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"Materials for Food Packaging, Storage and Transportation"

1. INTRODUCTION

Food packaging is concerned with the containment of surplus foods which are not required to be eaten immediately; the protection of these from pests, dirt, moisture and other harmful climatic effects; from physical damage and from contamination by microbes or bacteria. Some form of identification is also usually needed - to indicate the type of food contained in the pack, and its place and date of origin.

A pack or container may vary in size from a large bulk vessel of one tonne or more down to a tiny unit pack of sugar or salt; and may be made from a wide range of materials. Each of them, however, has to provide the same mix of performance as already listed. In addition to those, consumer packs are increasingly required to "sell" themselves in modern retail stores; and to provide a degree of convenience to the end user. All of these functions must be achieved at the minimum cost, in a safe and lawful way and with the least possible harm to the environment.

2. PERFORMANCE REQUIREMENTS

2.1 **Physical Protection:** Packs may be split or torn during handling, or crushed under high loads in storage. They may be scuffed by vibration during a journey and suffer side shocks or punctured during mechanical transfers. All of these can be measured and packs can be made strong enough to withstand them, but only up to a certain economic limit.

2.2 **Climatic:** Heat, light, water and the oxygen in the air, can all have harmful effects on many foods; these effects are often made worse in combination. For instance, high temperature plus moisture; or light plus oxygen.

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2.3 **Biological:** Attacks may come from minute spores or bacteria, tiny insects or small animals or birds. Protection from the first kind should start before the food is introduced into the pack, since if the pack is contaminated spoilage will certainly occur (unless retorted). It is more difficult to provide protection against insects and small animals by the package or packaging material alone, and this is in practice mainly achieved by good housekeeping conditions in the storage environment.

2.4 **Safety and Quality:** Packaging materials intended to come into contact with foods have especially stringent requirements. They must not transfer any harmful constituents into the food, nor result in any unacceptable change in taste, texture or appearance. They should also provide protection against the loss of any component of the food (especially moisture or volatile ingredients) and against the ingress of oxygen or water vapour, where these would affect the food. Packaging materials should also ensure that no odour or taint is picked up from any external source.

As a rule, the higher the gas barrier performance, the better, but with certain moist and processed foods, complete anaerobic conditions must be avoided.

Manufacturing hygiene must be particularly good, and similar requirements apply to protective packaging and the conditions in which food packaging materials are stored and transported.

3. DEVELOPMENTS IN INDIVIDUAL PACKAGING MATERIALS AND FORMS

3.1 **Metal:** The most commonly used metals are tinplate and aluminium: and the most important cost factor in retail size metal containers is their materials content. This means that even small savings of material are worthwhile. In tinplated steel the greatest amount of development has centred on ways of reducing or totally replacing the tin component; in reducing the wall thickness; in reducing materials usage by modifying the fabrication processes; and in reducing the diameter of the steel ends. Three-piece cans made by seam welding the body cylinder are now using induction, or laser fusion and 'cement' adhesion. These methods are all possible, and will give small materials savings as well as other benefits.

Tin-free steel is extensively used, modern inorganic coatings (chrome/chrome oxide) and organic lacquers are used in association with this. These materials are also capable of being formed by the same deep-drawing techniques as tinplate and aluminium. Of the two best known techniques, the draw-wall-iron (DWI) allows greater materials savings than does the alternative draw-re-draw (DRD), since in the latter the wall and base thicknesses are virtually identical. Ultra-thin walls are acceptable for carbonated soft drinks due to the stiffening effect of the internal pressure. It is possible, with some limitation, to introduce internal pressure into other food cans by the use of liquid nitrogen or CO_2. This technique, which is already beginning to find applications, is most appropriate for mobile liquids. Tinplate therefore has ample performance and it can be reduced in weight by the techniques mentioned but there is clearly an equation linking the materials savings to the higher processing costs and a break-even point must exist.

Extrusion coating and lamination offer prospects of utilising the properties of steel and plastics in combination. This has already been commercialised in Japan, notably the small iron foil trays, adhesive laminated with polypropylene, from Toyo Seikan.

Aluminium is used for a wider range of applications than steel - examples are tubes, pressed foil trays and laminates. It is ductile enough to be rolled to thicknesses as low as 5-6um although 7um is normally the thinnest in general use. A major proportion of its cost must always be the energy required to refine it from the bauxite ore in which it is found. Since energy (especially the electrical form mainly used for this) is unlikely in the short term to become cheap, this will remain a limitation to the economic production of aluminium. However, if reprocessing of scrap aluminium recovered from the domestic waste stream, can be increased, then the picture becomes very different and it provides a big incentive for beverage containers (the major single use) to be made all of one material. All-aluminium containers are very common, but easy-open steel ends are now possible and all-steel or all-tinplate versions equally meet the requirement for improved recycling potential.

Some new approaches to the fabrication of aluminium containers have been developed; it is capable of being friction welded and extrusion- or adhesive-coated with polymers, both of which allow very lightweight containers to be made. Cold forming of polymer coated heavy foil is another technique which can be adopted for the manufacture of retort pouches and trays. The most extreme form of metal reduction is in vacuum metallisation. This is a technique in which a minutely thin layer of metal (usually aluminium) is deposited as a vapour from a boiling crucible under high vacuum onto a reel of plastics film. The coating is about .02·m thick and is not fully opaque, but it does provide greatly improved barrier performance to gases and light.

Other forms in which metal is used include closures - which can also be in aluminium or tinplate. The former is usually applied by a technique in which the thread is produced by rolling it into the neck finish of the container; and the latter is more often a lug or preformed threaded closure. The traditional crown cork is now less used as single trip bottles are increasingly adopted, although a variation on this - the Scru-seal has been developed which has a plastics layer inside it. It is applied in the normal way by crimping but the plastic grips a fine thread on the glass neck finish and can thus be removed by unscrewing.

