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19190 (1of2)

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

CONFERENCE ON ECOLOGICALLY SUSTAINABLE INDUSTRIAL DEVELOPMENT

Copenhagen, Denmark, 14-18 October 1991

Distr.
LIMITED

ID/WG.516/15
8 August 1991

ORIGINAL: ENGLISH

PLASTICS AND PLASTICS WASTE RECYCLING

Case Study No. 5

Prepared by

the UNIDO Secretariat

V.91-27810 7794T

EXPLANATORY NOTES

ABS acrylonitrile butadiene styrene
APP atactic polypropylene
HDPE high density polyethylene
LDPE low density polyethylene
LLDPE linear low density polyethylene
PET polyethylene terephthalate
PP polypropylene
PS polystyrene
PVC polyvinylchloride
SAN styrene acrylonitrile

In August 1991, $US 1 - DM 1.75

Contributions to this document have been made by A.G. Buekens, Professor at the Vrije Universiteit Brussels, Belgium.

This document has been printed on environmentally friendly paper.

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ABSTRACT

In the paper a brief analysis is made of the plastics industry worldwide in terms of production, source of energy used and waste produced. The production of plastics is compared to that of petrochemicals in general and oil products at large. The trends in the plastics and plastics waste sectors are analyzed and the future evolution over the coming years is examined. The environmental requirements of plastics industry are related to the production process on the one hand and production, conversion and consumption of wastes on the other. Barriers to the more efficient use of energy and to reduction of the environmental impact are examined. The role of industry, government and international co-operation is highlighted.

1. INTRODUCTION

The development of synthetic plastics materials undoubtedly has been one of the major technical achievements of the twentieth century. Their growth has been especially impressive since the fifties both in terms of quantity and quality.

Plastics are synthetic materials characterized by their ability to soften when heated and to be shaped into complex forms, with or without melting. The unusual properties of plastics result from their molecular structure. Plastics are composed of giant molecules, or polymers, which are synthesized from small and relatively simple monomeric units, produced by the petrochemical industry.

The polymerization process can be conducted under different reaction conditions and using various catalyst systems. Thus, the molecular weight distribution and structure can be tailored to the subsequent needs of the plastics conversion process making plastics materials available in a large number of grades.

The resulting polymer powders or granulates are generally compounded with a variety of additives to improve their durability and properties and to render their processing easier.

These additives are stabilizers, antioxidants, plasticizers, lubricants, pigments or dyes, antistatic additives, flame retardants, reinforcing agents and filters. At the end, almost every product has a different composition.

Plastics have numerous advantages, such as lightness, toughness and ease of colouring. They are fabricated in a variety of forms, in a range of temperatures, typically 120 to 250 °C.

Plastics are related to certain classes of natural products with a polymer structure (cellulose, natural rubber, lignin, resins and waxes) and to other synthetics, such as rubber, artificial fibres, glues and coatings. They are major products within the petrochemical industry and use up approximately 7 per cent of the total consumption of oil and gas. Nevertheless, the rapid rise of plastics consumption and its further potential rise clearly justify the attention of UNIDO in a perspective of sustainable growth, oil consumption, waste prevention, reuse and recycling.

Attention is first focused on plastics production and consumption, later the environmental consequences of present and future production are analyzed.

2. CURRENT STATUS OF INDUSTRY

Bulk plastics are generally produced by large international or local state-held companies which have their main activity in oil refining and/or petrochemicals. Companies of this size are highly structured with separate administrative, financial, marketing and R & D divisions and production facilities. The typical capacity of production for bulk plastics is in the range of 40,000 to 400,000 t/a per production plant. Engineering plastics are manufactured in plants whose size is typically one order of magnitude smaller.

The production of plastics is closely linked with the petrochemical industry, since ethylene, propylene, butadiene and styrene (vinylbenzene) are major building blocks for plastics. The production of vinylchloride also requires a source of hydrogen chloride (in the now obsolete acetylene-based process) or chlorine (ethylene dichloride pyrolysis + ethylene oxychlorination route) which links the process to brine electrolysis.

Until the first oil price shock, in 1973/74, plastics production and consumption in all industrialized nations had enjoyed impressive annual growth rates in the order of 10 to 15 per cent per annum. At present, growth figures on the average have declined to some 4 per cent annually.
(Tables 1 & 2).

Thermoplastics consist of a number of generic groups of polymers of which the polyolefins, LLDPE, HDPE, PVC and PP, are by far the most important. Table 1 shows some production, sales and captive use and growth rates for the U.S. (1959 to 1989). Table 2 shows the distinction in growth rates for various bulk plastics. Table 3 gives some sales figures of various plastics and resins in the U.S.A., western Europe and the U.K. Amongst the bulk plastics, polypropylene shows the highest growth rate. The *older* types of plastics, polyvinylchloride (PVC), polystyrene (PS) and LDPE have a lower but still substantial rate of growth.

TABLE 1. EVOLUTION OF U.S. PRODUCTION AND SALES + CAPTIVE USE* FIGURES

Year	1959	1969	1979 Mt	(1988)	1989	
Production	2.7	8.9	18.9	(27.13)	26.89	
Sales + Captive Use	2.4	7.5	18.4	(26.58)	26.85	
Growth rate Production	12.7	7.8		3.6		%
Sales + Captive Use	12.1	9.4		3.85		%

Source: European Plastics News, EPN, March 1990, p. 27

* Captive Use: Product used by the producing companies or by customers linked by long-term delivery contracts.

TABLE 2. GROWTH RATE AND CONSUMPTION OF SOME BULK PLASTICS

IN WESTERN EUROPE
%/a

		Growth rate %/a	Consumption Mt/a	
	1978	1988-95	1988	1995
PP	11.1	8	3.0	5.2
HDPE	7.0	4.5	2.6	3.7
L/LDPE	3.2	3	5.0	6.2
PVC	2.8	2	4.7	5.3
PS	1.6	3	1.6	1.9
Total	4.4	4	16.9	22.3

Source: European Plastics News, December 1990, p. 9.

TABLE 3. CONSUMPTION OF MAJOR POLYMERS

	U.S. Resins Sales (1)	W. Europe Consumption (2) MAJOR THERMOPLASTICS ONLY	U.K. (3)
THERMOPLASTICS			
LDPE	} 17.6%	} 29.6%	21.8%
"L/LDPE"			6.5%
HDPE	13.7%	15.4%	15.3%
PP	12.2%	17.8%	20.6%
PVC	14.3%	27.8%	24.8%
other vinyl	0.3%		
PS	8.8%	9.5%	8.3%
ABS	2.1%	100%	
SAN/Styrenics	2.2%		
PA	1%		
Engineering resins	2.4%		
Polyester (a)	2.9%		
Other	12%		
	89.5%		
EPS			1.6%
THERMOSETS			
Melamine	0.4%		
Urea	2.4%		0.8% Aminos
Phenolic	4.6%		0.4%
Epoxy	0.8%		
Polyester (b)	2.2%		100%
	10.4%		
Total m/t	26.9		

(a) thermoplastic
(b) unsaturated

(1) 1989 Figures, EPN, March 90, p.27
(2) EPN, December 1990, p. 9
(3) EPN, March 1991, p. 34-5.

