastewater from slag granulation: Overflow of water from slag granulation primarily depends on water availability and is in the range 0.125 – 10 m^3/t pig iron produced, containing some metals like Pb, Cr, Cu, Ni and Zn.
- Blow down from cooling water circuit. Information on representative quantities and chemical composition is not available.

6. CEMENT KILN

The basic chemistry of the cement manufacturing process begins with the decomposition of calcium carbonate ($CaCO_3$) at about 900°C to leave calcium oxide (CaO, lime) and liberate gaseous carbon dioxide (CO_2); this process is known as calcination. This is followed by the clinkering process in which the calcium oxide reacts at high temperature (typically 1400-1500°C) with silica, alumina, and ferrous oxide to form the silicates, aluminates, and ferrites of calcium which comprise the clinker. The clinker is then ground or milled together with gypsum and other additives to produce cement[34].

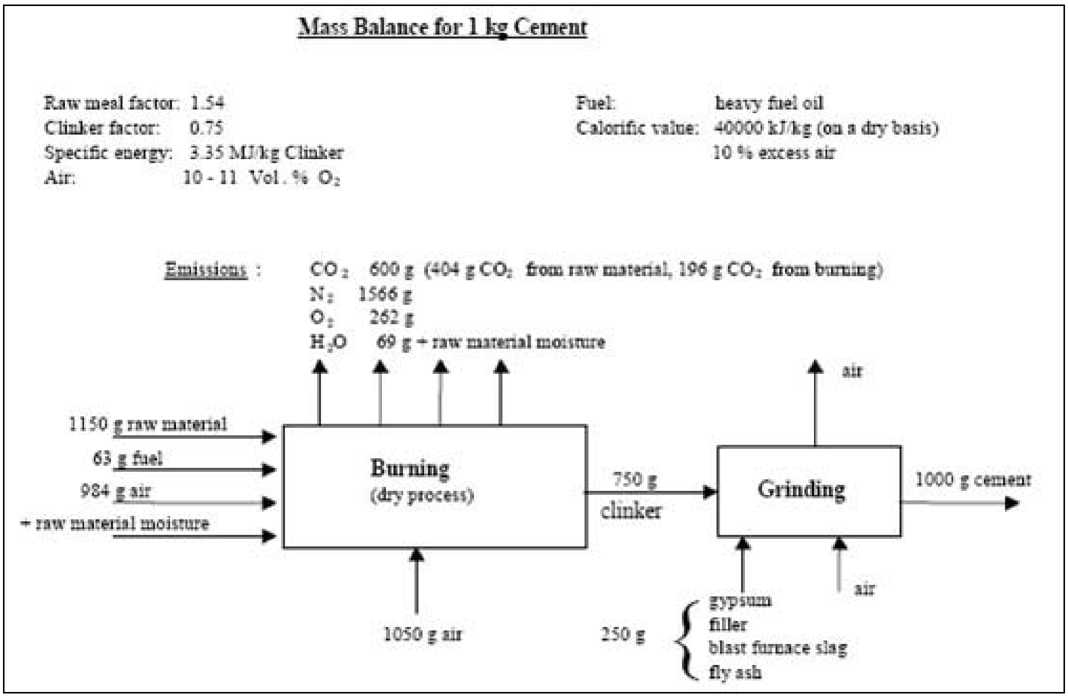

Figure 14. Mass balance for the production of 1 kg cement[34]

Various fuels can be used to provide the heat required for the process. Three different types of fuels are mainly used in cement kiln firing; in decreasing order of importance these are

- pulverised coal and petcoke;
- (heavy) fuel oil;
- Natural gas.

Annually, the energy equivalent of about 25 million tonnes of coal is required by CEMBUREAU (the European Cement Association) members to service the demand for cement in Europe[35]. This is a significant use of non-renewable primary fossil fuel, and therefore the industry is committed to seeking alternative fuels.

Waste plastics from residual recycling or commercial/industrial activities are used in cement kilns as alternative fuels in Austria, Belgium, Denmark, Germany, the Netherlands and Sweden. Plastics have been trialled in the UK as part of Profuel by Castle Cement. It is shredded and mixed with other wastes before injection and co-firing[18.] Plastics from end of life vehicles (ASR-automotive shredder residues) are reported to be co-incinerated as secondary fuels in cement kilns in Belgium[18]. Fibre reinforced plastics ("composites") are used in clinker production. The inorganic part substitutes natural siliceous, aluminium and calcium compounds. The organic part contributes to the energy input of the operation[18].

The European average energy substitution rate for secondary fuels in the cement industry is reported to range between 1 and 40%. It was reported that in 1995, that fuel usage in the cement industry in Europe was about 10% for waste derived fuels, compared with 39% of pet coke and 36% of coal, 7% of fuel oil, 6% of lignite and 2% of gas[18].

6.1. ATMOSPHERIC EMISSIONS

Typical kiln exhaust gas volumes expressed as m^3/tonne of clinker (dry gas, 101.3 kPa, 273 K) are between 1700 and 2500 for all types of kilns. Suspension preheater and precalciner kiln systems normally have exhaust gas volumes around 2000 m^3/tonne of clinker (dry gas, 101.3 kPa, 273 K)[34].

Emission data from kilns in operation is given in Table 18. The emission ranges within which kilns operate depend largely on the nature of the raw materials, the fuels, the age and design of the plant, and also on the requirements laid down by the permitting authority.

Table 18. Emission ranges data from European cement kilns[34]

Substance	mg/Nm³		mg/tonne clinker	
	min	max	min	max
NOx (as NO_2)	<200	3000	400000	6000000
SO_2	<10	3500	20000	7000000
Dust	5	200	10000	400000
CO	500	2000	500000000	3000000000
CO_2	400000	520000	800000000	1040000000
TOC	5	500	10	1000
HF	<0.4	5	<800	10000
HCl	<1	25	<2000	50000
PCDD/F	<0.0000001	0.0000005	<0,0002	0,001
Metals:				
Hg, Cd, Tl	0.01	0.3 (mainly Hg)	20	600
As, Co, Ni, Se, Te	0.001	0.1	2	200
Sb, Pb, Cr, Cu, Mn,V, Sn, Zn	0.005	0.3	10	600

- Volatile Organic Compounds: Because of the high temperatures and the chemically basic environment, cement kilns are suited for combustion of waste materials[36]. However, wastes injected at mid- or feed-end locations do not experience the same elevated temperatures and long residence times as wastes introduced at the hot end [37]:
  - Wastes that are fed through the main burner will be decomposed in the primary burning zone, at temperatures up to 2000 °C.

– Waste fed to a secondary burner, preheater or precalciner will be burnt at lower temperatures, which not always is enough to decompose halogenated organic substances. Volatile components in material that is fed at the upper end of the kiln or as lump fuel can evaporate. These components do not pass the primary burning zone and may not be decomposed or bound in the cement clinker. Therefore the use of waste containing volatile metals (mercury, thallium) or volatile organic compounds can result in an increase of the emissions of mercury, thallium or VOCs when improperly used: In a worst-case scenario, volatile compounds may be released from the charge so rapidly that they are not able to mix with oxygen and ignite before they cool below a critical temperature, forming PICs (Dellinger et al, 1993). Increased PICs, or precursor organics, may enhance formation of PCDD/Fs[37].

Different trials carried out report high Destruction and removal efficiency (DRE) of organid substances fed to the fuel kilm. For example, The test burn result of pesticides showed a DRE of >99.9999 , and a test burn with two expired chlorinated insecticide compounds introduced at a rate of 2 tons per hour through the main burner was carried out in Vietnam in 2003 showed a DRE for the introduced insecticides >99.99999 %[37].

- CO: The emission of CO is related to the content of organic matter in the raw material, but may also result from poor combustion when control of the solid fuel feed is sub-optimal. Depending on the raw material deposit, between 1.5 and 6 g of organic carbon per kg clinker are brought into the process with the natural raw material[34].Although some cement kilns operate at elevated carbon monoxide levels, these levels are not necessarily indicative of poor combustion. A portion of the carbon monoxide in cement kilns is due to the calcinations' process. The calcinations of limestone releases large quantities of carbon dioxide, which can subsequently decompose into carbon monoxide at the extremely high temperatures in the kiln. In addition, carbon monoxide may be formed at the kiln gas exit end where total hydrocarbons are volatilized from the raw materials and are partially oxidized[37].

- CO_2 emissions: Approximately 60% CO_2 originates in the calcining process and the remaining 40% is related to fuel combustion. The CO_2 emissions resulting from the combustion of the carbon content of the fuel is directly proportional to the specific heat demand as well as the ratio of carbon content to the calorific value of the fuel. For example, a specific heat demand of 3000 MJ/tonne of clinker and the use of hard coal with a calorific value of 30 MJ/kg and a carbon content of 88% results in a CO_2 emission of 0.32 tonne per tonne of clinker, when regarding fuel part only. Using natural gas instead reduces this level by approximately 25%[30].

- SO_2 emissions from cement plants are primarily determined by the content of the volatile sulphur in the raw materials. Although a potential reduction on SOx emissions due associated to the substitution of conventional fuels by plastics (with nearly no S content)[18], the report for the establishment of best available technologies determines that sulphur in the fuels fed to preheater kilns will not lead to significant SO_2 emissions, due to the strong alkaline nature in the sintering zone, the calcination zone and in the lower stage of the preheater. This sulphur will be captured in the clinker. The excess oxygen (1 to 3% O_2 maintained in the kiln for satisfactory cement product quality) will normally immediately oxidise any released sulphide compounds to SO_2[34].

  However, in long kilns the contact between SO_2 and alkaline material is not so good, and sulphur in the fuels can lead to significant SO_2 emissions[34].