Metal strapping or wire is still used for the heaviest duty applications, but has been extensively replaced by plastics types in many areas.

3.2 **Paper:** This was the first material used for "mass produced" packaging and it has retained its pre-eminent position on a tonnage basis to this day. Paper making has evolved continually, mainly in energy savings and improved quality and hygiene, but there has been no fundamental change to the process, which remains basically the Fourdrinier technique with its high energy requirement for the de-watering and drying stages.

There have however been some major changes in application. All forms of bags and sacks are targets for substitution by plastics - usually high density or low density polyethylene, although the traditional SOS block bottom bag is making something of a comeback where its higt quality graphics potential can be exploited. Small cartons have retained their traditional form and material, despite various attempts to develop plastics substitutes. In the larger sizes, very fine corrugated boards (E-flute and micro-flute) are being increasingly used (detergent packs are a good example). The problem of achieving high visual quality has been overcome by the extensive use of pre-printed liners or by laminating sheet with printed board or paper.

Moving up in material and pack sizes, corrugated boards continue to replace solid board for transit and shipping cases. Improved water resistance of the adhesives used, and enhanced stiffness by impregnating the fluting medium with resin (and in some instances, by combining two fluting layers with a stiffening adhesive/resin) have all improved the cost/performance ratio; and a steady pattern of down-gauging has continued.

Composite containers, based on the traditional spiral winding technique, retain their place for certain dry foods - a major benefit being the saving of space if produced in-house. There are, however, many competitive systems now available, including those using pre-cut blanks (Horauf, Can Shield and Cekacan). A new approach to this form of paper pack shown for the first time at Pack-Pro exhibition in Germany early in

1988, is the Sirpak made from narrow strips of paper in a continuous tubing technique around a shaped mandrel (somewhat akin to paper sack manufacture). this has board ends which are sealed and bead rolled - a characteristic also of the Cekacan.

The bag-in-box pack has found a niche for wine, milk and some catering products like tomato sauce, where it usually competes with metal cans or glass bottles or jars. Sizes range from 500ml to 1000 litre, although the smallest types (e.g. Cebox) have found limited applications to date; and the largest types - intermediate bulk containers - are related to changes in the transport and distribution of bulk foods such as frozen concentrated orange juice and tomato paste. The most popular size range for wine and other retail containers is 3-10 litres.

Without doubt the most significant developments in paper packaging are where this material is allied to a plastics component. Coated boards are used to produce liquid-tight trays - for microwave or conventional oven heating (depending upon whether they are extrusion coated with polypropylene, polyester, or TPX); and for liquid carton systems. It is in the latter where the most spectacular growth has been seen. Three companies dominate the area, Tetra Pak from Sweden, Combibloc from Germany and Elopak from Norway. All are multi-national companies and the Tetra Pak in particular is today used in over 100 countries. Together they represent a total market between 60 and 100 billion containers per annum, in sizes from 150-3,000 ml.

Products packed in liquid cartons now include milk, fruit juice, wine, oil, sauces, tea, water, soups, tomato pulp, jam, jelly, cooked rice - even whisky, and many, many more. The foods may be packed under aseptic conditions to provide six or twelve months shelflife; or fresh and distributed under chilled conditions. Two main forms dominate, the "brick" and the "gable top", but there are variants ranging from the original tetrahedral pack (Tetra Pak standard) to the latest Tetra Top, a square cross-section carton with an injection-moulded top formed in situ, and incorporating a reclosable tab.

Among other manufacturers are Dai Nippon and Toppan from Japan - both of whom offer gable top cartons with plastics reclosable pouring spouts; International Paper in the U.S.A.; SIG in Switzerland (the latest to enter the field - in 1988); and Bosch in Germany with their aluminium-ended Hypa and Hypa-S packs.

Some recently published research results indicate that the Hypa-S might be able to withstand the internal pressure of carbonated drinks. If this is progressed then a further huge market development becomes possible (other countries are known to be similarly interested). Most of these liquid carton systems use reel-fed materials which invariably include polyethylene as the heat sealing medium, but can incorporate aluminium foil for high barrier, and other plastics as required.

3.3 **Glass:** This is the only technology involving a single process from raw material to finished pack. The basic constituents of glass account for only about 15% of the total cost of the pack, and for cost saving the emphasis must therefore be on process economies. This is one major area of development. It is known that the possibilities of using the theoretical strength of glass are enormous. The most promising development of this nature is one pioneered in Japan by Yamamura Glass Company. It involves the substitution of sodium ions in the surface layer of the glass by larger, potassium ions, the effect of which is to produce in situ a pre-stressed surface layer giving very much enhanced toughness. It has not been extensively adopted in other countries, largely because of the high capital costs involved.

Processing developments have included pre-mixing of constituents, pre-heating by introducing ingredients via the hot flue, computer control of glass making machines, and electronic gob-weight control. CAD/CAM developments have led to improvements in wall thickness control and lower mould making costs, as well as reduced rejection rates of the finished product. All of these have helped to keep glass commercially competitive.

The second approach has been to protect the surface of glass from scuffing, abrasion and impact damage, which are the main causes of mechanical failure. "Hot" and "cold" end treatments using titanium and tin oxides and polyethylene emulsions, to provide a high strength surface and lubrication properties respectively, have been in use for many years, and improvements continue but these are a matter of degree rather than representing any fundamental breakthrough.

Shrink sleeves provide another form of surface protection, and both foamed polystyrene and clear PVC are used - in both instances they double as a label and can also provide tamper-evidence. Another protective route is to coat the bottle surface in a layer of plastics material. This may be achieved by spray, roller coating or dipping from an emulsion in the hot or cold state; it can also be used to provide attractive colours and, if applied over a label, will protect this. A recent innovation developed in Japan by Kirin Breweries is to coat the bottle with a surface lubricant and protective skin of zinc stearate. By use of an appropriate solvent washing technique, this coating can be removed each time a returnable bottle is used, and it is then re-coated on the filling line - so maintaining the bottle's surface strength throughout its life.