Industrialized countries have much higher per capita production and consumption figures than others. Belgium is one of the leading countries, with a per capita annual production of 280 kg and a conversion level of 144 kg. Japan and Indonesia have a comparable population number, but their respective consumption figures are widely different.

TABLE 4. PLASTICS CONSUMPTION IN JAPAN AND INDONESIA

Plastics	Japan kt/a	Indonesia kt/a	Ratio Japan/Indonesia
LDPE	1,313	85.5	15.4
HDPE	989	109.9	9.0
PP	1,719.2	202.1	8.5
PS	857	17.4	49.2
PVC	1,932	108.3	17.8
Total	6,810.2	523.2	

Source: Solvay-Central Petrochemical Division-Exportation

Indonesia is still an oil-producing country, rich in resources and culture, and fairly open to free world trade. Many other countries have fewer or no resources and are confronted with economic restrictions; their condition is obviously reflected in their consumption patterns, those of plastics included. Another factor of influence is the existence of local production and conversion facilities. Table 5 shows the local African producers and the plastics manufactured. A wider range of plastics are manufactured in Asia, nevertheless some countries have inadequate local production facilities, (table 6).

TABLE 5. AFRICAN PRODUCERS OF BULK PLASTICS

S. Africa	LDPE, HDPE, PP, PVC, PS
Algeria	LDPE, HDPE
Egypt	PVC
Libya	PVC
Morocco	PVC

Source: Solvay-Central Petrochemical Division-Exportation.

TABLE 6. PRODUCERS OF BULK PLASTICS
IN ASIA AND OTHER COUNTRIES

Saudi Arabia	LDPE	HDPE	-	PVC	PS
China	LDPE	HDPE	PP	PVC	PS
Democratic People's Republic of Korea	LDPE	-	-	PVC	-
Republic of Korea	LDPE	HDPE	PP	PVC	PS
Hong-Kong	-	-	-	-	PS
India	LDPE	HDPE	PP	PVC	PS
Indonesia	LDPE	HDPE	PP	PVC	PS
Israel	LDPE	-	-	PVC	PS
Japan	LDPE	HDPE	PP	PVC	PS
Malaysia	-	-	PP	PVC	PS
Pakistan	-	-	-	PVC	-
Philippines	-	-	-	PVC	PS
Quatar	LDPE	-	-	-	-
Singapore	LDPE	HDPE	PP	PVC	-
Taiwan Province, China	LDPE	HDPE	PP	PVC	PS
Thailand	-	HDPE	PP	PVC	PS
Turkey	LDPE	HDPE	PP	PVC	PS

Source: Solvay-Central Petrochemical Division-Exportation

These data can be summarized as follows:

- 12 producers in Asia, 5 in Africa for PVC
- 11 producers in Asia, 1 in Africa for PS
- 11 producers in Asia, 2 in Africa for LDPE
- 9 producers in Asia, 2 in Africa for HDPE
- 9 producers in Asia, 1 in Africa for PP

Plastics can also be subdivided according to their area of application. The figures in table 7, 7a and 7b illustrate this point.

TABLE 7. PLASTICS-MARKET SHARE PER APPLICATION

	USA (a) market share 1989	USA 1979	UK (b) by value 1990	
Packaging	31.2%	26%	32.8	packaging
Building & construction	22.2%	20%	26.3	building products
Industrial, machinery	1.5%	1%	8.1	engineering components
Electrical, electronic	5.9%	8%		
Consumer & inst.	10.1%	10%	6.3	consumer goods
Furniture, furnishing	4.2%	5%	11.6	custom moulding, others
Transportation	4.4%	6%	10.8	automotive products
Adhesives, inks & coatings	2.4%	8%	1.3	medical pharma-ceutical agricultural
Other domestic	9.1%	8%	1.3	
Exports	9%	8%		
	100%	100%	100%	

(a) EPN, March 1991, p.34
(b) EPN, March 1990, p. 27 - Source SPI Committee on Resin Statistics

TABLE 8. BALANCE OF THE CONSUMER MARKETS OF PLASTICS MATERIALS IN SPAIN

	1989
Packing and Packaging	43.76%
Construction	14.40%
Electrical and electronic	3.78%
Home appliances	2.86%
Furniture	6.99%
Automotive	7.91%
Agriculture	6.00%
Rest of markets	14.30%
	100%

EPN, December 1990, p. 25.

Annexes I to V give some statistical data with respect to production, import, export and consumption figures in a selection of African, Asian and other countries.

Consumption figures in African and Asian countries are probably underestimated as a result of the intense recycling activity and the importation of plastic scraps.

At present, there are no available data with respect to the consumption pattern. There is probably emphasis on products of first necessity, such as PVC shoe soles, LDPE buckets, PVC and PE water ducts, PE or PVC agricultural film and multi-coloured PVC ribbon curtains. On the other hand, in many countries packaging is only a minor application.

Plastics can be converted according to different techniques. The most important are injection and blow moulding, extrusion and thermoforming. In most developing countries there is little conversion capacity available, so that many plastic products are imported, either as a part of various kinds of equipment or as packaging. Local production is generally less diversified from the viewpoint of both the plastics and the conversion methods used.

Some conversion methods, such as extrusion and calendering, are mainly directed to the production of semi-finished goods (sheets, plates, profiles, tubes, etc.), others are mainly used for producing machine parts (injection) or packaging (blow moulding, thermoforming, injection). The unit investment required is highly variable depending on the following factors:

- type of processing;
- size and capacity of the unit;
- new or second-hand equipment;
- level of automation;
- presence of peripheric equipment (automatic feeding of granulate, collection, grouping and packaging of products).

Many countries in Africa face economic problems which may lead to an inadequate supply of spare parts. Most equipment originates in exporting countries where it is least expensive.

The use of second-hand equipment in developing countries can sometimes be recommended on the following grounds:

- lower acquisition cost;
- lower level of sophistication required for operation;
- better capability of using reclaimed instead of virgin materials.

The conversion of plastics requires a sizeable amount of electric power. The availability of adequate amounts of cooling water is also an important factor in selecting a site for the production facilities.

3. ENVIRONMENTAL ASPECTS

The production of plastics is accompanied by the formation of some by-products, such as low molecular weight polymer, atactic polypropylene, reactor crusts, wastewater polymer sludge. Most production wastes can readily be recycled.

Sometimes solvent and plasticizer fumes and monomers (e.g. the carcinogenic vinyl chloride) are vented, e.g. in the drying or curing of resins. The extraction and neutralization of polymerization catalysts may also be hazardous. The production of PVC generates heavily chlorinated tars, which are an environmental problem. Proper disposal procedures, such as incineration, are indispensable, but expensive. Dumping at sea is prohibited by international agreements.