- NOx: Nitrogen oxides (NOx) are of major significance with respect to air pollution from cement manufacturing plants. NO and NO_2 are the dominant nitrogen oxides in cement kiln exhaust gases (NO >90% of the nitrogen oxides). There are two main sources for production of NOx:

- Thermal NOx: part of the nitrogen in the combustion air reacts with oxygen to form various oxides of nitrogen.
- Fuel NOx: nitrogen containing compounds, chemically bound in the fuel, react with oxygen in the air to form various oxides of nitrogen.

- Metals: In the same way as the major elements, metals which may be introduced with liquid or solid fuels will also be incorporated into the clinker structure to a large extent. Exceptions are metals which are partly or completely volatilised in the kiln system such as mercury, thallium or cadmium. These elements will be captured in the kiln (filter) dust or may to some extent escape with the stack emissions (mercury) if not managed appropriately[37].
- Dioxins and furans: The Stockholm Convention is explicitly mentioning cement kilns firing hazardous waste as a fuel substitute as a potential source category for the formation and release of PCDD/Fs. The level of PCDD/F emissions from a cement kiln may potentially be affected by a number of factors. However, the inlet temperature to the particulate matter control device is one factor that has been shown to consistently affect PCDD/F formation, irrespective of fuel used (Chadbourne, 1997)[38].

The average PCDD/F flue gas concentration in European kilns is approximately 0.02 ng TEQ/m3, representing hundreds of measurements. In general terms, emissions from the cement industry can be classified as low today, even when wastes and hazardous wastes are used as a co-fuel[38]. (average exhaust-gas volume of 2300 Nm3/ton clinker is assumed and a clinker/cement ratio of 0.8).

Many recent studies have concluded that the use of alternative fuels and raw materials doesn't influence or affect the emissions of PCDD/Fs . In general, it seems that the ranges of PCDD/Fs emission concentration resulting from the use of conventional fuels such as coal and petcoke overlap with the ranges obtained with the use of secondary fuel, regardless of the type of secondary fuel[38].

The German cement research institute VDZ carried out approximately 160 PCDD/F emission measurements of German cement kilns between 1989 and 1996; see figure below (VDZ, 2003). The measurements was carried out under baseline conditions (only fossil fuel) and when feeding alternative fuels and secondary raw materials. VDZ concludes that no influence on the PCDD/F emissions can be identified. The substitution of fossil fuel and normal raw materials with alternative fuel and raw materials (AFR) increased in German cement kilns from an average of 23 % in 1999 to nearly 35 % in

2002[37], giving an average concentration amounts to about 0.02 ng TEQ/m^3 [34].

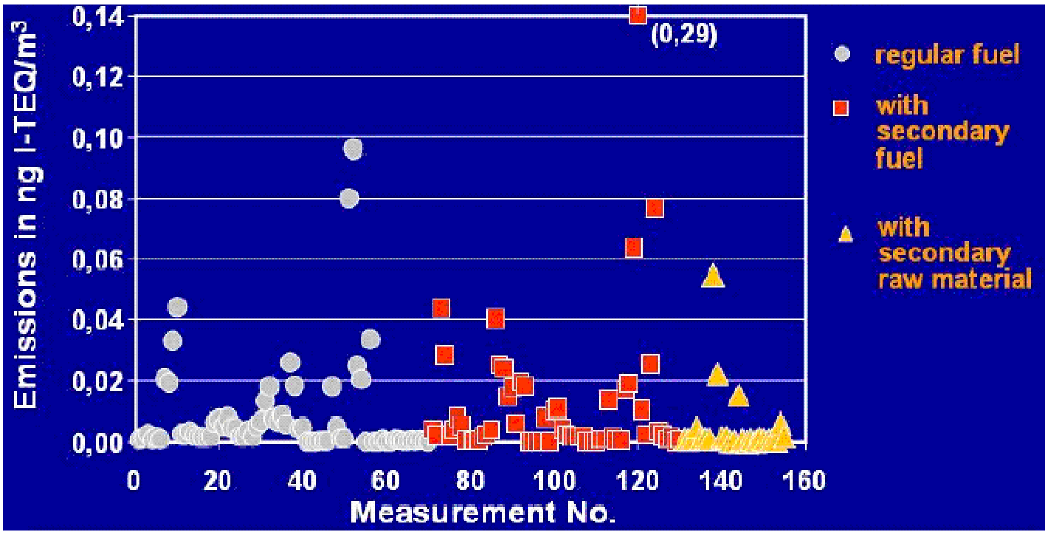

Figure 15. PCDD/F emissions of German cement kilns between 1999 and 2002[38].

6.2. WASTEWATER

Waste water discharge is usually limited to surface run off and cooling water only and causes no substantial contribution to water pollution. The storage and handling of fuels is a potential source of contamination of soil and groundwater[34].

7. INCINERATION PLANTS

Incineration of plastic waste in installations suitable for Municipal Solid Waste has been considered. The thermal treatment applied in these installations may be based on different technologies, being the most relevant ones: grate incinerator, rotary kiln and fluidised beds (pyrolysis and gasification have already been considered in other chapters of this study). Fluidised bed technology requires some degree of pre-treatment and/or selective collection of waste[39].

7.1. MATERIAL CONSUMPTION

Most relevant consumptions of auxiliary materials are detailed in the table below.

Table 19. Auxiliary material consumption in MSW incinerators[39]

Substances	MIN	MAX	Unit
CaO	1.33	97	kg/t waste
NH_4OH	3.1		kg/t waste
Active carbon	0.3	19.31	kg/t waste

Although a proportional correlation can be established among many auxiliary materials consumed and the substances being incinerated, for the purpose of this study average consumptions have been considered.

7.2. ENERGY

Typical electricity generated per tonne of MSW is 400-700 kWh. The amount of energy available for export usually depends upon the amount produced and the degree of self-consumption by the installation, which can vary significantly.

7.3. ATMOSPHERIC EMISSIONS

Emission control is a key aspect of this technology. For the purpose of this study, a system with wet flue gas cleaning, particle removal with ESP, DeNOx and dioxin removal. In fact, around 44% of MSW incinerators use a wet flue-gas treatment system. This system achieves highest reduction of HCl, HF, NH_3 and SO_2 emissions and produce low wastes. However, they consume larger amount of water, and also generate more wastewater. Also energy consumption is higher due to pump demand.

There are several studies estimating the contribution to materials in waste to the atmospheric emissions, drawing the following conclusions:

- Carbon compounds:

  Carbon compounds are inorganic or organic combustion products of the carbon content of the product.

  Calculation of net CO_2 emissions from waste incineration is based on the fossil carbon content of the waste (kg fossil carbon/kg waste), multiplied by the amount of CO_2 generated per amount of carbon (kg CO_2/kg fossil carbon).

Table 20. Carbon content in main commodity thermoplastics[40]

Polymer	Fossil C (g C / kg waste)	Biological C (g C / kg waste)
PE	856	0
PP	855	0
PS	889	0
PET	640	0
PVC	401	0

- NOx: The NO and NO_2 emitted from waste incineration plants originate from the conversion of the Nitrogen contained in waste (so-called fuel NOx) and from the conversion of atmospheric nitrogen from the combustion air into Nitrogen Oxides (thermal NOx). In MSW incineration plants, the proportion of thermal NOx is usually very low due to lower temperatures in the afterburner chamber. Production of thermal NOx generally becomes more significant at temperatures above 1000°C. Literature[41] estimates that 75% of NOx are formed from N in the waste, while the remaining 25% is thermal NOx.

  The mechanisms for the formation of NOx from the nitrogen contained in the waste are very complicated. Amongst other reasons, this is because nitrogen can be contained in the waste in many different forms, which depending on the chemical environmental, can react either to NOx or to elementary Nitrogen. A conversion rate of around 10-20% of the fuel nitrogen is usually assumed depending on the waste type. The proportion of NO/NO_2 in total NOx emissions is usually approx 95% NO and 5% NO_2.

Table 21. NOx emission factors in MSW incinerators (aggregated values from literature)

NOx generation		NO	NO_2
Fuel NOx	g/kg N in waste	30-45.42	0.9-2.87
Thermal NOx	g/ t waste	74.5-128.69	2.3-8.13

In the case of plastic incineration only fuel NOx is relevant. The following emissions can be estimated:

Table 22. NOx emission factors in plastic incineration (estimated values)

NOx emissions	NO	NO_2
g/m^3	0.012-0.028	0.0004-0.0018
g/t waste	74.5-128.69	2.3-8.13

- SOx: The generation of this compound depends on the S content in the waste, which is negligible in plastics.
- Dioxins and furans: According to literature (BREF on Waste Incineration[39]), dioxins and furans entering the process with the waste are destroyed very efficiently, if sufficiently high incineration temperatures and appropriate process conditions are used. The dioxins and furans found in the crude flue-gas of waste incineration plants are the result of a recombination reaction of carbon, oxygen and chlorine.

- Metal emissions and other halogenated compounds: Average HCl emissions have an average of 0.1-10 mg/m^3. According to the literature[39, 41, 42], the following percentages of metals in wastes are emitted to the atmosphere.