Improvements in dimensional tolerance to glass have made it possible to heat seal lacquer- or polythene- coated foil membrane lids to the rims of widemouth glass jars. This has led to some extension of the use of this material. Ceramic inks which are fused onto the surface to provide permanent 'labels' can also be used to provide either opaque or translucent decorative coatings.

3.4 **Plastics:** As the most recently developed material to be used for packaging, and one based on high technology processes, it has shown the greatest versatility and development. About ten basic polymers are used but the variations on these, and the range of possible combinations of two or more (as well as with non-plastics) makes the number of permutations almost infinitely large. It is therefore simpler to discuss plastics packaging developments under the headings of rigid, semi-rigid, flexible, and composites.

3.4.1. **Developments in polymers:** Completely new polymer materials rarely appear and the range already available is capable of meeting most requirements. Current developments include:

Linear LDPE - a branched molecular structure, halfway between low density and high density in nature. It is made by a low pressure gas phase route, offering energy savings to the manufacturer. Physical performance is improved allowing down-gauging and consequent cost savings. Most new plant commissioned is capable of producing this.

Ultra low density polyethylene - in densities below $0.91 g/cm^3$ also offers improved strength, better heat sealing properties (especially through contamination) and enhanced optical quality, while giving increased yield.

Many derivatives of the polyester family are being developed but only two have so far been commercialised. PETG - glycol modified polyester - is extensively used for plastics bottles produced by the extrusion blow moulding route. Amorphous PET is in use for thermoforming, providing high gloss and mechanical strength. This is being offered as a replacement to PVC but at higher cost.

Other polyesters such as polybutylene terephthalate and copolyesteramides are also being evaluated.

Polycarbonate and polyetherimide are two engineering grade plastics being promoted for certain packaging uses. They have extremely high mechanical strength and heat resistance but their costs are equally high at present.

TPX - a methylpentene copolymer developed by ICI in the 1970s, and allowed to lapse - is now taken up by Japanese companies and offered in film form also for bottle blowing. It has high temperature, solvent, and grease resistance. It is also used for extrusion coating of board for oven use.

EVOH - a copolymer of ethylene and vinyl alcohol - has extremely good gas barrier performance but is moisture sensitive (pure polyvinyl alcohol is also made and used to produce water-soluble films, so the moisture sensitivity relates to the proportion of this element present). Grades are now available which are more stable and the material can be produced as coated films for lamination; but it is more often used in coextruded form in films or containers.

Most recently, and potentially very important, is the range of naturally derived copolyesters, typified by polyhydroxybutyrate (trade name Biopol when made by ICI). This is a truly biodegradable plastic material with properties very similar to polypropylene. It is made by a bacteriological conversion of carbohydrate feedstock (e.g. sugar). Different forms have been described including copolymers of hydroxybutyrate/hydroxyvalerate; and of different molecular configurations e.g. 3-hydroxybutyrate/4-hydroxybutyrate. The proportion of all types can be varied to give widely different properties which range from elastic to rigid.

The most recent development announced by the Tokyo Institute of Technology holds promise of this material being produced at a cost little higher than traditional petrochemical based plastics. This is most significant since the early trial materials were extremely expensive.

3.4.2. **Rigid containers:** may be produced by injection moulding, extrusion blow moulding, rotational moulding, stretch-blow moulding, and thermoforming (from heavy sheet). The route chosen depends upon the shape required, the quality of internal or external finish and the selective control over wall thickness needed.

Injection moulding has traditionally been used to produce rigid packs. The high pressures involved allow extremely fine detail to be reproduced, material distribution to be selectively controlled, and extremely good dimensional precision - especially of the neck finish area. Recent developments in collapsible mould techniques have made it possible to produce more complex designs, including undercuts and threaded sections. At the same time, improvements in melt rheology of the plastics materials themselves have made it possible for extremely thin walled packs to be produced. Engineering techniques such as spark erosion and computer controlled milling also provide the necessary degree of precision for the manufacture of these very finely dimensioned moulds.

An important variation on injection moulding, developed over the past ten to fifteen years is injection-blow-stretch. This involves the production of small thick-walled preforms by injection moulding in which the neck finish and top aperture is produced full size. In a second production stage, these are "conditioned" by heating, mechanically stretched by pneumatically operated pistons and then blown into a full size mould to produce the final shape. This procedure of stretching the containers in two directions produces biaxial orientation of the molecules which improves physical strength, clarity and barrier properties. In narrow neck form these have been extensively adopted for carbonated soft drinks, where their light weight and pressure-resistance are advantages. The process can be used with a number of different polymers - PVC and polypropylene are used but PET (polyethyleneterephthalate or polyester) has been the major choice.

One important area of development specifically for pressurised products such as carbonated soft drinks, involves design of a flat base which can withstand the high internal pressures (4 bars). At first, all bottles had hemispherical ends to contain this pressure, and separate caps were applied by hotmelt adhesive to provide a stable base. The second generation 'one-piece' containers employed an annular "champagne base" design to contain this pressure, but this is primarily suitable for small sized bottles up to about 0.5 litres. For sizes above this various permutations of multiple-dome and rib designs are used to contain this pressure. These have varied from relatively simple 5 or 6 dome arrangements (petalloid) to very complex engineering designs which lock up the stress into a series of ribs and facets. The disadvantages of these one-piece designs are that greater quantities of PET material are usually needed, more complex preforms and higher blowing pressures are needed for distributing the material into the detailed shapes, and they do not present a full-area, flat base to provide stability on the filling lines.

Even higher pressures can be withstood by the latest designs of PET bottles and aerosols made from this material are now in use for some limited products ranges. The high strength of these packs makes them also suitable for certain hazardous materials including agro-chemicals.