The conversion of resins into (semi-)finished products is not really problematic. Noise, odour or polymer dust can be controlled by suitable technical means.

The use of plastics as a fuel seems a wasteful practice and can hardly be recommended. Moreover, its uncontrolled incineration gives rise to pollutants and soot formation.

4. FUTURE TRENDS

The production of plastics has enjoyed a tremendous growth in industrialized countries, mainly because plastics are light, easy to process and convenient to use. Their consumption is still expanding (albeit at a more reasonable growth rate) so that it is turning into an environmental problem.

The per capita consumption of plastics in developing countries is much lower than elsewhere and mainly directed towards products of first necessity. However, both the local production and the available inventory can be expected to grow considerably in the future. In the context of sustained growth, attention should be given to:

- proper use of the raw materials and energy;
- stimulation of reuse, recycling and, as a last resort, waste as a source of fuel;
- environmental aspects, including the proper management of production residues and post consumer plastic wastes.

5. THE REUSE OF PLASTICS WASTE

At first sight it would seem that all thermoplastics materials are predestinated to be recycled as they are valuable and can be remoulded innumerable times. But, despite a favourable economic and social context, surprisingly little progress has been achieved in recycling consumer waste in industrialized countries.

Plastics reclamation and recycling can be subdivided into the following steps:

- source separation of plastics waste possibly supplemented by curbside and dumpsite retrieval;
- identification, grouping and sorting;
- shredding, washing, drying;

- regranulation, possibly after preliminary densification;
- conversion to new products.

The most critical steps in the process are:

- a correct identification of the plastics in hand. Mixing different resins leads to a catastrophic loss in quality and to the manufacturing of useless products;
- regranulation of contaminated materials requires experience and good strainers. Light materials have to be fed by means of a special auger feeder.

5.1. Sources of plastics waste

Plastics waste generated by polymer manufacturers consists of:

- **production wastes**, such as the deposits formed on the walls of a polymerization vessel or the driers, or sludges separated from process waters;
- **off grade products**;
- **extrusion purgings** and lumps;
- **floor sweepings**;
- wastes arising during **quality control** and laboratory testing.

Manufacturers are large multinational petrochemical companies, which normally will not commercialize off-grade products under their own trade names, or indulge in relatively small-scale reclamation. All their waste is taken over by specialized recycling firms, which classify the wastes according to homogeneity and condition.

Off-grade products are directed towards non-critical applications. Floor sweepings are carefully purified by means of mechanized sorting methods, which should completely eliminate dust, dirt and occasional foreign objects. Sweepings are composed of various grades of the same polymer; which cannot be separated by simple means. Suitable outlets should be found, which take into account the unusual rheological properties of such a mixture.

Atactic polypropylene (APP), which for a long time has been a useless by-product of propylene polymerization, is no longer a problem:

- improvements in the catalyst system, the reactor configuration and operating conditions have considerably reduced the generation of APP;

- all available APP is recovered and blended into roofing or road asphalt bitumen, to improve its elasticity and mechanical properties.

Low molecular weight polyethylene polymer can also be reused to a certain extent.

Only minor amounts of wastes arise during the production of masterbatches and the compounding of polymers, but the recycling of such wastes may be difficult.

A second large category of wastes arises during the conversion of plastics raw materials into semi-finished (plates, tubes, etc.) or finished products. They consist of trimmings, sprues, runners, distorted and incomplete formed products, surpluses, products rejected during quality control and material arising during the starting-up or the shutting-down of the plant.

Technical improvements in both equipment and polymer quality have considerably reduced the occurrence of production losses. Sprues from injection moulding have been eliminated by the use of *hot runners*. A better mould design, suitable injection cycle and polymer quality control reduce the occurrence of incompletely formed objects. Also the ejection and the collection of the products has been markedly improved, so that less injected parts are inadvertently caught by the closing of the mould.

Table 9 gives a survey of waste arisings, classified according to the conversion method used.

TABLE 9. TYPE AND GENERATION QUOTA OF WASTE IN VARIOUS PROCESSING METHODS

Origin	Type and quantity of waste
Dry blending Banbury mixer	Powder agglomerates, removed by screening drippings, aborted runs.
Extrusion compounding	Chunks and strands from extruder purging. Wastes generated during faulty operation (overheating, impure feed). Custom compounding: 1-2% of throughput. In line compounding: 0.2% of throughput.
Injection moulding	Sprues and runners. Normally reground and reprocessed in amounts ranging from 1-15% of total feed. About 1% dirty grindings, floor sweepings, chunks from purging and contaminated mouldings.
Extrusion of pipe, rod, tubing and profiles	2-3% scrap for common extrusion processes. Up to 40-50% scrap for items machined from rod stock.
Film blowing	Start up, tail and reject film. Extruder purgings.
Sheet extrusion	Scrap generation: 15% in PE, 25% in PVC, 40% in oriented PP-film.
Extrusion coating	6% loss in extrusion coating on paperboard, 5-6% in wire and cable coatings.
Coextrusion	9-10% scrap (sometimes 20%), generally sold to convertors.
Injection blow moulding	Practically no scrap.
Extrusion blow moulding	Amount of pinch-off, depending upon excess length of parison. Minimised by good design.
Rotational moulding	Removal of open sections and small amounts of trim flash.
Dip and slush moulding	No cut-off arises, since the material forms a solid solution on the mould. There is, however, a great potential for contamination of the plastisol or the fluidised solids-bath, resulting in rejected parts.
Casting	3-5% loss.
Calendering	Drippings from mixer and calender rolls (less than 1%). Trim, front and strip and tails (6-7%).
Thermoforming	Trimmings arise in significant quantities.
Laminating	8% in high pressure lamination. Side trimmings or scrap cuttings when forming labels, bags, etc. from laminates.
Spreader coating	6-10% scrap, little of which can be recycled.
Cellular plastics	5-10% in expanded PS.
Compression and transfer moulding	2-5% Flash (excess) material.

Source: A. Buekens, Some observations on the recycling of plastics and rubber, Conservation and Recycling, 1, 247-71, 1977.

Even smaller firms can no longer afford to waste these raw materials. Waste is carefully segregated at the source, according to its nature, colour, and additives. Contamination by dust, oil or *burned* (i.e. thermally decomposed) material is avoided. In general the waste is ground and recycled, either directly in the same or a similar production, or in a less critical application.

Sometimes direct recycling is not desirable or possible because:

- the material is grossly polluted or *burnt*, or has taken up moisture from the air;

- the material is composite, e.g. multilayered film, insulated of electric cable, coated textile and various floorings;

- the production method does not incorporate a step, in which the wastes can be melted. This occurs in the thermoforming of PVC-sheet, the rotation moulding of plastic powders and in the conversion of plastic semi-products to a final product by operations such as welding, gluing, cutting, drilling, etc.

- the dimensional specifications are too strict. Milled plastic scrap has not the same bulk density and flow properties as virgin material. The addition of scrap may alter the metering of plastics by the screw, hence also the temperature and viscosity of the melt and ultimately the degree of filling and pressure in the mould. For this reason the scrap is often being regranulated or, at least, added in a fixed proportion to virgin material.