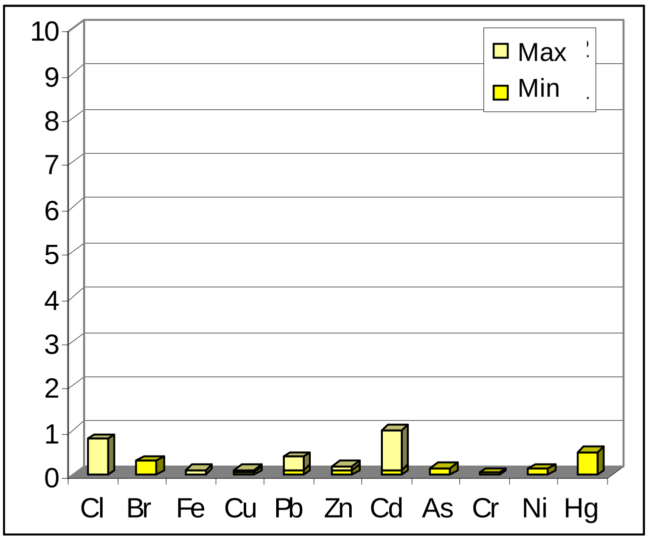

Figure 16. Air emission factors (min and max) of metals and other halogenated compounds in waste incineration(%)

7.4. WASTEWATER

Regarding wastewater emissions, wet flue gas cleaning consumes 0.6-1.1 m^3 water/tonne of waste.

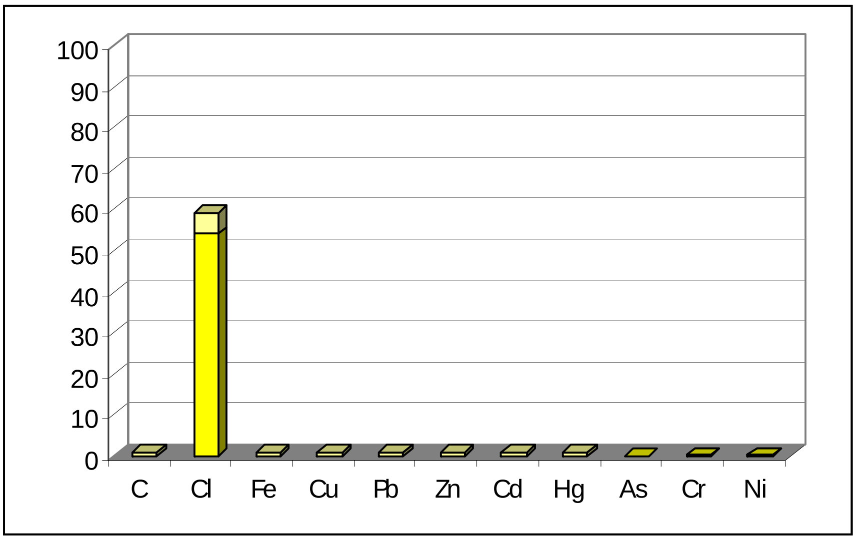

Figure 17. Wastewater emission factors (min and max) in waste incinerator(%)[39, 41, 42]

8. GLOSSARY

BGL: British Gas – Lurgi (gasifier)

ESP: ElectroStatic Precipitator

I-TEQ: International Toxic Equivalent

MSW: Municipal Solid Waste

Nm^3: normal cubic metre (gas volume measured at standard conditions)

PCDD/F: Polychlorinated dioxin and furans

SNRC: Selective Non-Catalytic Reduction

SRC: Selective Catalytic Reduction

TEQ: Toxic Equivalent

tpy: tonnes per year (=tpa: tonnes per annum)

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ANNEX 4

POLYMER RECOVERY TECNOLOGIES. MARKET SHEETS & SWOT

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Energy recovery from mixed plastic waste in cement kilns
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	50,000-200,000
	Application	general and polymer specific
	Running requirements	utilities
	Environmental effects	air emissions and solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	concentrated // recycling facilities
	Nature of waste generation points	industrial
	National or local collection schemes	no
	Distance to consolidation points, km	50-200
	Distance to treatment points, km	50-200
Plastic waste quality (input material)	Consistency of supply	steady
	Quality of supply	variable
	Nature of contamination	other plastics materials and non-plastic materials
	Required sorting technology for material classification	yes // size, density and texture
	Required cleaning technology for contaminant removal	no
Product quality (output material)	Product nature	energy
	Product added value (MECHANICAL RECYCLING only)	
	Product purity	assured
	Standards for recycled product	no // required minimum heating value
Markets and prices	Existence of markets for the recovered product(s)	yes // cement kilns and other coincineration facilities
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	
	Gate fee (treatment cost), EUR/t	
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	no // specific for every facility
	Existence of recycling and recovery targets per material	yes // more than waste stream type than per material type
	Existence of other legislation affecting this plastic recovery route	yes
	Relevant national legislation (if so, specify country of the EU-25)	emission limits for cement kilns (AT)
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	profit opportunity
	Environmental drivers	energy efficiency
	Social drivers/barriers	administration policies and stakeholders interest or resistance
	Special regional/national barriers or drivers	
Detected barriers/ proposed drivers for further implementation of the present process		Drivers: Directive 2000/76/EC on co-incineration and energy recovery targets on packaging waste, ELV and WEEE Directives

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Simple and traditional technology
	What does it do well?	---
	What relevant waste streams are accessible for recycling?	All kind of plastic containig waste without hazardous contaminations and limited content on metallic and halogen elements
	What do other technologies cannot do?	---
Weaknesses	What could it improve?	Energy efficiency
	What does it do badly?	---
	What should it avoid?	Transport cost
Opportunities	Where are the good opportunities facing it?	---
	What are the interesting trends it is aware of?	Increase of energy recovery from waste demand, CO_2 emission reduction, decrease of use of non renewable fuels
	Changes in technology and markets on both a broad and narrow scale	---
	Changes in government policy related to this field	Yes, support and positive perception of energy recovery activities
	Changes in social patterns, population profiles, life style changes, etc.	Yes, industry awareness on landfill rate reduction
	Local events	---
Threats	What obstacles does it face?	Very narrow economic margin for secondary fuels from waste when compared with cheap alternative fuels like coke Authorisation needed
	What is the competitor technology doing?	---
	Are the required specifications for its product or service changing?	No
	Is a changing technology threatening its position?	No
	Are there bad debt or cash flow problems?	Yes, the amount of investment for adaptation (texturization and feeding) of plants for secondary fuels usage
	Could any of the weaknesses seriously threaten the technology?	No

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Incineration with other wastes
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	>200,000
	Application	general
	Running requirements	energy, utilities
	Environmental effects	air emissions, solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	concentrated // dispersed
	Nature of waste generation points	industrial // domestic
	National or local collection schemes	no
	Distance to consolidation points, km	50-200
	Distance to treatment points, km	50-200
Plastic waste quality (input material)	Consistency of supply	steady
	Quality of supply	variable
	Nature of contamination	non-plastic materials // organic and inorganic
	Required sorting technology for material classification	yes // size, density and texture
	Required cleaning technology for contaminant removal	yes
Product quality (output material)	Product nature	energy
	Product added value (MECHANICAL RECYCLING only)	
	Product purity	assured
	Standards for recycled product	no // required minimum heating value
Markets and prices	Existence of markets for the recovered product(s)	yes // other incineration facilities
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	
	Gate fee (treatment cost), EUR/t	
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes
	Existence of recycling and recovery targets per material	yes // more than waste stream type than per material type
	Existence of other legislation affecting this plastic recovery route	yes
	Relevant national legislation (if so, specify country of the EU-25)	emission limits for incineration facilities
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	profit opportunity
	Environmental drivers	energy efficiency
	Social drivers/barriers	administration policies and stakeholders interest or resistance
	Special regional/national barriers or drivers	public policies in favour of on waste incineration
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		Drivers: Directive 2000/76/EC on co-incineration and energy recovery targets on packaging waste, ELV and WEEE Directives

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Simple and traditional technology
	What does it do well?	---
	What relevant waste streams are accessible for recycling?	All kind of plastic containig waste without hazardous contaminations and limited content on metallic and halogen elements
	What do other technologies cannot do?	---
Weaknesses	What could it improve?	Energy efficiency and emission control
	What does it do badly?	Ash and solid waste generation
	What should it avoid?	Transport cost
Opportunities	Where are the good opportunities facing it?	---
	What are the interesting trends it is aware of?	Landfill restriction
	Changes in technology and markets on both a broad and narrow scale	---
	Changes in government policy related to this field	Yes, support and positive perception of energy recovery activities
	Changes in social patterns, population profiles, life style changes, etc.	Yes, industry awareness on landfill rate reduction
	Local events	Landfill closing
Threats	What obstacles does it face?	Negative social perception
	What is the competitor technology doing?	---
	Are the required specifications for its product or service changing?	No
	Is a changing technology threatening its position?	No
	Are there bad debt or cash flow problems?	No
	Could any of the weaknesses seriously threaten the technology?	No