Another area of development has been directed into improving the gas barrier performance. To achieve this, external coatings (usually PVdC but other chemicals such as acrylic emulsions and EVOH [ethylene vinyl-alcohol copolymer] emulsion have also been described). An alternative approach is to make the preform using a co-injection moulding technique in which a high barrier material (EVOH, a form of nylon such as MXD6, or an acrylic multipolymer such as Barex) is introduced as a core layer between two outer layers of PET.

The third area of research has been in heat resistance. Currently, PET bottles and jars will deform if heated at temperatures over about 60 - 70°C. This means they cannot be used for in-container processing, or hot filling, and this restricts the range of potential applications. Enhanced thermal stability can be achieved by improving the basic polymer - much effort is targeted to this, especially in the area of modified polyesters - and some development materials are undergoing trials. Polycarbonate is an engineering plastic which is being considered: "TPX" (a methyl pentene copolymer) and "U" polymers (forms of polyacrylate) are also available.

A further route to providing heat resistance is polymer alloys, which are analogous to metal alloys - intimate mixtures of dissimilar materials which do not form new compounds as such but which offer a range of properties different from either of the constitnents. Many of these use standard commodity polymers such as high impact polystyrene and polypropylene. Finally, a procedure for providing heat resistance which is applicable to certain limited ranges only - notably polyester - is to incorporate a crystallisation initiator in the polymer which then, during a slightly extended heating period in the mould, will result in crystallisation of the polymer into a much more heat stable form. This is most used with PET, the resulting material is usually commonly referred to as CPET and its primary use has been in thermoforming but some rigid PET containers in Japan are treated selectively in the neck area to induce this crystallisation. Its characteristic white appearance denotes that this has been done.

Extrusion blow moulding is the second route for producing rigid plastics containers, and is the norm for narrow necked bottles and closed head plastics drums - essentially any item where internal access is not possible. The process can also be used to produce wide-mouth jars by trepanning the top from a bottle shape, or cutting two containers from one such form by centrally slitting. The main limitation is that only the outer face can be precisely controlled dimensionally since only this is in contact with the mould. The process also requires a nip-line across the base - where the extruded tubular parison has been closed off. A further limitation is that cooling can take place from one side only so mould cycles may be slower. Finally, material distribution within the wall - despite the development of variable thickness parisons by means of movable extruder dies - can never be as good as injection moulding.

Against these the process has some very important advantages. It is a single stage operation; and only one mould is required (which is less expensive than an injection moulding tool). A major benefit is that coextrusion techniques can be employed to provide multilayer bottles which make the best use of the properties of different plastics. Examples include, high gas barrier using sandwich layers of PVdC or EVOH, or an outer skin of polyamide or Barex; improved temperature resistance by incorporating one layer of polycarbonate; decorative high gloss and/or coloured external surfaces, e.g. by using an outer layer of polyamide. Other decorative effects include a "comb" coextrusion which allows different colour stripes to be produced in the bottle. In economic terms the incorporation of a middle layer of scrap material can be very important in optimising production costs.

Due to physical and chemical differences in individual polymers, in only a few instances can two or more different materials be directly co-extruded through the same die and adhere satisfactorily. The most important material development involved in this technology has therefore been in the technology of tie-layers - the "adhesive" needed to hold together these otherwise incompatible layers.

One specific technique developed by the Du Pont company in the U.S.A. is to extrude a blend of two imiscible materials in such a way that the smaller constituent forms a series of thin platelets within the matrix of the main material. Combinations evaluated have been mainly based on an amorphous polyamide (Selar PA) in a polyolefin (e.g. polypropylene). The platelet formation is encouraged by the mixing and extrusion processing arrangements; and these lie in a regular plane to produce a "tile-like" effect. The main benefit is a great improvement in the gas barrier performance for what is essentially a single (if mixed) material.

Another process particularly suitable for improving the barrier properties of blow moulded containers is the gaseous modification of the inner surface. Best known of these is fluoridation - a technique particularly applicable to polyolefin materials and which uses the high chemical reactivity of fluorine containing gas to produce in-situ, over the inside walls, a layer of fluoride-substituted polyolefin. This has much improved resistance to solvents, especially hydrocarbon types. The reactive gas (there are also others producing sulphonation, for example) can be incorporated into the blowing gas.

Rotational moulding is a method of producing relatively undemanding containers in large sizes by using heated moulds into which a controlled volume of granular polymer is introduced and rotated. The polymer then fuses and distributes itself around the heated wall of the container. This is frequently used for garden type tubs, rainwater butts etc. A major advantage is the lower mould cost, especially for very large items such as intermediate bulk containers.

3.4.3 Semi-rigid plastics containers (often called thin walled) are mainly produced by the thermoforming process from thin (0.5-1mm) plastics sheeting. This is extruded by the conventional routes and offers all the advantages mentioned above, under extrusion blow moulding. Major benefits of thermoforming are that less material may be used; in-house production is possible (and provides benefits in reduced storage of packaging materials); mould costs are lower; and in particular in-line thermoform-fill-seal systems are available.

A major limitation is that material distribution uniformity can be difficult especially if a deep-drawn and square profile container is formed. Since in most instances the material is drawn in one suction action, the areas of the body furthest from the initial plane are most excessively thinned. Ways of overcoming this include plug assist in which the sheet material is stretched into a certain preformed configuration prior to the final blowing; and the development of other "hybrid" techniques such as solid phase pressure forming and melt phase thermforming where either moulded preforms with selected distribution of material are used, or the container is formed directly from the extruder on a die into a mould. A special variation of multi-layer thermoformable sheet is that used in the NAS (neutral aseptic system) which involves stripping away a poorly-bonded surface layer to expose a sterile surface into which processed foods can be filled after thermoforming under sterile conditions.

Another variation on thermoforming of thin walled containers is the incorporation of in-mould paper or plastics labels which can improve both the barrier and stiffness of the container.