- the acquisition of sophisticated equipment, capable of purifying or densifying specific waste (foam, fibre, film), cannot always be justified economically;

- the raw materials cost in some cases is only of secondary importance (electronic industry).

The most important potential source of plastics waste is to be found in **consumer wastes**, arising in trade and industry and in private households. Municipal refuse in industrialized countries typically contains about 7 wt.% of plastics, mainly packaging materials, consisting of various grades of polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC) and polystyrene (PS). Engineering plastics may occur under the form of kitchen utensils and in various parts and mechanisms. Trade and industrial wastes contain similar types of plastics, but in different proportions. Moreover, they are normally less contaminated by putrescibles.

Consumer wastes form largely untapped sources of recyclable plastics. Some well defined industrial wastes have been recycled after use, e.g. plastic containers, fertilizer bags, agricultural film, shrinking film, shockproof packaging, etc. Outside developing countries, plastics in municipal refuse have never been recycled on a long-term consistent commercial basis.

A major difficulty lies in the logistic problem of collecting suitable amounts of plastics, which are reasonably free from putrescibles and contaminants and can be transported economically to the cleaning, grading and reprocessing plant.

5.2. Technical barriers to the introduction of plastics recycling

The largest tonnage of plastics waste available for recycling is post consumer consisting of mixed and/or contaminated products.

Plastics waste is available in a wide variety of types, forms, kinds and levels of contamination. A substantial range of recycling technologies are required. Some are mature, others developmental. To produce a product of acceptable quality, washing and separation of post-consumer plastics waste are essential. Ideally the waste to be recycled should have no colour or as a second choice the same colour. Variable colouration limits the market for recycled product.

Currently, no mechanical system is proven or available to separate plastics waste into its different constituents and meet the requirements of the recycling industry. Several systems, based on sink/float principles or on hydrocyclone cascades, are being demonstrated and hold the promise of separating at least an olefinic fraction.

Both PVC and PET are commonly used in bottling, however, PVC is generally less desirable for recycling because it melts and then decomposes at the lower temperatures experienced during reprocessing. Several recycling ventures are working on X-ray detectors which could then be connected to automated sorting systems to separate PVC.

5.3 Economic constraints on plastics recycling

The collection of plastics materials may assume different forms, such as:

- door to door collection of source separated plastics;
- separate collection by civic associations;
- collection at schools;
- manual sorting of household waste at a sorting belt;
- source separated waste delivered by an individual to a container park, civic centre shop, etc.

Dumpsite collection is unsanitary and dangerous to public health.

In western Europe numerous surveys have been conducted with respect to collection cost. The cost of a *door to door* collection is astronomical, with figures from 2,500 DM/t to 8,000 DM/t. In the first case, plastics were collected in separate sacks parallel to ordinary collection. In the second, plastic bottles packed in PE bags were collected by a curbside collection.

A scheme based on collection at schools proved to be very expensive (5,500 DM/t). Furthermore, although it has some pedagogic value, it cannot be considered as a long-term method of waste recycling. Youth associations collected PVC bottles at a cost of 950 DM/t of PVC. The cost for manual retrieval of PVC bottles by sorting from a belt was similar (1,050 DM/t of PVC).

At a maximum value of 0.4 to 0.5 DM/kg of plastic film any manual sorting of such film from mixed waste can only be marginally profitable. A much higher sorting yield can be attained for thick walled or dense products but the resulting mixed plastic fraction is not likely to command a good price.

Processing costs for plastic waste can be subdivided into:

- Manual sorting or cleaning costs. These are inversely proportional to productivity, which in turn is related to the type of operation, e.g..

  * picking plastic bottles from a refuse stream;
  * splitting a plastics stream into a number of categories;
  * skimming a plastics stream for recognizable objects;
  * manually clean plastic products by eliminating PVC from polyolefin film, removing caps from bottles, etc.

  (The productivity of such operations is very poorly documented)

- Processing of sorted plastics to the level of recoverable product. The following are actual commercial data, no overhead cost is included:

- shredding	0.15 DM/kg
- washing, drying	0.30 DM/kg
- extrusion & granulation	0.30 DM/kg
	0.75 DM/kg

Generally, the price given to baled polyethylene film, originating in trade waste (packaging) and free from contaminants varies between 0.15 and 0.45 DM/kg, according to the market price of virgin material. The latter has fluctuated erratically over the years. When prices are low reclamation in industrialized countries is no longer economically feasible.

In developing countries the investment cost of recycling equipment including mill, additive blending and regranulation may be prohibitive. On the other hand labour for collection is usually available and cheap. The manual washing of contaminated agricultural film poses no problem provided that suitable feeding or sintering equipment is available.

5.4 Social issues and experience with plastics recycling in developing countries

In developing countries a serious problem relates to the high intrinsic value of plastic utensils, including used containers. Reuse of containers should be restricted as containers used for packaging of hazardous chemicals would contaminate foodstuffs and drinking water, etc. even after extensive rinsing.

Plastic waste is being actively recycled in most developing countries. Collection takes place at several levels:

(1) Waste may be collected at source (in homes or in shops, etc.). This system is only feasible when there is a well organized collection circuit so that everyone can supply the material.
Some major cities have an organized network of shops buying source-segregated waste materials;

(2) More frequently, recyclable waste materials are scavenged from household dustbins. Recyclable materials can be set aside by the rubbish collection crews and marketed on their way to the disposal site. The latter system operates for plastics materials. Finally, the scavenging of recyclable waste materials at the tipping site is an essential activity for a number of trades that depend on this supply. However, the conditions can vary, depending on the degree of organization.

It is difficult to assess collection cost, because it may either be on a voluntary basis, with the selling of the material as a reward, or on a basis of cheap labour. Sorting normally is entirely manual. Washing often also proceeds by hand with the drying of shredded plastics by solar heat.

Sometimes, washing and sorting are somewhat mechanized. In Istanbul, for example, plastics are hand sorted, but the sorting is tested using a sink/float separation operated in a bathtub. The flotsam is collected manually by means of a plastic strainer.

Factory techniques may be employed cleaning impact-proof polystyrene yoghurt beakers by means of shredding, washing in a conventional (laundry) washing machine, dewatering and thermal drying with hot air, generated by mixing flue gas and air.

Regranulation is often conducted using second-hand or even locally made equipment. An essential part is the strainer, taking out non-melting impurities, and degassing, to evacuate volatiles and residual moisture.

Many of the people active in the recycling circuit are regarded as unskilled labourers operating under harsh conditions both financially and in terms of the working environment.

Scavenging on the dumpsite may be officially forbidden but frequently is tolerated. Under these conditions the scavengers enjoy no protection and even operate immediately in the tracks of compacting equipment. Organization of this activity is well established with individuals financing the operation and allocating territory and fixing pay scales.

A more just regular organization of scavenging, sorting and cleaning would be more beneficial to all parties concerned. This could assume the form of sorting from a belt in a partly mechanized plant.