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Waste plastic as a reduction agent in the blast furnaces
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	>200,000
	Application	polymer specific
	Running requirements	energy, utilities and chemicals
	Environmental effects	waste water, air emissions and solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	dispersed
	Nature of waste generation points	domestic
	National or local collection schemes	yes; separated and dedicated
	Distance to consolidation points, km	
	Distance to treatment points, km	>200
Plastic waste quality (input material)	Consistency of supply	transient
	Quality of supply	contaminated and variable
	Nature of contamination	other plastics materials and non-plastic materials
	Required sorting technology for material classification	yes
	Required cleaning technology for contaminant removal	yes
Product quality (output material)	Product nature	polymer
	Product added value (MECHANICAL RECYCLING only)	intermediate (e.g., flakes or pellets)
	Product purity	assured
	Standards for recycled product	yes
Markets and prices	Existence of markets for the recovered product(s)	
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	75 EUR/t (packaging DSD)
	Gate fee (treatment cost), EUR/t	100 EUR/t (DSD?)
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery route	IPPC Directive, GHG emission reduction policies (IPCC Guidelines)
	Relevant national legislation (if so, specify country of the EU 25)	Plastic waste diversion from MSWI in Denmark, landfill bans for separate collected waste and ELV in Belgium, landfill bans for organic material in Germany, France, Sweden, etc.
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	
	Environmental drivers	
	Social drivers/barriers	
	Special regional/national barriers or drivers	
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		
SWOT	**QUESTIONS**	**ANSWERS and FACTS**
Strengths	What advantages does it have?	Large-scale stable treatment is possible as waste is fed into running process (existing industrial plants) as alternative raw material
	What does it do well?	Provides saving energy and resources by effective use of waste plastics which cannot be recycled as raw material for plastic, allowing reduced and more effective consumption of fossil fuels.
	What relevant waste streams are accessible for recycling?	MPW from packaging waste (PVC min.), industrial scrap (automotive, packaging, E&E housings), ASR light fraction
	What do other technologies cannot do?	Extremely low emission of dioxins and decrease SO2 and CO2 emissions (versus coke and pulverised coal).
Weaknesses	What could it improve?	The process of conversion of packaging plastic waste to raw material for blast furnace is complex and costly
	What does it do badly?	ASR light fraction performance is bad and requires pretreatment. Its only possibility is adding it in small rates to coal feed.
	What should it avoid?	worsening standard operation conditions
Opportunities	Where are the good opportunities facing it?	Installed capacity enough to treat arising packaging waste.
	What are the interesting trends it is aware of?	
	Changes in technology and markets on both a broad and narrow scale	
	Changes in government policy related to this field	Best practices derived from IPPC, GHG emission reduction policies (IPCC Guidelines)
	Changes in social patterns, population profiles, life style changes, etc.	Socially positive perception
	Local events	
Threats	What obstacles does it face?	problem for ironmakers when using auxiliary substances and wastes is to maintain a smooth, highly productive operation, suitable metal quality and production costs Regarded as WTE process (energy recovery) and not as feedstock recycling in EU: is waste plastic used as raw material and ingredient, while a very small portion is used as fuel in blast furnaces? (similar consideration in cement kiln)
	What is the competitor technology doing?	
	Are the required specifications for its product or service changing?	steelworks would prefer plastic waste PVC-free to avoid corrosion problems but more stringent specifications would keep them out of the market as all MPW have some PVC content
	Is a changing technology threatening its position?	
	Are there bad debt or cash flow problems?	it seems to be economically viable only if subsidised
	Could any of the weaknesses seriously threaten the technology?	

BARRIERS AND DRIVERS FOR PLASTIC WASTE RECOVERY OPTIONS – FORM F2

The project "ASSESSMENT OF THE ENVIRONMENTAL ADVANTAGES AND DRAWBACKS OF EXISTING AND EMERGING POLYMERS RECOVERY PROCESSES" (Contract no. 150200-2005-F1ED-ES) focuses on the recovery options for post-consumer plastic waste from any of the following sources:

1. Municipal Solid Waste (MSW)
2. Packaging Waste
3. Agricultural Waste
4. End of Life Vehicles (ELV)
5. Waste Electric and Electronic Equipment (WEEE)
6. Construction and Demolition Waste

We would be grateful if you could help us identify the barriers to spreading the plastic recovery technology that you supply and analyse the supportive framework that might help to overcome those barriers in the EU-25. Below there is a list of points that we think can constitute either barriers or drivers for further implementation of plastic waste recovery technologies, but feel free to comment out of the proposed checklist.

Please tick the aspects that apply to your technology and the plastic waste treated or simply add your comments in the section *ad hoc* at the end of the form. Thanks for your co-operation.

The answers can be send either by e-mail (delgado@gaiker.es) or by fax (+34 94 600 2324) to GAIKER Technology Centre (Attn. Clara Delgado).

Process data

PROCESS	Waste plastic as a reductant in the blast furnaces
Supplier	Kobe Steel
Contact data	
Recovery route	☐ mechanical recycling ☒ feedstock recycling ☐ energy recovery

Industrialisation aspects

Technology status:	☐ research	☐ pilot/bench scale	☒ industrial
Capacity for scale economy, kg/h:	☐ < 100	☐ 100-1000	☒ >1,000
Investment in Euro:	☐ < 50,000	☐ 50,000-200,000	☒ > 200,000
Application:	☐ general	☒ polymer specific	☐ product specific
Running requirements:	☒ energy	☒ other utilities	☒ chemicals
Environmental effects:	☒ waste water	☒ air emissions	☒ solid waste

Existing collection and logistics for the post-user plastic waste to be fed to the process

Location of waste generation points :	☐ concentrated	☒ dispersed	
Nature of waste generation points:	☐ industrial	☒ domestic	
National or local collection schemes:	☒ Yes	☐ No	
	☐ bulk	☒ separated (waste stream specific, e.g., packaging)	
	☒ dedicated	☐ shared (with other materials in the same waste stream)	
Distance to consolidation points, km:	☐ < 50	☐ 50-200	☐ >200
Distance to treatment plant, km:	☒ < 50	☒ 50-200	☒ >200

Plastic waste quality (input material)

Consistency of supply:	☐ steady	☒ transient (☐ increasing / ☐ decreasing)	
Quality of supply:	☐ clean	☒ contaminated	
	☐ fixed	☒ variable	
Nature of contamination:	☒ other plastic materials	☒ non-plastic materials	
Required sorting technology for material classification:		☒ Yes	☐ No
Required cleaning technology for contaminant removal:		☒ Yes	☐ No

Product quality (output material)

Product nature:	☒ polymer	☐ monomers	☐ basic chemicals, syngas
	☐ fuel, oils	☐ energy	

Product added value (MECHANICAL RECYCLING only): ☐ low (e.g., regrind) ☒ intermediate (e.g., flakes or pellets) ☐ high (e.g. finished products)

Product purity: ☒ assured ☐ risk of contamination

Standards for recycled product: ☒ Yes ☐ No (☐ proposed, under discussion)

Markets and prices

Existence of markets for the recovered product(s): ☐ Yes ☐ No

☐ Established ☐ In development

FEEDSTOCK RECYCLING & ENERGY RECOVERY:

Price of primary raw materials/fuel replaced by the plastic waste, Euro/t:..

Associated cost for collection and pretreatment of plastic waste, Euro/t:...

Gate fee (treatment cost), Euro/t:...

MECHANICAL RECYCLING:

Price of virgin plastic (Euro/t): ....

Relative price of inlet waste plastic (as % of virgin plastic's):...

Relative price of outlet recycled plastic (as % of virgin plastic's):..

Associated cost for collection and transport of waste plastic (as % of virgin plastic's): ....

Associated cost for recycling of waste plastic (as% of virgin plastic's):..

Legislation

Existence of waste management legislation (for the waste stream treated): ☒ Yes ☐ No ☐ Expected changes

Existence of recycling and recovery targets per material: ☒ Yes ☐ No ☐ Expected changes in next years

Existence of other legislation affecting this plastic recovery route (e.g., legislation on emissions and waste of industrial processes, legislation on recycled/recovered materials, legislation on potential applications of recyclates —e.g. food-contact applications—, etc.). Specify:

Relevant national legislation (if so, specify country of the EU-25):

Sustainability (economic-environmental-social aspects)

Economic drivers/barriers:	☐ profit opportunity	☐ new markets	☐ technological risks
Environmental drivers:	☐ energy efficiency	☐ resource efficiency	
Social drivers/barriers:	☐ administration policies	☐ social demand	☐ innovation barriers
	☐ stakeholders interest or resistance		

Special regional/national barriers or drivers:

Detected barriers and proposed drivers for further implementation of the present plastic recovery process

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Thermalysis
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	100-1000
	Investment in Euro	>200,000
	Application	general
	Running requirements	energy
	Environmental effects	air emissions and solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	concentrated
	Nature of waste generation points	industrial and domestic
	National or local collection schemes	yes, separated and dedicated
	Distance to consolidation points, km	< 50
	Distance to treatment points, km	< 50
Plastic waste quality (input material)	Consistency of supply	transient (increasing)
	Quality of supply	contaminated; variable
	Nature of contamination	other plastics materials and non-plastic materials
	Required sorting technology for material classification	yes
	Required cleaning technology for contaminant removal	yes or no
Product quality (output material)	Product nature	fuel, oils
	Product added value (MECHANICAL RECYCLING only)	
	Product purity	assured
	Standards for recycled product	yes
Markets and prices	Existence of markets for the recovered product(s)	yes, established
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	550
	Associated cost for collection and pretreatment of plastic waste, EUR/t	80
	Gate fee (treatment cost), EUR/t	350
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes, expected changes
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery route	Spanish Royal Decree 1700/2003 diesel fuel specifications, Directive 2003/17/CE, Standard CEN EN 590
	Relevant national legislation (if so, specify country of the EU 25)	Spani: Spanish Order of 18 October 1976 on prevention and correction of air pollution of industrial origin, Spanish Royal Decree 653/2003 on incineration of waste, Law 10/1998 on waste, Autonomic Decree 174/2005 to rule waste production and management and general register of Galician waste producers and managers, Royal Decree 782/1998, regulation for development and fulfilment of the Law 11/1997 on packaging waste
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	profit opportunity and technological risks
	Environmental drivers	resource efficiency
	Social drivers/barriers	administration policies, social demand, innovation barriers and stakeholders interest or resistance
	Special regional/national barriers or drivers	
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		Main barrier is the consideration of Thermalysis process as a mere WTE process instead of as chemical recycling, according to current interpretation of EU legislation (Incineration Directive)
		the obtained product is not Energy but a regular "ecodiesel" (fuel substitute of a fossil fuel in diesel engines)

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	marketable product is a fuel for automobile diesel engines with low emissions. White spirit as by-product
	What does it do well?	plastic contamination is accepted (soil, paints, metals, etc.) as it is converted into char
	What relevant waste streams are accessible for recycling?	Bulk and Selectively collected polyolefins and PS packaging waste (min. PET and PVC), agricultural films, and production rejects
	What do other technologies cannot do?	unsorted and dirt PE film and packaging PP and PS recycling (no washing and sorting required)
Weaknesses	What could it improve?	less strict specifications for polymer composition in feed, energy recovery from off-gas burner
	What does it do badly?	does not treat complex waste streams (WEEE, ELV). Cannot treat FRP unless fibres are removed previously
	What should it avoid?	
Opportunities	Where are the good opportunities facing it?	collection initiatives for agricultural plastic waste can assure input volumes
	What are the interesting trends it is aware of?	
	Changes in technology and markets on both a broad and narrow scale	
	Changes in government policy related to this field	recycling targets forcing polymer recycling
	Changes in social patterns, population profiles, life style changes, etc.	
	Local events	
Threats	What obstacles does it face?	regarded as energy recovery and not as feedstock recycling
	What is the competitor technology doing?	mechanical recycling can treat efficiently certain waste streams targeted by Thermalysis
	Are the required specifications for its product or service changing?	
	Is a changing technology threatening its position?	
	Are there bad debt or cash flow problems?	only forecasts are available: if pretreatment costs can be minimised under 80 euro/t no problems foreseen
	Could any of the weaknesses seriously threaten the technology?	