3.4.4. **Flexible Packaging:** Although not all materials used in flexible packaging are plastics-based, there is a close association between the two. Flexible packaging materials are often defined as thin single or multi-layer structures, which may be supplied in reel form for use on form-fill-seal machinery, or in prefabricated form as bags, pouches or covers. In this review a wider interpretation is adopted, adhering more to the literal definition of "flexible" but restricting discussion to materials up to about 300um thick.

The materials used in flexible packaging include paper, aluminium foil, regenerated cellulose film, in addition to the major polymers of polyethylene, polypropylene, polyamide, polyester, polystyrene and PVC. All are capable of being handled separately, and may be combined in various forms to produce materials for use on either vertical or horizontal form-fill-seal machines - these are the materials traditionally associated with flexible packaging.

The materials may be combined either by adhesion lamination (in which the adhesive layer performs only that function) or extrusion lamination - usually with a polyethylene or EVA resin, when the adhesive can provide some further functional properties in its own right. An alternative to separate lamination of discrete films is coextrusion. The principle involved has been described earlier - multiple extruders feeding different materials into a common die. Major benefits are that very thin layers of high cost constituents can be produced in situ. The process is a single stage one. The compound material may be stretched to enhance clarity or strength, and two-sided effects (e.g. different colours) are possible.

Disadvantages are that tie layers are often required, sandwich printing is not possible, non thermoplastics materials cannot be incorporated, and process scrap cannot usually be recycled in house.

Each of these processes has its market suitability; neither meets all requirements of flexible packaging and therefore both are used. A "compromise" approach is to use coextrusion and adhesive lamination or to use coextruded layers as adhesives themselves.

The properties of flexible materials may also be modified after forming. Film manufacturers can produce modified forms of standard polymer films with increased tensile strength, clarity and barrier properties as a result of orientation (stretching) and heat setting techniques. Oriented polypropylene, high density polyethylene, polyester and nylon films are the best known examples, but other materials are also available in similarly modified form.

Treatment by gamma, electron beam or ultraviolet irradiation to promote cross linking and to improve bonding between components, is another post film treatment, and the introduction of ozone into the interface between laminates or coextruded materials combined outside the die, are other examples of process modification.

A range of films often described as pearlised OPP make use of an effect which is neither a function of the initial polymer properties nor the result of post film treatment. By incorporating a small addition of an expanding agent and sometimes traces of white pigment in the polymer the plastic film is formed with a microcellular foamed structure in its core, and the effect of light diffraction on these results in varying degrees of opacity and a pearlescent effect. Due to the cellular texture this material has a high degree of stiffness and an extremely low density - making it suitable as a substitute for paper in a number of applications. These range from small food pouches made on form-fill-seal machines, to labels and carrier bags.

Woven plastics, made from thin stretched tapes of HDPE or polypropylene, after about 20 years on offer for sacks, are now finding their greatest application in the manufacture of flexible intermediate bulk containers where their high strength and flexible fabrication potential is particularly appropriate.

Early problems of u/v degradation have been overcome. They can also be laminated or extrusion coated to provide strong, siftproof materials.

3.4.5. **Surface coatings and high barrier:** A variety of surface coatings can be applied to flexible films either to enhance their existing properties or to provide completely new ones.

Vacuum metallisation, a technique using well established principles, is described earlier at 3.1. Initially the process was used mainly for its decorative appeal, but these materials are now accepted as providing significantly increased barrier properties to water vapours and gases as well as the more obvious light barrier and thermal reflection potential.

Most plastics are suitable as substrates, cellulose films were dominant in the early period (1970's). More recently the benefits of barrier improvement and low metallising costs have been recognised with ultra thin layers of polyester, oriented nylon and polypropylene film.

The enhancement of gas barrier performance depends upon the value for the original material. It is achieved to only a limited extent for an initially good barrier such as regenerated cellulose (in respect to oxygen) but is very significant for medium range barrier materials such as PET and PA. Through these the oxygen transmission rate can be reduced by a factor of about 100 (from 60 - $100/m^2/day$ to 0.5 or less). The process requires a very high vacuum - pressures of 10^{-4} or $^{-5}$Torr being typical - and so batch processing is still the preferred method. Setting-up times on the machine are a major cost component which is why the very thin films (12um and even less). and increasingly large machines (now up to 2.2m in width) are used to improve production economics. A schematic diagram of a vacuum metallising chamber is shown at figure........

Other materials based on polymer layers deposited from emulsions, solutions, or by hot melt extrusion, include nitrocellulose, PVdC (polyvinylidene chloride) acrylic compounds, pressure sensitive adhesive layers, and hotmelt sealing films. Many of these perform two functions simultaneously - improving barriers and making heat sealing possible.

Cold seal coatings have greatly increased in use over recent years - they are formulations of natural latex which stick only to themselves and may be coated all over (either solid or patterned) or in specific areas where seals are required. This is achieved by register printing of the latex during the printing stage. Benefits are mainly in machine speed and simplicity - no heaters, temperature control or minimum contact time are needed. Earlier problems with short shelflife, taint and susceptibility to dust, have been largely overcome.

Notes on barrier performance:

The most effective flexible barrier to gas, water vapour and light is a continuous layer of aluminium foil. When incorporated into a plastics/foil laminate even the tiny pinholes which are present in the thinnest gauges, do not result in any effective gas transmission.

The barrier performance of metallised and other coated films is a function of the weight of coating material, its intrinsic impermeability and the "compactness" with which it has been laid down. For metallised materials, three ways of measuring this can be used. Chemical analysis of the amount of aluminium per unit area; electrical resistance in ohms per square; and optical density. Of these the last is the simplest, and research work has shown reasonable (but not absolute) correlation between this and barrier performance. As a general guide, optical density (OD) values in the numerical range of 3 to 4 or above represent extremely good barrier materials.