5.5. Government incentives to promote plastics recycling

For a number of years individual European Economic Community (EEC) countries as well as the EEC as an entity have taken measures to reduce the generation of refuse. Beverage containers have been targeted in this respect (EC Directive of June 27, 1985, 85/339/EEC). The latter has given rise to distinctive measures in the various Member States of the EEC, ranging from a ban on non-reusable containers (Denmark) to voluntary (weight) reduction schemes to be implemented by industry.

Current legislation in several EEC countries provides for banning non-recyclable or even non-reusable packaging and the compulsory recycling of (plastics) packaging.

Government incentives such as deposit schemes are required to promote recycling PET bottles and HDPE containers.

The requirements of some European countries can be summarized as follows[1]:

- Italy: 40% of packaging to be recycled by 1992, with 50/50 material/energy. All shopping bags must be biodegradable or pay 100 lire/bag, tax.

- Holland: Different targets for packaging and the rest but the overall trend is for a 10% reduction in waste, 50% minimum re-use/recycling, 30% incineration with energy recovery and 10% maximum to landfill by year 2000, with intermediate 1994 targets.

- Belgium: 30% recycling by 1995; balance for incineration, with landfill last resort.

- UK: 50% of recyclable to be recycled by year 2000; i.e. 25% of total.

- France: 50% ultimate recycling target, either as material or energy.

Recent packaging proposals for Germany are extremely demanding where a 64% recycle rate is required by 1995, with energy recycling essentially excluded. There are also mandatory take-back requirements throughout the supply chain which can only be replaced by industry establishing separate waste collection and recovery outside the normal municipal system. This is called the "Dual System", which will be financed by a "Green Spot" approval system, where verification and approval of a package's recyclability will have to be obtained, with payment of some 0.02 DM per package, depending on size, to cover the cost of collection and crude separation. A further fee to support

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a recycling subsidy is also being considered. The necessary industry structures required to operate the Dual System are currently being established, and no doubt other European countries will be following progress closely.

In contrast, initial proposals from the EEC were more flexible, seeking a recuperation rate of 80% for packaging, but including energy recovery.

The latest draft, however, has moved closer to the German/Dutch situations and proposes:

- A "standstill" principle for packaging waste, five years after adoption, at the 1990 level.

- by which time, 60% minimum to be recycled as material.

- 30% maximum as energy.

- 10% maximum to landfill.

Draft legislation for other end use sectors e.g. automotives and agriculture are expected to follow. A number of plastics producers such as General Electric, and numerous car manufacturers are studying the reuse or recycling of certain parts such as car bumpers.

It is the role of both government and industry to provide a reliable source of information with respect to the hazards, as well as the economic potential related to plastics, including their production life cycle and waste aspects. The relative importance of the latter is particularly evident in non-industrialized countries because:

- the cost for collection, manual cleaning and sorting is more easily borne;
- the limited variety of plastic types eases their retrieval, identification and reclamation.

Legislation, designed to provide incentives to recycle plastic waste from packaging, offers a good example of the potential clash between the interests of trade and environment. Within the EC, if a product meets standards set in its home market, it should generally be deemed to meet standards in other Member States. GATT insists only that a country apply the same standards to imports and to domestic products.

Environmental concerns of northern European GATT members are criticized by some less progressive and developing countries which contend that industrial countries may misuse the environment as one more excuse to exclude their products.

Increasingly, countries specify green characteristics for products which could affect some plastics.

5.6 Industry initiatives to promote plastics recycling

Major plastics users, including the automotive and appliance industries, are starting to view the use of plastics in their products from the standpoint of design for disassembly, where part-structure and composition take ease of separation and reuse into account. This would favour thermoplastics over thermosets and composites.

Plastics waste are usually recycled by specialized firms, which either upgrade the material and bring it up to specifications, or convert it to non-critical products, such as:

- garden hoses, drainage pipes, buckets, refuse bags, or toys in polyethylene (LDPE);
- plastic 'lumber'
- flooring, shoe soles, bicycle saddles, drainage pipes, protective cover plates in polyvinylchloride (PVC);
- foam products in polystyrene (PS);
- carpet underlayers in insulating packaging in polyamides (PA).

Grossly polluted and composite materials have a low potential for being recycled.

The recovery of plastics is a marginal and often unprofitable business in western Europe. The major product is LDPE film, retrieved from commercial packaging waste. The operation has been mechanized by means of a suction duct.

The washing of agricultural film is a well established operation. Some problems are the large amount of earth and abrasive sand, the exposure to ultra-violet light and the accidental presence of PVC film, which renders the reclaim unusable.

Priority R & D areas such as development of coextrusion techniques, processing of plastics materials recovered from other recycling operations such as shredded cars and electronic components.

ANNEX I

POLYETHYLENE HD

AFRICA

Country	Year	Production	Import	Export	Consumption
South Africa	1989	90	0	0	125
Algeria	1989	5	19	0	24
Angola	1989	0	1	0	1
Cameroon	1989	0	5	0	5
Ivory Coast	1989	0	2.1	0	2.1
Egypt	1989	0	28	0	28
Ghana	1989	0	1	0	1
Kenya	1989	0	6	0	6
Libya	1989	0	2	0	2
Morocco	1989	0	16.4	0	16.4
Nigeria	1989	0	32	0	32
Senegal	1989	0	1	0	1
Sudan	1989	0	5	0	5
Tunisia	1989	0	7	0	7
Zambia	1989	0	5	0	5
Zimbabwe	1986	0	2	0	2
TOTAL	1989	95	0	0	261

ASIA and other countries

Country	Year	Production	Import	Export	Consumption
Saudi Arabia	1988	295	(25)	(270)	(18)
P. Rep. of China	1989	320	130	0	450
DPR of Korea	1986	0	3	0	3
Rep. of Korea	1990	484	(52.6)	(23.5)	399
Hong-Kong	1989	0	37	0	37
India	1989	40	98	0	138
Indonesia	1989	0	109.9	0	109.9
Irak	1986	0	9	0	9
Iran	1986	0	25	0	25
Israel	1989	0	22	0	22
Japan	1990	1120	18	149	989
Jordan	1986	0	2	0	2
Qatar	1986	0	1	0	1
Kuwait	1983	0	1.8	0	1.8
Lebanon	1988	0	2	0	2
Malaysia	1988	0	50	0	50
Oman	1983	0	2	0	2
Pakistan	1983	0	10	0	10
Philippines	1988	0	42	0	42
Singapore	1988	150	0	120	30
Sri Lanka	1983	0	2	0	2
Syria	1986	0	7.2	0	7.2
Taiwan Province, China	1989	160	60	0	220
Thailand	1988	60	10	0	70
Turkey	1989	44	0	0	40
TOTAL	1990	1069	648.9	390	1291.9