BARRIERS AND DRIVERS FOR PLASTIC WASTE RECOVERY OPTIONS – FORM F2

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1. Municipal Solid Waste (MSW)
2. Packaging Waste
3. Agricultural Waste
4. End of Life Vehicles (ELV)
5. Waste Electric and Electronic Equipment (WEEE)
6. Construction and Demolition Waste

We would be grateful if you could help us identify the barriers to spreading the plastic recovery technology that you supply and analyse the supportive framework that might help to overcome those barriers in the EU-25. Below there is a list of points that we think can constitute either barriers or drivers for further implementation of plastic waste recovery technologies, but feel free to comment out of the proposed checklist.

Please tick the aspects that apply to your technology and the plastic waste treated or simply add your comments in the section *ad hoc* at the end of the form. Thanks for your co-operation.

The answers can be send either by e-mail (delgado@gaiker.es) or by fax (+34 94 600 2324) to GAIKER Technology Centre (Attn. Clara Delgado).

Process data

PROCESS	THERMALYSIS
Supplier	TECNOAMBIENTE INGENIEROS
Contact data	Javier MartÍn Padura, Tfno: 91 631 65 89; e-mail: jmpadura@telefonica.net
Recovery route	☐ mechanical recycling ☒ feedstock recycling ☐ energy recovery

Industrialisation aspects

Technology status:	☐ research	☐ pilot/bench scale	☒ industrial
Capacity for scale economy, kg/h:	☐ < 100	☒ 100-1000	☐ >1,000
Investment in Euro:	☐ < 50,000	☐ 50,000-200,000	☒ > 200,000
Application:	☒ general	☐ polymer specific	☐ product specific
Running requirements:	☒ energy	☐ other utilities	☐ chemicals
Environmental effects:	☐ waste water	☒ air emissions	☒ solid waste

Existing collection and logistics for the post-user plastic waste to be fed to the process

Location of waste generation points :	☒ concentrated	☐ dispersed	
Nature of waste generation points:	☒ industrial	☒ domestic	
National or local collection schemes:	☒ Yes	☐ No	
	☐ bulk	☒ separated (waste stream specific, e.g., packaging)	
	☒ dedicated	☐ shared (with other materials in the same waste stream)	
Distance to consolidation points, km:	☒ < 50	☐ 50-200	☐ >200
Distance to treatment plant, km:	☒ < 50	☐ 50-200	☐ >200

Plastic waste quality (input material)

Consistency of supply:	☐ steady	☒ transient (☒ increasing / ☐ decreasing)	
Quality of supply:	☐ clean	☒ contaminated	
	☐ fixed	☒ variable	
Nature of contamination:	☒ other plastic materials	☒ non-plastic materials	
Required sorting technology for material classification:		☒ Yes	☐ No
Required cleaning technology for contaminant removal:		☒ Yes	☒ No

Product quality (output material)

Product nature:	☐ polymer	☐ monomers	☐ basic chemicals, syngas
	☒ fuel, oils	☐ energy	

Product added value (MECHANICAL RECYCLING only):
☐ low (e.g., regrind)
☐ intermediate (e.g., flakes or pellets)
☐ high (e.g. finished products)

Product purity:	☒ assured	☐ risk of contamination
Standards for recycled product:	☒ Yes	☐ No (☐ proposed, under discussion)

Markets and prices

Existence of markets for the recovered product(s):	☒ Yes	☐ No
	☒ Established	☐ In development

FEEDSTOCK RECYCLING & ENERGY RECOVERY:

Price of primary raw materials/fuel replaced by the plastic waste, Euro/t:..550 €/t

Associated cost for collection and pretreatment of plastic waste, Euro/t:...80 €/t

Gate fee (treatment cost), Euro/t:..350 €/t

MECHANICAL RECYCLING:

Price of virgin plastic (Euro/t): ....

Relative price of inlet waste plastic (as % of virgin plastic's):...

Relative price of outlet recycled plastic (as % of virgin plastic's):...

Associated cost for collection and transport of waste plastic (as % of virgin plastic's):.........................

Associated cost for recycling of waste plastic (as% of virgin plastic's):..

Legislation

Existence of waste management legislation (for the waste stream treated): ☒ Yes ☐ No ☒ Expected changes

Existence of recycling and recovery targets per material: ☒ Yes ☐ No ☐ Expected changes in next years

Existence of other legislation affecting this plastic recovery route (e.g., legislation on emissions and waste of industrial processes, legislation on recycled/recovered materials, legislation on potential applications of recyclates —e.g. food-contact applications—, etc.). Specify:

- Diesel fuel specifications defined by Spanish Royal Decree 1700/2003 15th december 2003.
- Europoean Directive 2003/17/CE of European Parliament and Council of 3rd march 2003.
- European standard CEN EN 590

Relevant national legislation (if so, specify country of the EU-25): (Spain)

- Order of 18th October 1.976 about prevention and correction of air pollution of industrial origin .
- Royal Decree 653/2003, of 30th may, on incineration of waste.
- Law 10/1998, 21st april, of Waste.
- Autonomic Decree 174/2005, 9th june, to rule waste production and management and General Register of Galician waste producers and managers.
- Royal Decree 782/1998, 30th april, Regulation for development and fulfilment of the Law 11/1997, 24th april, of Packaging Waste (BOE no. 104, 1st may 1998)

Sustainability (economic-environmental-social aspects)

Economic drivers/barriers:	☒ profit opportunity	☐ new markets	☒ technological risks
Environmental drivers:	☐ energy efficiency	☒ resource efficiency	
Social drivers/barriers:	☒ administration policies	☒ social demand	☒ innovation barriers
	☒ stakeholders interest or resistance		

Special regional/national barriers or drivers:

Detected barriers and proposed drivers for further implementation of the present plastic recovery process

According to current interpretation of european legislation, the main barrier is the consideration of this thermalysis process as a mere waste to energy recovery process instead of a more accurate consideration as a chemical recycling, because the obtained product is not energy but a regular "ecodiesel" fuel substitute of a fossil fuel in diesel engines

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Thermoselect: Gasification to syngas for electricity
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	>200.000
	Application	general
	Running requirements	energy, utilities, chemicals
	Environmental effects	air emissions and solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	dispersed/concentrated
	Nature of waste generation points	domestic/industrial
	National or local collection schemes	yes; separated
	Distance to consolidation points, km	
	Distance to treatment points, km	
Plastic waste quality (input material)	Consistency of supply	transient
	Quality of supply	contaminated and variable
	Nature of contamination	non-plastic materials
	Required sorting technology for material classification	no
	Required cleaning technology for contaminant removal	no
Product quality (output material)	Product nature	basic chemicals (to energy)
	Product added value (MECHANICAL RECYCLING only)	
	Product purity	assured
	Standards for recycled product	
Markets and prices	Existence of markets for the recovered product(s)	yes (established for electricity, metals, salt and sulphur and in development for by-product vitrified
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic	
	Associated cost for collection and pretreatment of plastic	75 EUR/t (collection packaging DSD)
	Gate fee (treatment cost), EUR/t	100-150 EUR/t (Feasibility study in Waste Management Plan, estimate for MPW)
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin	
	Associated cost for collection and transport of waste plastic	
	Associated cost for recycling of waste plastic (as % of virgin	
Legislation	Existence of waste management legislation (for the waste	yes
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery	Incineration directive
	Relevant national legislation (if so, specify country of the EU-	Plastic waste diversion from MSWI in Denmark, landfill bans for separate collected waste and ELV in
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	
	Environmental drivers	Waste reduction (stable solid waste: slag) and low emissions
	Social drivers/barriers	
	Special regional/national barriers or drivers	national landfill and/or incineration avoidance policies for plastic waste
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Process with great flexibility, as syngas is cleaned and can be used as a fuel for a boiler, gas turbine or gas engine, or for other purposes (syntesis of chemicals), on site or over-fence (allowing the user to select an optimum generation method from the view points of equipment scale and site conditions.)
	What does it do well?	Waste feed does not need shredding or pelletising, it's just pressed compacted (according to manufacturer) Waste is pyrolised and gasified to a clean fuel gas, with recovery of both the ash and metals in fused forms. Salt, sulphur and Zn also recovered. It has a relatively high power export level (optimised energy effciency)ç
	What relevant waste streams are accessible for recycling?	MSW, MPW from packaging, ASR (ELV) and RDF. Also C&D plastic waste in Japan
	What do other technologies cannot do?	Non-oxidised metals, salt, Zn and sulphur recovery
Weaknesses	What could it improve?	It has a requirement for oxygen and natural gas for the gasification/ash melting reactor It can treat ASR to a maximum of 45 wt% in the feed Experience suggests that pretreatment of waste is required (shredding to 20 inches) Karlsruhe plant: Energy recovery from the clean syngas in steam turbine after burning in two boilers (lower energy effciency option!) : only 20% of power produced helps to generate revenue (the rest for internal load). In Chiba plant (JP) clean syngas is exported to a turbine combined-cycle power plant.
	What does it do badly?	Problems with halogenated compounds: PVC content must be limited, Not suitable for WEEE plastics. The process uses considerable amounts of energy to vitrify the ash at very high temperatures (2000ºC). Difficult to defend as the ash can be sintered at 850°C to give a relatively stable residue for nonhazardous landfill.
	What should it avoid?	Karlsruhe plant: technical difficulties and process modifications until reaching a throughput of half its design capacity, meeting the strict German emission levels and getting a permit for regular operation.
Opportunities	Where are the good opportunities facing it?	achieving recycling targets in complex waste streams as ELV
	What are the interesting trends it is aware of?	
	Changes in technology and markets on both a broad and	
	Changes in government policy related to this field	
	Changes in social patterns, population profiles, life style	Socially positive perception (vs incineration)
	Local events	
Threats	What obstacles does it face?	Regarded as co-incineration plant by EU legislation, as the clean syngas generated is conducted to a steam turbine for electricity and district heating Commercial difficulties to secure supply to reach design capacities Permits for regular operation cannot be granted due to the unproven state of the technology By-products (metals, Zn, salt) may be not recovered (in significant amounts) if only plastic waste streams are treated
	What is the competitor technology doing?	
	Are the required specifications for its product or service	
	Is a changing technology threatening its position?	
	Are there bad debt or cash flow problems?	cost efficiency is not clear (German plant was closed by strategic reasons, a loss of 500 million US
	Could any of the weaknesses seriously threaten the	