Variations on the metallisation process have included the use of electron beams as a high energy source to vapourise the metal (previously electric induction heating had been the norm); and the use of this same energy to produce coatings of clear inorganic materials on plastics films. Most important of these in recent years has been silicon oxide which can be visualised as a microscopically thin layer of flexible glass. Silicon nitride is also used, and this has a whiter appearance than the yellow tint which is characteristic of a silicon oxide.

More fundamentally different is the alternative way of producing metallised films - indirect or transfer metallisation. These processes make use of a metallised film produced in the traditional way, but the base film is treated to resist adhesion and the surface of the metal layer is coated with a heat activated lacquer. To produce metallic layers on other substrates, this "carrier web" is brought into contact via a heated roller and the metallic layer is stripped off and transferred. Major benefits of this (considerably more expensive) route are that extremely high gloss effects can be achieved on poor surfaces such as paper, and the problem of moisture loss for paper which occurs during direct metallisation as a result of the high vacuum conditions, are overcome.

A topical use of special types of metallised film is as a "susceptor" for use in packs intended for reheating in microwave ovens. The small amount of metal, adhesively attached to cartonboard or a bag, concentrates the microwave energy and gets very hot (up to 200°C) promoting crispness and an improved baked effect to foods contained in the packs.
There are also some extremely high barrier materials produced as a result of composite treatment techniques (barrier lacquers such as PVdC on top of metallisation, and the use of two metallised layers adhesively laminated metal to metal).

3.4.6 **Applications of flexible packaging materials.**

Form-fill-seal machines, as already mentioned, are a major area of application. Others in which technical developments have been recorded, include:

Cling and stretch film - these are used in two major ways; the first is as high clarity overwraps for trays, lidding or collation of packs. Two types of material are in common use; plasticised PVC, and PE or PE/EVA. As a result of adverse publicity on the possibility of plasticisers used in the former type migrating into certain fatty foods, newer, low plasticiser, types have been launched recently. Other materials, based on various polyolefin blends, are also available. Cling performance, transparency and stretch resilience of these non-PVC materials have been greatly improved over recent years but they still do not usually match the PVC in all respects.

For stretch wrapping similar properties are required but are often less critical, and grades of polyolefin, especially LLDPE and EVA are widely used. Some are coextruded layers of two materials to enhance blocking and/or to minimise sticking to wrapped items.

In shrink wrapping, where heat is used, similar coextruded materials are available which prevent the film from adhering to plastics coated pallet loads (e.g. polyethylene sacks).

Heavy duty plastic sacks may also be produced in coextruded material, with improved barrier performance, although this is not common. High mechanical strength is a requirement, though, for some arduous distribution systems or for containing very hazardous materials; and two variations of cross lamination technique (multiple layers of materials stretched in one direction each, and cross laminated) have been developed. "Valeron" is a twin layer adhesively combined structure; "Reed XF" consists of four layers combined by a cold blocking process.

3.4.7 Labels

Label stock can also be considered a form of flexible packaging - especially when this is based on a plastics material. In brief, current developments include greater use of self-adhesive types, and their increasing sophistication. Multiple layers, over-laminated, embossed textured effects, all now widen the scope of the traditional label. Two major innovations in the self-adhesive area are based on eliminating the traditional released coated backing web. "Monoweb" from J. Waddington in the U.K. is similar to printed tape and the special shapes of the labels are cut from this in line on the application machine at the users' premises. "Solo" is a form of stack fed self-adhesive labels using modified traditional applicators and magazines. Both have involved developments in the release coating materials themselves and in their application. Related to this is an electron beam cured process which makes it possible to coat silicone release material onto very thin and inexpensive plastics webs (the reduced heating effect gives less stretch and distortion, making cheaper substrates technically possible).

The use of plastics labels has also widened including "invisible" ones of printed clear PET and of a pearlised OPP. One benefit from the latter material is its ability to stretch when used in a full wraparound style label on a large PET bottle for carbonated soft drinks. These bottles under pressure have a slight tendency to creep and bulge, and this can snap a sealed paper label.

In-mould labelling techniques can be used. These rely on the heat of the molten plastics to adhere a heat sensitive layer on the label at the time the container is produced. They provide two different types of benefit. One (already mentioned at 3.4.3) is when they are used in thermoforming to provide a wall-stiffening function. The second is in conjunction with injection moulding, extrusion blow or injection-blow-stretch moulding of plastics containers. No loose edges or wrinkles with paper labels occur, and this was originally seen as the main benefit. But more recently the concept has been extended to plastics labels. If these are of the same polymer (or a compatible variant) then in-plant scrap containers may be recycled directly. This also facilitates ultimate recovery and recycle in the post consumer waste stream (see section 5 below).

The most significant single change in labelling has been the wider introduction of the shrink-sleeve technique developed in Japan in the 1970's. Printed transparent film is adhesive- or heat-sealed into sleeves (print surface on the inside) and flattened for handling. These are slipped loosely over the necks of containers and heat applied which causes them to shrink and grip tightly, conforming to the pack shape (within certain limits). Most of the sleeves are made from UPVC, but recent advances have made polypropylene suitable as a material, and this can be expected to grow.

Shrink labelling offers other benefits in addition to simply providing the label. They include:

A security function, since the label can readily be positioned to cover the closure (with perforations or tear strips as required to facilitate opening).

Coloured base films give the impression of coloured glass containers when used with standard white flint glass.

When all-over applied to bottles for carbonated soft drinks, the label can reduce the spread of flying fragments in the event of a filled bottle being dropped and broken.

Multiple items may be combined together to provide promotional multi-pack offers, sets of associated products, or for attaching samples or gifts.

3.5 Timber based materials

Wood, one of the most traditional materials for heavy duty packaging, retains its role for large machinery and certain other very demanding applications. Most of the developments of recent years have been into ways of using forest products with greater efficiency. In packaging this means exploiting better the inherent strength properties and at the same time making the most efficient use of the material. Plywood and large particle board panels achieve the former; and hardboard is a good example of the latter.