( ) older data

ANNEX II

POLYETHYLENE LD

AFRICA

Country	Year	Production	Import	Export	Consumption
South Africa	1988	(100)	0	0	102
Algeria	1986	24	0	0	51
Angola	1985	0	4	0	4
Cameroon	1986	0	3.5	0	3.5
Ivory Coast	1986	0	11.1	0	11.1
Egypt	1986	0	48	0	48
Ethiopia	1986	0	2.5	0	2.5
Ghana	1986	0	4.1	0	4.1
Kenya	1986	0	9	0	9
Libya	1986	0	10.6	0	10.6
Morocco	1986	0	25	0	25
Nigeria	1986	0	50	0	50
Senegal	1986	0	2.8	0	2.8
Sudan	1986	0	2.4	0	2.4
Tunisia	1986	0	14	0	14
Zambia	1984	0	19	0	19
Zimbabwe	1986	0	8	0	8
TOTAL	1988	100	0	0	364

ASIA and other countries

Country	Year	Production	Import	Export	Consumption
Saudi Arabia	1987	380	3	355	28
Bangladesh	1985	0	6	0	6
P. Rep. of China	1988	320	325	0	645
DPR of Korea	1985	32	0	0	32
Rep. of Korea	1990	388	(90)	(12)	441
Hong-Kong	1988	0	79	0	79
India	1988	101	27	0	128
Indonesia	1989	0	85.5	0	85.5
Irak	1986	0	20	0	20
Iran	1986	0	35	0	35
Israel	1989	88	0	30	55
Japan	1989	1501.6	77.1	112.7	1313
Jordan	1986	0	3	0	3
Qatar	1987	100	0	100	0
Kuwait	1985	0	14.9	0	14.9
Lebanon	1985	0	13	0	13
Malaysia	1988	0	38	0	38
Oman	1985	0	15	0	15
Pakistan	1986	2	17	0	19
Philippines	1988	0	57	0	57
Singapore	1988	145	0	131	14
Sri Lanka	1986	0	3	0	3
Syria	1986	0	25	0	25
Taiwan Province, China	1988	210	(76.5)	(22.1)	275
Thailand	1988	65	(25)	0	97
Turkey	1988	184.6	-	-	-
TOTAL	1990	3127.2	945	750.8	3000.4

( ) older data

ANNEX III

POLYPROPYLENE

AFRICA

Country	Year	Production	Import	Export	Consumption
South Africa	1989	46	(20)	(0)	75
Algeria	1989	0	7.5	0	7.5
Angola	1989	0	1	0	1
Cameroon	1989	0	2	0	2
Ivory Coast	1989	0	5	0	5
Egypt	1988	0	19	0	19
Ghana	1989	0	1	0	1
Kenya	1989	0	5	0	5
Libya	1989	0	4	0	4
Morocco	1989	0	12	0	15
Nigeria	1989	0	37	0	37
Senegal	1989	0	1	0	1
Tunisia	1989	0	8	0	8
Zambia	1988	0	1	0	1
Zimbabwe	1988	0	3	0	3
TOTAL	1989	46	0	0	175

ASIA and other countries

Country	Year	Production	Import	Export	Consumption
Saudi Arabia	1988	0	19	0	19
P. Rep. of China	1989	265	260	0	525
DPR of Korea	1989	0	4	0	4
Rep. of Korea	1990	615	(15.2)	(92.8)	561
Hong-Kong	1989	0	51	0	51
India	1989	40	25	0	65
Indonesia	1989	3.8	203.6	5.3	202.1
Irak	1989	0	3	0	3
Iran	1989	0	3	0	3
Israel	1989	0	22	0	22
Japan	1989	1727.5	(5)	68.6	1719.2
Jordan	1989	0	1	0	1
Kuwait	1989	0	3	0	3
Lebanon	1989	0	1	0	1
Malaysia	1989	0	66	0	66
Pakistan	1988	0	32	0	32
Philippines	1989	0	82	0	82
Singapore	1989	(150)	0	(138)	12
Sri Lanka	19[illegible]	0	1	0	1
Syria	[illegible]	0	7	0	7
Taiwan Province, China	[illegible]	(245)	35	(15)	257
Thailand	1989	3	100	0	103
Turkey	1989	65	0	0	71
TOTAL	1989	2823	0	0	3082

( ) older data

ANNEX IV

POLYSTYRENE

AFRICA

Country	Year	Production	Import	Export	Consumption
South Africa	1988	(10)	0	0	24
Algeria	1983	0	12	0	12
Angola	1983	0	1	0	1
Ivory Coast	1983	0	1	0	1
Egypt	1983	0	12	0	12
Kenya	1983	0	1	0	1
Libya	1983	0	1	0	1
Morocco	1984	0	4	0	4
Nigeria	1978	0	6	0	6
Tunisia	1988	0	10	0	10
Zambia	1983	0	5	0	5
Zimbabwe	1983	0	1	0	1
TOTAL	1985	16.2	(43)	0	(63.2)

ASIA and other countries

Country	Year	Production	Import	Export	Consumption
Saudi Arabia	1989	60	0	39	21
Bangladesh	1983	0	1	0	1
P. Rep. of China	1989	70	150	0	220
DPR of Korea	1983	0	2	0	2
Rep. of Korea	1989	420	8	108	320
Hong-Kong	1989	99	230	0	329
India	1986	20	10	0	30
Indonesia	1989	14.5	(3.4)	(0)	(17.4)
Irak	1983	0	7	0	7
Iran	1983	0	23	0	23
Israel	1983	10	3	0	13
Japan	1989	1149.7	(23)	(130)	(857)
Jordan	1983	0	4	0	4
Kuwait	1983	0	4	0	4
Lebanon	1983	0	2	0	2
Malaysia	1989	29	0	1	28
Oman	1983	0	5	0	5
Pakistan	1986	0	10.8	0	10.8
Philippines	1983	15	4	0	16
Singapore	1989	0	66	0	66
Sri Lanka	1983	0	1	0	1
Syria	1983	0	3	0	3
Taiwan Province, China	1989	257	0	0	257
Thailand	1989	43	1	0	44
Turkey	1988	19.2	0	0	0
TOTAL	1989	64.2	79.8	0	121.8

( ) older data

ANNEX V

POLYVINYL CHLORIDE

AFRICA

Country	Year	Production	Import	Export	Consumption
South Africa	1989	160	0	0	135
Algeria	1986	20	0	0	39
Angola	1983	0	4	0	4
Cameroon	1983	0	8	0	8
Ivory Coast	1983	0	16	0	16
Egypt	1987	42	0	0	74
Ghana	1983	0	5	0	5
Guinea	1971	0	2	0	2
Kenya	1983	0	20	0	20
Libya	1987	52	0	0	29
Morocco	1987	25	0	0	25
Nigeria	1985	0	52	0	52
Senegal	1983	0	4	0	4
Sudan	1978	0	1.6	0	1.6
Tunisia	1985	0	5	0	5
Zaire	1974	0	4.9	0	4.9
Zambia	1985	0	13	0	13
Zimbabwe	1985	0	4	0	4
TOTAL	1989	310	0	0	450