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Gasification to methanol and energy - SVZ
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	>200,000
	Application	general
	Running requirements	energy and utilities
	Environmental effects	air emissions and solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	dispersed/concentrated
	Nature of waste generation points	domestic/industrial
	National or local collection schemes	yes; separated
	Distance to consolidation points, km	
	Distance to treatment points, km	
Plastic waste quality (input material)	Consistency of supply	transient
	Quality of supply	contaminated and variable
	Nature of contamination	non-plastic materials
	Required sorting technology for material classification	no
	Required cleaning technology for contaminant removal	no
Product quality (output material)	Product nature	chemicals and energy
	Product added value (MECHANICAL RECYCLING only)	
	Product purity	assured
	Standards for recycled product	yes
Markets and prices	Existence of markets for the recovered product(s)	yes (established form methanol and electricity and in development for by-product slag in construction)
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	75 EUR/t (collection packaging DSD)
	Gate fee (treatment cost), EUR/t	150 EUR/t (TNO estimate for MPW)
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery route	Incineration directive
	Relevant national legislation (if so, specify country of the EU 25)	Plastic waste diversion from MSWI in Denmark, landfill bans for separate collected waste and ELV in Belgium, landfill bans in Germany, France, Sweden, etc. The emission control requirements of feedstock recycling plants are outside the scope of those imposed on waste disposal plants. In Germany, for example, the requirements for such plants are established on the basis of the Clean Air Technical Directive "TA Luft".
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	
	Environmental drivers	Waste reduction (stable solid waste: slag) and low emissions
	Social drivers/barriers	
	Special regional/national barriers or drivers	national landfill and/or incineration avoidance policies for plastic waste
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	The plant gasifies high calorific waste materials and simultaneously along with low-rank coals. Acceptance criteria is wide
	What does it do well?	Waste is converted into a contaminant-free synthesis gas and mineral slag (final waste is a stable granulate)
	What relevant waste streams are accessible for recycling?	The waste materials include used plastics, auto-fluff, shredded WEEE, MSW.
	What do other technologies cannot do?	Products are both energy (steam & electricity) and chemicals. Integrated gasification, methanol and combined-cycle electricity production plant that converts contaminated and difficult to handle waste materials to clean, value-added products.
Weaknesses	What could it improve?	process has been modified several times for technical difficulties and improvements
	What does it do badly?	PVC content must be limited
	What should it avoid?	
Opportunities	Where are the good opportunities facing it?	achieving recycling targets in complex waste streams (WEEE, ELV)
	What are the interesting trends it is aware of?	
	Changes in technology and markets on both a broad and narrow scale	
	Changes in government policy related to this field	
	Changes in social patterns, population profiles, life style changes, etc.	Socially positive perception
	Local events	
Threats	What obstacles does it face?	
	What is the competitor technology doing?	
	Are the required specifications for its product or service changing?	
	Is a changing technology threatening its position?	
	Are there bad debt or cash flow problems?	cost efficiency is not clear
	Could any of the weaknesses seriously threaten the technology?	

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	TwinRec: Gasification to electricity
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	>200,000
	Application	general
	Running requirements	energy and utilities
	Environmental effects	air emissions and solid waste
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	dispersed/concentrated
	Nature of waste generation points	domestic/industrial
	National or local collection schemes	yes; separated
	Distance to consolidation points, km	
	Distance to treatment points, km	
Plastic waste quality (input material)	Consistency of supply	transient
	Quality of supply	contaminated and variable
	Nature of contamination	non-plastic materials
	Required sorting technology for material classification	no
	Required cleaning technology for contaminant removal	no
Product quality (output material)	Product nature	fuel gas (to energy)
	Product added value (MECHANICAL RECYCLING only)	
	Product purity	assured
	Standards for recycled product	
Markets and prices	Existence of markets for the recovered product(s)	yes (established for electricity, metals, salt and sulfur and in development for by-product slag in construction)
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	
	Gate fee (treatment cost), EUR/t	N/A (EUR200+ Net cost/ton MSW delivered)
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery route	Incineration and Waste Framework directives, recycling in construction materials
	Relevant national legislation (if so, specify country of the EU-25)	Plastic waste diversion from MSWI in Denmark, landfill bans for separate collected waste and ELV in Belgium, landfill bans for organic material in Germany, France, Sweden, etc.
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	
	Environmental drivers	Waste reduction (stable solid waste: slag) and low emissions
	Social drivers/barriers	
	Special regional/national barriers or drivers	national landfill and/or incineration avoidance policies for plastic waste. Construction materials technical specifications and environmental certifications.
Detected barriers and proposed drivers for further implementation of the present plastic recovery		

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Syngas from ASR (of wide composition range) gasification is used as a "clean" fuel for a boiler to produce electricity and steam (district heating) and marketable by-products are recovered
	What does it do well?	Waste feed (ASR) does not need pretreatment, it can be fed as delivered from shredder. high calorific waste is gasified to a clean fuel gas, with recovery of metals and of ashes as a molten slag. Zn also recovered. It has no requirement for extra oxygen and natural gas for the gasification/ash melting reactor
	What relevant waste streams are accessible for recycling?	ASR (ELV)
	What do other technologies cannot do?	Non-oxidised pure metals and alloys recovery. Ash melting of process and external ashes (mineral dust and metal oxide powder) into a glass granulate
Weaknesses	What could it improve?	Low energy export level (10000 MJ/ton?) Recovery of volatile metal salts from gas cleaning process (APC), as already done in one of the plants
	What does it do badly?	
	What should it avoid?	technical difficulties and process modifications
Opportunities	Where are the good opportunities facing it?	achieving recycling targets in complex waste streams as ELV
	What are the interesting trends it is aware of?	Waste materials which are to be used as fuel are subject to relevant licensing controls regarding their movement and utilization. Permitting (licensing) controls are established by Member States through their implementation of the WFD. R1 implies that where waste is used 'principally as a fuel or other means to generate energy', Member States can exempt such processes from licensing.
	Changes in technology and markets on both a broad and narrow scale	
	Changes in government policy related to this field	
	Changes in social patterns, population profiles, life style changes, etc.	Socially positive perception (vs incineration)
	Local events	
Threats	What obstacles does it face?	Regarded as co-incineration plant by EU legislation, as the syngas generated is combusted in a boiler Difficulties in securing waste streams supply Permits for regular operation cannot be granted due to the unproven state of the technology
	What is the competitor technology doing?	
	Are the required specifications for its product or service changing?	
	Is a changing technology threatening its position?	
	Are there bad debt or cash flow problems?	cost efficiency is not clear
	Could any of the weaknesses seriously threaten the technology?	