All sheet materials based on wood have very high rigidity and puncture resistance, and offer very versatile fabrication options. Some of the softer grades also provide cushioning properties which may be exploited. All are more expensive than the heavy duty grades of corrugated and solid boards now available, and so their use must be justified by either extremely demanding conditions or on their potential after-use (which they offer to a greater extent than any other packaging material).

3.6 Ancillary materials or packaging components

3.6.1. Closures

Many of the traditional metal closures are now being replaced by plastics. This is especially true in the carbonated soft drinks area, now that some of the earlier problems of thread creep and "missiling" have been resolved. Interest currently centres on tamper resistance or tamper-evidence as a requirement for closures - the latter is a much more realistic expectation than the former. Where determined criminal tampering is intended, the necessary levels of expertise and resources can be employed to overcome most available systems. Child resistant closures are another important sub-section and almost all of these are made in plastics due to the intricacy of moulding which is possible with these materials. To achieve tamper evidence, techniques such as oxygen removal and the insertion of oxygen sensitive coloured indicators is one method being promoted. Destructible multilayer labels with very strong adhesives are another, complex designs such as holograms are also used on closures and/or labels associated with them, others make use of pressure differential to provide diffraction effects from grating patterns printed on surfaces which are stressed due to positive or negative pressure.

3.6.2 **Adhesives** These can be the most vital ingredient in all forms of packaging, from high speed food lines to heavy duty corrugated cases; an importance which is frequently under-rated. While the traditional animal and starch based types are still in general use (and the latter has undergone major developments), it is in the synthetics area where there has been the greatest amount of technical development. Water based emulsion types, especially those based on polyvinylacetate (PVA) offer greatly improved performance, although details of formulation and adhesion mechanisms are rarely publicised.

Hotmelt and cold seal (already mentioned) have in common their instant adhesion performance. Both have been developed to meet the needs of the very high speed machinery now in use - line speeds of up to 1,000 per minute are possible. These are also far less dependent upon the properties of the substrates than are the aqueous based types - also enhancing their "tolerance" level on sealing lines.

In the self adhesives tape and labels area, the most recent developments are in water based systems - especially those based on acrylic emulsions. Their most important benefits are to the converter who is able to meet the increasingly stringent emission regulations and who can instal plant for greatly reduced capital outlay. This can result in lower production costs which may be passed on to the end user.

3.6.3 **Tapes and Strapping:** The major developments in sealing tapes concern the range of self adhesive materials now available (mentioned above). The effect of this is likely to be to increase the use of self adhesive tapes at the expense of the traditional water-activated paper types. In strapping tapes - made from steel, polyester, polypropylene, polyamide and rayon - the situation is similar. They have been replaced for many applications by shrink and (especially) stretch films for palletised collations. They remain, however, important for specific situations such as newspapers, bundles of tubular items. For very heavy duty situations only steel can provide the "ultimate" in high strength.

4. SPECIFICATIONS, STANDARDS & LEGISLATION

4.1 **Specifications:** allow properties of a pack or a material which affect its performance, to be described in terms which can be measured. The two main types are, material properties and performance based. The first is the more often used - largely because such properties are easily checked - but it is the latter which is much more important. Some material properties reflect only its basic nature, others do relate closely to its performance.

In writing performance or any other specific quantitative requirements into purchasing specifications, both supplier and buyer should use standard and easily understood terminology. Standardised units, by reference to agreed standard laboratory test methods, are also essential, and a tolerance level for every value should also be set. This should take into account commercial manufacturing limitations and the discrimination which is possible with the defined test methods. Test conditions must also be quoted, especially for paper-based materials. Excessively tight tolerances can only add to the costs since a high level of inspection and rejection rate may result.

Sampling and testing procedures carried out on receipt at the user's premises are often called "quality control" - this is wrong, because at this stage no influence can be brought on the manufacturing process - the only scope is to record any shortcomings observed. True quality control, carried out at the manufacturer's premises on the production line, may be duplicated by materials testing or quality assurance procedures carried out at the user's premises, but these latter do take into account any deterioration or changes which have occurred since the time of manufacture and despatch.

The supplier should be asked to agree that information on the manufacturing test results is made available, together with specimens of samples and/or test pieces to his customer. This minimises the costs to the user. A procedure should be agreed whereby, in the event of any dispute, there is both the mechanism and the necessary samples which can be subsequently checked by either the purchaser or an independent assessor.

Non-standard materials, shapes or styles are always more expensive than those made in large quantities for wide ranges or standard applications. It is possible, for instance, for a lightweight paper to cost more than one of heavier weight, if the latter is a "standard" material. Purchasers should always check initially on what standard materials are available before setting their own specifications.

Proliferation of pack sizes and styles often grows up in large companies over a long period of time. Benefits of reducing these can include larger ordering quantities and reductions in stock holding and storage requirements.

Large scale purchasing usually results in lower prices, particularly at the lower end of the scale. Against this there can often be operational disadvantages, including tied up capital, risk of damage and deterioration during storage, inflexibility when design changes are contemplated and larger storage requirements. The aim should be to balance all of these.

Quality assurance schemes are becoming increasingly widely used, and the International Standards Organisation has set out a unified procedure for checking that good standards are applied in this respect. ISO 9000 is awarded to manufacturers meeting certain laid down standards of manufacturing quality, inspection and control procedures. The possession by packaging supply companies of this or a national equivalent (in the U.K. it is BS 5750) provides a level of confidence to their customers.

Once specifications have been agreed it is equally important to monitor the performance of the material or packs supplied. This is best done on the production line itself and in the market (since these represent the ultimate quality tests).

By checking on physical, machine running, and protection performance under actual conditions, specifications may be refined and costs reduced. Establishing the difference between "critical" parameters and others is the most important single aspect of this exercise.

4.2 **Standards** are documents issued by national and governmental organisations and other bodies to describe procedures, performance and test methods. They are very important in the context of specifications and quality inspection or assurance. The two main functions are to establish minimum performance or safety criteria (e.g. pressure resistance of aerosol cans) and to define the test methods which should be used to measure such properties.