ASIA and other countries

Country	Year	Production	Import	Export	Consumption
Saudi Arabia	1989	180	0	88	92
Bangladesh	1983	0	5	0	5
P. Rep. of China	1989	630	(100)	(80)	625
DPR of Korea	1986	21	0	0	24
Rep. of Korea	1990	520	(53)	(37)	599
Hong-Kong	1989	0	(81)	(9)	75
India	1989	136	84	0	220
Indonesia	1989	92.8	14.6	12.3	108.3
Irak	1986	0	0	0	50
Iran	1988	0	0	0	115
Israel	1989	94	0	0	60
Japan	1989	1941.3	63	64.8	1932
Jordan	1984	0	8	0	8
Qatar	1983	0	3	0	3
Kuwait	1984	0	8	0	8
Lebanon	1989	0	12	0	12
Malaysia	1989	39	0	5	35
Oman	1983	0	10	0	10
Pakistan	1987	(13)	22	(0)	27.3
Philippines	1987	26.8	11.7	0	38.5
Singapore	1989	22	12	0	34
Sri Lanka	1983	0	6	0	6
Syria	1985	0	4.6	0	4.6
Taiwan Province, China	1989	805	0	0	908
Thailand	1989	152	0	17	135
Turkey	1989	136	0	0	98
TOTAL	1989	4142	0	0	4128

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19190 (2of2)

UNIDO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

CONFERENCE ON ECOLOGICALLY SUSTAINABLE INDUSTRIAL DEVELOPMENT

Copenhagen, Denmark, 14-18 October 1991

Distr.
LIMITED

ID/WG.516/15/Summary
21 August 1991

ORIGINAL: ENGLISH

PLASTICS AND PLASTICS WASTE RECYCLING

Case Study No. 5

Executive Summary

Prepared by

the UNIDO Secretariat

V.91-28145

EXPLANATORY NOTES

ABS	acrylonitrile butadiene styrene
APP	atactic polypropylene
HDPE	high density polyethylene
LDPE	low density polyethylene
LLDPE	linear low density polyethylene
PET	polyethylene terephthalate
PP	polypropylene
PS	polystyrene
PVC	polyvinylchloride
SAN	styrene acrylonitrile

In August 1991, $US 1 - DM 1.75

Contributions to this document have been made by A.G. Buekens, Professor at the Vrije Universiteit Brussels, Belgium.

INTRODUCTION - THE PLASTICS INDUSTRY

The development of synthetic plastic materials undoubtedly has been one of the major technical achievements of the twentieth century.

The production of plastics has enjoyed a tremendous growth in industrialized countries, mainly because plastics are light, easy to process and convenient to use. Their consumption is still expanding (albeit at a more reasonable growth rate)and becoming an environmental problem.

Bulk plastics are generally produced by large international or local state-held companies which have their main activity in oil refining and/or petrochemicals. Companies of this size are highly structured with separate administrative, financial, marketing and R & D divisions and production facilities. The typical capacity of production for bulk plastics is in the range of 40,000 to 400,000 t/a per production plant. Engineering plastics are manufactured in plants whose size is typically one order of magnitude smaller. Industrialized countries have much higher per capita production and consumption figures than others.

Plastics can be converted according to different techniques. The most important are injection and blow moulding, extrusion and thermoforming. In most developing countries there is little conversion capacity available, so that many plastic products are imported, either as a part of various kinds of equipment or as packaging. Local production is generally less diversified from the viewpoint of both the plastics and the conversion methods used.

Some conversion methods, such as extrusion and calendering, are mainly directed to the production of semi-finished goods (sheets, plates, profiles, tubes, etc.), others are mainly used for producing machine parts (injection) or packaging (blow moulding, thermoforming, injection). The unit investment required is highly variable depending on the following factors:

- type of processing;
- size and capacity of the unit;
- new or second-hand equipment;
- level of automation;
- presence of peripheric equipment (automatic feeding of granulate, collection, grouping and packaging of products).

The conversion of plastics requires a sizeable amount of electric power. The availability of adequate amounts of cooling water is also an important factor in selecting a site for the production facilities.

The production of plastics is accompanied by the formation of some by-products, such as low molecular weight polymer, atactic polypropylene, reactor crusts, wastewater polymer sludge. Most production waste can readily be recycled.

The per capita consumption of plastics in developing countries is much lower than elsewhere and mainly directed towards products of first necessity. However, both the local production and the available inventory can be expected to grow considerably in the future. In the context of sustained growth, attention should be given to:

- proper use of the raw materials and energy;
- stimulation of reuse, recycling and, as a last resort, waste as a source of fuel;
- environmental aspects, including the proper management of production residues and post consumer plastics waste.

Recycling options

It would seem that all thermoplastics materials are predestinated to be recycled as they are valuable and can be remoulded innumerable times. However, little progress has been achieved in recycling consumer waste in industrialized countries.

Plastics reclamation and recycling can be subdivided into the following steps:

- source separation of plastics waste possibly supplemented by curbside and dumpsite retrieval;
- identification, grouping and sorting;
- shredding, washing, drying;
- regranulation, possibly after preliminary densification;
- conversion to new products.

The most critical steps in the process are:

- a correct identification of the plastics in hand. Mixing different resins leads to a catastrophic loss in quality and to the manufacturing of useless products;
- regranulation of contaminated materials requires experience and good strainers. Light materials have to be fed by means of a special auger feeder.

Plastics waste generated by polymer manufacturers consists of:

- production waste, such as the deposits formed on the walls of a polymerization vessel or the driers, or sludges separated from process waters;
- off grade products;
- extrusion purgings and lumps;
- floor sweepings;
- waste arising during quality control and laboratory testing.

Manufacturers are large multinational petrochemical companies, which normally will not commercialize off-grade products under their own trade names, or indulge in relatively small-scale reclamation. Their waste is taken over by specialized recycling firms which classify it according to homogeneity and condition.

Off-grade products are directed towards non-critical applications. Floor sweepings are carefully purified by means of mechanized sorting methods, which should completely eliminate dust, dirt and occasional foreign objects. Sweepings are composed of various grades of the same polymer; which cannot be separated by simple means. Suitable outlets should be found, which take into account the unusual rheological properties of such a mixture.

Atactic polypropylene (APP), which for a long time has been a useless by-product of propylene polymerization, is no longer a problem:

- improvements in the catalyst system, the reactor configuration and operating conditions have considerably reduced the generation of APP;

- all available APP is recovered and blended into roofing or road asphalt bitumen to improve its elasticity and mechanical properties.

Low molecular weight polyethylene polymer can also be reused to a certain extent.

Technical improvements in both equipment and polymer quality have considerably reduced the occurrence of production losses. Sprues from injection moulding have been eliminated by the use of hot runners. A better mould design, suitable injection cycle and polymer quality control reduce the occurrence of incompletely formed objects. Also the ejection and the collection of the products has been markedly improved, so that less injected parts are inadvertently caught by the closing of the mould.