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	RPET Recycling / Bottle to bottle process-Bühler AG (Switzerland)
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	> 200,000
	Application	polymer specific // PET
	Running requirements	// electricity, water, chemicals
	Environmental effects	waste water
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	concentrated
	Nature of waste generation points	domestic
	National or local collection schemes	yes, separated (packaging) and dedicated
	Distance to consolidation points, km	<50
	Distance to treatment points, km	>200
Plastic waste quality (input material)	Consistency of supply	steady
	Quality of supply	contaminated
	Nature of contamination	other plastics materials and non-plastic materials
	Required sorting technology for material classification	yes
	Required cleaning technology for contaminant removal	yes
Product quality (output material)	Product nature	polymer
	Product added value (MECHANICAL RECYCLING only)	high
	Product purity	assured
	Standards for recycled product	yes
Markets and prices	Existence of markets for the recovered product(s)	yes, established and in development
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	
	Gate fee (treatment cost), EUR/t	
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	
	Relative price of inlet waste plastic (as % of virgin plastic's)	
	Relative price of outlet recycled plastic (as % of virgin plastic's)	
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery route	food contact application
	Relevant national legislation (if so, specify country of the EU-25)	Directive 2004/12/EC
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	profit opportunity and technological risks
	Environmental drivers	energy efficiency and resource efficiency
	Social drivers/barriers	
	Special regional/national barriers or drivers	
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		The main barrier is the organisation of a stable, efficient collection system, in order to guarantee a stable and reliable material flow to the industrial plant
		The higher the volume, the more profitable is the recycling process
		Export of post consumer PET bottles, mainly to China, disrupts the national material availability and price structure for the PET recycling industry

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Devoted process
	What does it do well?	Steady product quality
	What relevant waste streams are accessible for recycling?	PET (domestic and industrial)
	What do other technologies cannot do?	Production of "as virgin" polymer
Weaknesses	What could it improve?	Reagents consumption
	What does it do badly?	---
	What should it avoid?	Impurities
Opportunities	Where are the good opportunities facing it?	Demand of high quality recycled PET
	What are the interesting trends it is aware of?	Increase of recycling demand
	Changes in technology and markets on both a broad and narrow scale	---
	Changes in government policy related to this field	Yes, support and positive perception of recycling activities
	Changes in social patterns, population profiles, life style changes, etc.	Yes, population awareness on domestic waste management and demand of more activity,
	Local events	---
Threats	What obstacles does it face?	Limited materials and limited application
	What is the competitor technology doing?	Reycled PET with similar charactersitics, only advantage on food contact application
	Are the required specifications for its product or service changing?	Yes, process control and product quality are demanded from public bodies, suppliers and customers
	Is a changing technology threatening its position?	No
	Are there bad debt or cash flow problems?	Yes, specially for new plants (investment/depreciation) or undercapacity (running cost)
	Could any of the weaknesses seriously threaten the technology?	Yes, aceptable input material scarcity

BARRIERS AND DRIVERS FOR PLASTIC WASTE RECOVERY OPTIONS – FORM F2

The project "ASSESSMENT OF THE ENVIRONMENTAL ADVANTAGES AND DRAWBACKS OF EXISTING AND EMERGING POLYMERS RECOVERY PROCESSES" (Contract no. 150200-2005-F1ED-ES) focuses on the recovery options for post-consumer plastic waste from any of the following sources:

1. Municipal Solid Waste (MSW)
2. Packaging Waste
3. Agricultural Waste
4. End of Life Vehicles (ELV)
5. Waste Electric and Electronic Equipment (WEEE)
6. Construction and Demolition Waste

We would be grateful if you could help us identify the barriers to spreading the plastic recovery technology that you supply and analyse the supportive framework that might help to overcome those barriers in the EU-25. Below there is a list of points that we think can constitute either barriers or drivers for further implementation of plastic waste recovery technologies, but feel free to comment out of the proposed checklist.

Please tick the aspects that apply to your technology and the plastic waste treated or simply add your comments in the section *ad hoc* at the end of the form. Thanks for your co-operation.

The answers can be send either by e-mail (delgado@gaiker.es) or by fax (+34 94 600 2324) to GAIKER Technology Centre (Attn. Clara Delgado).

Process data

PROCESS	RPET Recycling / Bottle to bottle process
Supplier	Bühler AG / Switzerland
Contact data	6.4.2006
Recovery route	☒ mechanical recycling ☐ feedstock recycling ☐ energy recovery

Industrialisation aspects

Technology status:	☐ research	☐ pilot/bench scale	☒ industrial
Capacity for scale economy, kg/h:	☐ < 100	☐ 100-1000	☒ >1,000
Investment in Euro:	☐ < 50,000	☐ 50,000-200,000	☒ > 200,000
Application:	☐ general	☒ polymer specific	☒ product specific
Running requirements:	☒ energy	☒ other utilities	☐ chemicals
Environmental effects:	☒ waste water	☐ air emissions	☐ solid waste

Existing collection and logistics for the post-user plastic waste to be fed to the process

Location of waste generation points :	☒ concentrated	☐ dispersed	
Nature of waste generation points:	☐ industrial	☒ domestic	
National or local collection schemes:	☒ Yes	☐ No	
	☐ bulk	☒ separated (waste stream specific, e.g., packaging)	
	☒ dedicated	☐ shared (with other materials in the same waste stream)	
Distance to consolidation points, km:	☒ < 50	☐ 50-200	☐ >200
Distance to treatment plant, km:	☐ < 50	☐ 50-200	☒ >200

Plastic waste quality (input material)

Consistency of supply:	☒ steady	☐ transient (☐ increasing / ☐ decreasing)	
Quality of supply:	☐ clean	☒ contaminated	
	☐ fixed	☐ variable	
Nature of contamination:	☒ other plastic materials	☒ non-plastic materials	
Required sorting technology for material classification:		☒ Yes	☐ No
Required cleaning technology for contaminant removal:		☒ Yes	☐ No

Product quality (output material)

Product nature: ☒ polymer ☐ monomers ☐ basic chemicals, syngas ☐ fuel, oils ☐ energy

Product added value (MECHANICAL RECYCLING only): ☐ low (e.g., regrind) ☐ intermediate (e.g., flakes or pellets) ☒ high (e.g. finished products)

Product purity: ☒ assured ☐ risk of contamination

Standards for recycled product: ☒ Yes ☐ No (☐ proposed, under discussion)

Markets and prices

Existence of markets for the recovered product(s): ☒ Yes ☐ No ☒ Established ☒ In development

FEEDSTOCK RECYCLING & ENERGY RECOVERY:

Price of primary raw materials/fuel replaced by the plastic waste, Euro/t:..

Associated cost for collection and pretreatment of plastic waste, Euro/t:..

Gate fee (treatment cost), Euro/t:..

MECHANICAL RECYCLING:

Price of virgin plastic (Euro/t): ....

Relative price of inlet waste plastic (as % of virgin plastic's):..

Relative price of outlet recycled plastic (as % of virgin plastic's):..

Associated cost for collection and transport of waste plastic (as % of virgin plastic's):........................

Associated cost for recycling of waste plastic (as% of virgin plastic's):...

Legislation

Existence of waste management legislation (for the waste stream treated): ☒ Yes ☐ No ☐ Expected changes

Existence of recycling and recovery targets per material: ☒ Yes ☐ No ☐ Expected changes in next years

Existence of other legislation affecting this plastic recovery route (e.g., legislation on emissions and waste of industrial processes, legislation on recycled/recovered materials, legislation on potential applications of recyclates —e.g. food-contact applications—, etc.). Specify:

food contact application

Relevant national legislation (if so, specify country of the EU-25): Directive 2004/12/EC

Sustainability (economic-environmental-social aspects)

Economic drivers/barriers:	☒ profit opportunity	☐ new markets	☒ technological risks
Environmental drivers:	☒ energy efficiency	☒ resource efficiency	
Social drivers/barriers:	☐ administration policies	☐ social demand	☐ innovation barriers
	☐ stakeholders interest or resistance		

Special regional/national barriers or drivers:

Detected barriers and proposed drivers for further implementation of the present plastic recovery process

The main barrier is the organisation of a stable, efficient collection system, in order to guarantee a stable and reliable material flow to the industrial plant . The higher the volume, the more profitable is the recycling process.
Export of post consumer PET bottles mainly to China disrupts the national material availability and price structure for the PET recycling Industry .

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	VINYLOOP®
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	>1000
	Investment in Euro	> 200,000
	Application	polymer specific // PVC
	Running requirements	// electricity, water, chemicals
	Environmental effects	// waste water (washing), solid waste (rejections), minor dust and vapours emissions
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	dispersed
	Nature of waste generation points	industrial & domestic
	National or local collection schemes	no
	Distance to consolidation points, km	---
	Distance to treatment points, km	>200
Plastic waste quality (input material)	Consistency of supply	steady
	Quality of supply	contaminated // contaminants under specified at input material sheet
	Nature of contamination	other plastics materials and non-plastic materials
	Required sorting technology for material classification	yes
	Required cleaning technology for contaminant removal	yes
Product quality (output material)	Product nature	polymer
	Product added value (MECHANICAL RECYCLING only)	intermediate (flakes or pellets)
	Product purity	risk of contamination
	Standards for recycled product	no
Markets and prices	Existence of markets for the recovered product(s)	yes, established and in development
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	
	Gate fee (treatment cost), EUR/t	
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	1000
	Relative price of inlet waste plastic (as % of virgin plastic's)	0
	Relative price of outlet recycled plastic (as % of virgin plastic's)	60-70
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	10-20 (estimated)
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	20-30 (estimated)
Legislation	Existence of waste management legislation (for the waste stream treated)	yes
	Existence of recycling and recovery targets per material	no (expected changes in next years)
	Existence of other legislation affecting this plastic recovery route	---
	Relevant national legislation (if so, specify country of the EU-25)	---
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	new markets
	Environmental drivers	energy efficiency and resource efficiency
	Social drivers/barriers	administration policies
	Special regional/national barriers or drivers	
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		The main barrier is the organisation of a stable, efficient collection system, in order to guarantee a stable and reliable material flow to the industrial plant
		The higher the volume, the more profitable is the recycling process

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Devoted process
	What does it do well?	Steady product quality
	What relevant waste streams are accessible for recycling?	PVC (industrial)
	What do other technologies cannot do?	Production of "as virgin" polymer
Weaknesses	What could it improve?	Reagents consumption
	What does it do badly?	---
	What should it avoid?	Impurities
Opportunities	Where are the good opportunities facing it?	Demand of recycled PVC
	What are the interesting trends it is aware of?	Increase of recycling demand
	Changes in technology and markets on both a broad and narrow scale	---
	Changes in government policy related to this field	Yes, support and positive perception of recycling activities
	Changes in social patterns, population profiles, life style changes, etc.	Yes, population awareness on domestic waste management and demand of more activity,
	Local events	---
Threats	What obstacles does it face?	Limited materials and limited application
	What is the competitor technology doing?	Reycled PVC with similar charactersitics
	Are the required specifications for its product or service changing?	No, defined by customers
	Is a changing technology threatening its position?	No
	Are there bad debt or cash flow problems?	Yes, specially for new plants (investment/depreciation) or undercapacity (running cost)
	Could any of the weaknesses seriously threaten the technology?	Yes, aceptable input material scarcity

BARRIERS AND DRIVERS FOR PLASTIC WASTE RECOVERY OPTIONS – FORM F2

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2. Packaging Waste
3. Agricultural Waste
4. End of Life Vehicles (ELV)
5. Waste Electric and Electronic Equipment (WEEE)
6. Construction and Demolition Waste

We would be grateful if you could help us identify the barriers to spreading the plastic recovery technology that you supply and analyse the supportive framework that might help to overcome those barriers in the EU-25. Below there is a list of points that we think can constitute either barriers or drivers for further implementation of plastic waste recovery technologies, but feel free to comment out of the proposed checklist.