Even smaller firms can no longer afford to waste these raw materials. Waste is carefully segregated at the source, according to its nature, colour, and additives. Contamination by dust, oil or burned (i.e. thermally decomposed) material is avoided. In general the waste is ground and recycled, either directly in the same or a similar production, or in a less critical application.

The most important potential source of plastics waste is to be found in consumer waste, arising in trade and industry and in private households. Municipal refuse in industrialized countries typically contains about 7 wt.% of plastics.

Consumer waste forms a largely untapped source of recyclable plastics. Some well defined industrial waste has been recycled after use, e.g. plastic containers, fertilizer bags, agricultural film, shrinking film, shockproof packaging, etc. Outside developing countries plastics present in municipal refuse have never been recycled on a long-term consistent commercial basis.

A major difficulty lies in the logistic problem of collecting suitable amounts of plastics, which are reasonably free from putrescibles and contaminants and can be transported economically to the cleaning, grading and reprocessing plant.

BARRIERS

Technical barriers

Plastics waste is available in a wide variety of types, forms, kinds and levels of contamination. A substantial range of recycling technologies are required. Some are mature, others developmental.

Currently, no mechanical system is proven or available to separate plastics waste into its different constituents and meet the requirements of the recycling industry.

Economic barriers

The largest tonnage of plastics waste available for recycling is post consumer consisting of mixed and/or contaminated products.

The collection of plastic materials may assume different forms, such as:

- door to door collection of source separated plastics;
- separate collection by civic associations;
- collection at schools;
- manual sorting of household waste at a sorting belt;
- source separated waste delivered by an individual to a container park, civic centre shop, etc.

Dumpsite collection is unsanitary and dangerous to public health.

Processing costs for plastics waste can be subdivided into:

- Manual sorting or cleaning costs. These are inversely proportional to productivity, which in turn is related to the type of operation, e.g.:

  * picking plastic bottles from a refuse stream;
  * splitting a plastics stream into a number of categories;
  * skimming a plastics stream for recognizable objects;
  * manually clean plastic products by eliminating PVC from polyolefin film, removing caps from bottles, etc.

(The productivity of such operations is very poorly documented).

In developing countries the investment cost of recycling equipment including mill, additive blending and regranulation may be prohibitive. On the other hand labour for collection is usually available and cheap. The manual washing of contaminated agricultural film poses no problem provided that suitable feeding or sintering equipment is available.

Social issues

Plastics waste is being actively recycled in most developing countries. Collection takes place at several levels:

(1) Waste may be collected at source (in homes or in shops, etc.). This system is only feasible when there is a well organized collection circuit so that everyone can supply the material.
Some major cities have an organized network of shops buying source-segregated waste materials;

(2) More frequently, recyclable waste materials are scavenged from household dust bins. Recyclable materials can be set aside by the rubbish collection crews and marketed on their way to the disposal site. The latter system operates for plastics materials. Finally, the scavenging of recyclable waste materials at the tipping site is an essential activity for a number of trades that depend on this supply. However, the conditions can vary, depending on the degree of organization.

Many of the people active in the recycling circuit are regarded as unskilled labourers operating under harsh conditions both financially and in terms of the working environment.

Scavenging on the dumpsite may be officially forbidden but frequently is tolerated. Under these conditions the scavengers enjoy no protection and even operate immediately in the tracks of compacting equipment. Organization of this activity is well established with individuals financing the operation and allocating territory and fixing pay scales.

A more just regular organization of scavenging, sorting and cleaning would be more beneficial to all parties concerned. This could assume the form of sorting from a belt in a partly mechanized plant.

It is difficult to assess collection cost, because it may either be on a voluntary basis, with the selling of the material as a reward, or on a basis of cheap labour. Sorting normally is entirely manual. Washing often also proceeds by hand with the drying of shredded plastics by solar heat.

INITIATIVES

Government incentives to promote plastics recycling

For a number of years individual European Economic Community (EEC) countries as well as the EEC as an entity have taken measures to reduce the generation of refuse.

Current legislation in several EEC countries provides for banning non-recyclable or even non-reusable packaging and the compulsory recycling of (plastics) packaging.

Government incentives such as deposit schemes are required to promote recycling PET bottles and HDPE containers.

The requirements of some European countries can be summarized as follows[1]:

- Italy: 40 per cent of packaging to be recycled by 1992, with 50/50 material/energy. All shopping bags must be biodegradable or pay 100 lire/bag, tax.

- Holland: Different targets for packaging and the rest but the overall trend is for a 10 per cent reduction in waste, 50 per cent minimum re-use/recycling, 30 per cent incineration with energy recovery and 10 per cent maximum to landfill by year 2000, with intermediate 1994 targets.

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In contrast, initial proposals from the EEC were more flexible, seeking a recuperation rate of 80 per cent for packaging, but including energy recovery.

It is the role of both government and industry to provide a reliable source of information with respect to the hazards, as well as the economic potential related to plastics, including their production life cycle and waste aspects. The relative importance of the latter is particularly evident in non-industrialized countries because:

- the cost for collection, manual cleaning and sorting is more easily borne;
- the limited variety of plastic types eases their retrieval, identification and reclamation.

Industry initiatives

Major plastics users, including the automotive and appliance industries, are starting to view the use of plastics in their products from the standpoint of design for disassembly, where part-structure and composition take ease of separation and reuse into account. This would favour thermoplastics over thermosets and composites.

Opportunities exist for upgrading recycling technology. In Europe the major product is LDPE film retrieved from commercial packaging waste. The recycling operation has been mechanized by means of a suction duct. The washing of agricultural film is a well established operation. Some problems are the large amount of earth and abrasive sand, the exposure to ultraviolet light and the accidental presence of PVC film, which renders the reclaim unusable.

Priority R & D areas include development of coextrusion techniques, processing of plastic materials recovered from other recycling operations such as shredded cars and electronic components.

Plastics waste is usually recycled by specialized firms, which either upgrade the material and bring it up to specifications, or convert it to non-critical products, such as:

- garden hoses, drainage pipes, buckets, refuse bags, or toys in polyethylene (LDPE);
- plastic 'lumber'
- flooring, shoe soles, bicycle saddles, drainage pipes, protective cover plates in polyvinylchloride (PVC);
- foam products in polystyrene (PS);
- carpet underlayers in insulating packaging in polyamides (PA).

For a number of years in the USA PET bottles have been turned into fibre batting for pillows and comforters.

Several systems, based on sink/float principles or on hydrocyclone cascades, are being demonstrated and hold the promise of separating at least an olefinic fraction. Several recycling ventures are working on X-ray detectors which could then be connected to automated sorting systems to separate polyvinylchloride (PVC).

In developing countries factory techniques may be employed cleaning impact-proof polystyrene yoghurt beakers by means of shredding, washing in a conventional (laundry) washing machine, dewatering and thermal drying with hot air, generated by mixing flue gas and air.

Regranulation is often conducted using second-hand or even locally made equipment. An essential part is the strainer, taking out non-melting impurities, and degassing, to evacuate volatiles and residual moisture.