Please tick the aspects that apply to your technology and the plastic waste treated or simply add your comments in the section *ad hoc* at the end of the form. Thanks for your co-operation.

The answers can be send either by e-mail (delgado@gaiker.es) or by fax (+34 94 600 2324) to GAIKER Technology Centre (Attn. Clara Delgado).

Process data

PROCESS	Vinyloop®
Supplier	Vinyloop Ferrara Sp. A. part of the Solvay group
Contact data	
Recovery route	☒ mechanical recycling ☐ feedstock recycling ☐ energy recovery

Industrialisation aspects

Technology status: ☐ research ☐ pilot/bench scale ☒ industrial

Capacity for scale economy, kg/h: ☐ < 100 ☐ 100-1000 ☒ >1,000

Investment in Euro: ☐ < 50,000 ☐ 50,000-200,000 ☒ > 200,000

Application: ☐ general ☒ polymer specific ☐ product specific

Running requirements: ☒ energy ☒ other utilities ☐ chemicals

Environmental effects: ☒ waste water ☒ air emissions ☒ solid waste

Existing collection and logistics for the post-user plastic waste to be fed to the process

Location of waste generation points : ☐ concentrated ☒ dispersed

Nature of waste generation points: ☒ industrial ☒ domestic

National or local collection schemes: ☐ Yes ☒ No

☒ bulk ☐ separated (waste stream specific, e.g., packaging)

☐ dedicated ☒ shared (with other materials in the same waste stream)

Distance to consolidation points, km: ☐ < 50 ☐ 50-200 ☒ >200

Distance to treatment plant, km: ☐ < 50 ☐ 50-200 ☒ >200

Plastic waste quality (input material)

Consistency of supply: ☒ steady ☐ transient (☐ increasing / ☐ decreasing)

Quality of supply: ☐ clean ☒ contaminated

☐ fixed ☒ variable

Nature of contamination: ☒ other plastic materials ☒ non-plastic materials

Required sorting technology for material classification: ☒ Yes ☐ No

Required cleaning technology for contaminant removal: ☒ Yes ☐ No

Product quality (output material)

Product nature: ☒ polymer ☐ monomers ☐ basic chemicals, syngas

☐ fuel, oils ☐ energy

Product added value (MECHANICAL RECYCLING only): ☐ low (e.g., regrind)

☒ intermediate (e.g., flakes or pellets)

☐ high (e.g. finished products)

Product purity: ☐ assured ☒ risk of contamination

Standards for recycled product: ☐ Yes ☒ No (☐ proposed, under discussion)

Markets and prices

Existence of markets for the recovered product(s): ☒ Yes ☐ No

☐ Established ☒ In development

FEEDSTOCK RECYCLING & ENERGY RECOVERY:

Price of primary raw materials/fuel replaced by the plastic waste, Euro/t:..

Associated cost for collection and pretreatment of plastic waste, Euro/t:..

Gate fee (treatment cost), Euro/t:...

MECHANICAL RECYCLING:

Price of virgin plastic (Euro/t): ....

Relative price of inlet waste plastic (as % of virgin plastic's):..

Relative price of outlet recycled plastic (as % of virgin plastic's):..

Associated cost for collection and transport of waste plastic (as % of virgin plastic's): ....

Associated cost for recycling of waste plastic (as% of virgin plastic's):...

All the commercial information requested are function of the market, the location of the customer and the customer itself. Therefore it is not possible to give an appropriate and precise answer.

Legislation

Existence of waste management legislation (for the waste stream treated): ☒ Yes ☐ No ☐ Expected changes

Existence of recycling and recovery targets per material: ☐ Yes ☐ No ☒ Expected changes in next years

Existence of other legislation affecting this plastic recovery route (e.g., legislation on emissions and waste of industrial processes, legislation on recycled/recovered materials, legislation on potential applications of recyclates —e.g. food-contact applications—, etc.). Specify:

Relevant national legislation (if so, specify country of the EU-25):

Sustainability (economic-environmental-social aspects)

Economic drivers/barriers: ☐ profit opportunity ☒ new markets ☐ technological risks

Environmental drivers: ☒ energy efficiency ☒ resource efficiency

Social drivers/barriers: ☒ administration policies ☐ social demand ☐ innovation barriers

☐ stakeholders interest or resistance

Special regional/national barriers or drivers:

Detected barriers and proposed drivers for further implementation of the present plastic recovery process

CATEGORY	PARAMETERS	OPTIONS and COMMENTS
Process data	Process	Mechanical recycling of HDPE bottles from packaging waste
Industrialisation aspects	Technology status	industrial
	Capacity for scale economy, kg/h	100-1000 or >1000
	Investment in Euro	>200,000
	Application	general // similar to other mechanical recycling of plastic from packaging waste
	Running requirements	// electricity, water
	Environmental effects	// waste water (washing), solid waste (rejections), minor dust and vapours emissions
Existing collection and logistics for the post-user plastic waste to be fed to the process	Location of waste generation points	dispersed
	Nature of waste generation points	domestic
	National or local collection schemes	yes, bulk or separated (packaging) and dedicated
	Distance to consolidation points, km	50-200 // sorting plants
	Distance to treatment points, km	>200 // authorised recyclers
Plastic waste quality (input material)	Consistency of supply	steady // local and seasonal variations, continuous slightly year increase in quantity
	Quality of supply	clean, fixed
	Nature of contamination	other plastics materials // minor presence of metals and paper labels
	Required sorting technology for material classification	yes // hand sorting predominant
	Required cleaning technology for contaminant removal	yes // plain water washing
Product quality (output material)	Product nature	polymer
	Product added value (MECHANICAL RECYCLING only)	intermediate // mainly pellets but regrinds, flakes or finished goods possible
	Product purity	assured // technical specification for materials from sorting plants
	Standards for recycled product	no, proposed
Markets and prices	Existence of markets for the recovered product(s)	yes, established
	FEEDSTOCK RECYCLING & ENERGY RECOVERY	
	Price of primary raw materials/fuel replaced by the plastic waste, EUR/t	
	Associated cost for collection and pretreatment of plastic waste, EUR/t	
	Gate fee (treatment cost), EUR/t	
	MECHANICAL RECYCLING	
	Price of virgin plastic, EUR/t	600
	Relative price of inlet waste plastic (as % of virgin plastic's)	40-50
	Relative price of outlet recycled plastic (as % of virgin plastic's)	50-60
	Associated cost for collection and transport of waste plastic (as % of virgin plastic's)	
	Associated cost for recycling of waste plastic (as % of virgin plastic's)	
Legislation	Existence of waste management legislation (for the waste stream treated)	yes // packaging
	Existence of recycling and recovery targets per material	yes
	Existence of other legislation affecting this plastic recovery route	yes // food
	Relevant national legislation (if so, specify country of the EU-25)	
Sustainability (economic-environmental-social aspects)	Economic drivers/barriers	profit opportunity
	Environmental drivers	resource efficiency
	Social drivers/barriers	administration policies, social demand
	Special regional/national barriers or drivers	
Detected barriers and proposed drivers for further implementation of the present plastic recovery process		

SWOT	QUESTIONS	ANSWERS and FACTS
Strengths	What advantages does it have?	Simple and traditional technology and established market
	What does it do well?	Steady product quality supply
	What relevant waste streams are accessible for recycling?	Plastic bottles from selective packaging waste collection, from bulk waste collection, from production rejects
	What do other technologies cannot do?	---
Weaknesses	What could it improve?	Resource efficiency
	What does it do badly?	---
	What should it avoid?	Overcapacity
Opportunities	Where are the good opportunities facing it?	---
	What are the interesting trends it is aware of?	Increase of recycling demand
	Changes in technology and markets on both a broad and narrow scale	---
	Changes in government policy related to this field	Yes, support and positive perception of recycling activities
	Changes in social patterns, population profiles, life style changes, etc.	Yes, population awareness on domestic waste management and demand of more activity,
	Local events	---
Threats	What obstacles does it face?	Limited materials, narrow economic margin
	What is the competitor technology doing?	---
	Are the required specifications for its product or service changing?	Yes, process control and product quality are demanded from public bodies, suppliers and customers
	Is a changing technology threatening its position?	No
	Are there bad debt or cash flow problems?	Yes, specially for new plants (investment/depreciation) or low capacity plants (running cost)
	Could any of the weaknesses seriously threaten the technology?	No

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Abstract

The report analyses the technical and environmental potential of various plastic recovery schemes, as well as assessing the possibilities for environmentally favourable existing and emerging processes to enter the market. Quality and quantity of plastic waste streams are estimated for 2015. For this purpose the six waste categories packaging, vehicles, electronic equipment, agriculture, municipal waste, and construction are analysed in detail. Existing plastic recovery technologies are analysed with regards to their environmental performance. As a result, the recovery technology mix for different scenarios is calculated which best achieves the objective of environmental sustainability.

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