4.3 **Legislation** The extent and nature of legal constraints applicable to packaging varies widely from country to country. In most situations laws which do impinge upon packaging come within one of the following areas:

* Health and hygiene of food packaging
* Packaging for the transport of dangerous goods by road, rail, sea and air
* Health and safety at the work place for manufacturers of packaging materials or their subsequent use
* Protection of the consumers e.g. tamper evidence and child resistance
* Weights and measures, legal requirements
* Product information and other labelling laws

* Environmental aspects
* Patent and design protection.

The first of those listed has the widest application, but few countries have anything as comprehensive as the FDA approval scheme operated in the U.S.A. and the similar BGA system in the Federal Republic of Germany. Within the EEC there is some legislation on specific items (e.g. vinylchloride monomer in PVC) and other more generally applicable (e.g. Materials and articles in contact with food Directive). Where no laws exist, organisations and companies often attempt to comply with the U.S. FDA procedure, regarding this as a "best defence" in the event of any problems arising.

In view of the variable situation in respect of each of these aspects of packaging, the best advice is to point out that attention must be given to them in the design, specification, purchasing and use of all packaging materials.

5. ENVIRONMENTAL CONCERN

In recent years a number of individual aspects of packaging have attracted attention under the umbrella title of "Environmental Impact". They include matters of health and safety, honesty of trade practices, consumer convenience, and social behaviour in addition to those identifiably related to the environment and mans' ecological relationship with it. The scope is too numerous to detail here, but under the classifications given above the following may be mentioned:

Health & Safety

* Dioxins in bleached paper board, and in emissions from waste-burning incinerators
* Migration of plasticisers, pigments or other additives from plastics into foods
* Lead from soldered seam cans

* Danger of pressurised glass bottles used for carbonated soft drinks exploding if dropped

Trade Practices

* Deceptively large packs
* Imitations of well known products (brand piracy)
* Adulteration of contents
* Limitation of choice (e.g. by imposition of multiple packs as the only unit of sale)

Social Behaviour

* Litter - in which used packaging features prominently <u>but is not in itself the cause</u>
* Product tampering

Consumer Convenience

* Openability of packs and their availability in a convenient size range

Environmental

* Use of CFCs (chlorofluorocarbons) in aerosols and for the manufacture of plastics foam
* Use of natural resources and recycling/recovery
* Disposal of household waste (including packaging)
* "Excessive" packaging

These cover most, but certainly not all, areas of concern, and in strict terms only the last should properly be regarded as an environmental matter.

The subject is highly emotive and there are few "facts" on which all observers agree. "Environmental concern" has been used as a pretext for trade barriers on the one hand, and exploited shamelessly to sell products on the other. This is not, of course, to imply that all people expressing concern over packaging and the environment come into either of these categories; the majority of independent organisations are motivated by true concern for the environment - something in which they do not have a monopoly though.

Most of the health risks described are extremely small and almost always exaggerated on the basis of highly sensitive analytical methods which now permit detection of materials such as dioxins in quantities as low as parts per trillion. They are also almost never put into the context of the alternative of less or inferior or, indeed, no packaging, when food safety standards would fall with very serious consequences for health and safety of consumers. In any discussion of this subject, impartial and objective advice should always be sought.

Simplistic "solutions" should be scrutinised carefully before being adopted. Examples of this include:

Banning or taxing one-way beverage containers. This can result in a reduction of choice and increased costs to the consumer as well as (possibly) greater environmental pollution from the container manufacturing and cleaning processes.

Degradable plastics are proposed as one way of dealing with litter. This is treating a symptom not the cause, and could in fact lead to higher levels of littering as well as significant economic penalties for the package manufacturers, and inhibiting the prospects for recycling.

Where scientists do agree on a real (or high probability of a) problem, as has been the case with CFCs, action can be taken quite quickly. Even so, the commercial pressures of individual countries often pose problems in getting universal action accepted - and even more on its implementation.

On the inter-related questions of resource conservation and waste disposal, if an economic case can be made for recovering used packaging materials then this is technically possible for all materials which are currently used. Economics depend upon the cost of collection, the technical difficulty in sorting and cleaning, and the market which can be developed for the recycled products - in which they must compete freely with alternatives.

6. SPECIAL PROBLEMS FOR DEVELOPING COUNTRIES

In a number of ways, packaging problems in developing countries are both more vital than in industrial nations and at the same time compounded by local conditions. Distributing safe and nutritious foods requires good quality packaging. This is one area in which development in industrialised countries can help - liquid-tight cartons are an example of a self-contained technology able to be operated anywhere in the world. The materials required, though, must have highly consistent performance and are usually produced in countries having the required standard of paper making and coating/laminating technology.

Protecting perishable products shipped for sale overseas calls for the appropriate performance standards, and for a good standard of "perceived quality" to promote sales. Farmers and packers are frequently unable to obtain the kind of packaging quality needed from local sources and often governmental restrictions prevent its import. Where packaging standards are laid down, inspection and enforcement is often patchy and always difficult.

The same problem of "perceived quality" acts against the exports of many manufactured products. In addition to the actual damage rate incurred during transit, the appearance of packaging itself frequently conveys an impression of low quality merchandise.

This is an area where government funded export boards have a major role to play - in conjunction with market development organisations and local packaging groups. Advice is available from specially qualified bodies such as the ITC in Geneva, and local packaging research institutes.

Indigenous resources of material suitable for packaging should be used where they do not detract from the quality. If these materials are suitable for simple traditional packaging forms - e.g. grass baskets or wooden crates - they should be used mainly to promote an "association with tradition" and their manufacture treated as an integral part of the export drive. It is also very feasible to combine ancient and modern, for example plastic bubble film protecting fruit inside traditional baskets.

In other instances where natural materials are converted into other forms (such as paper) this should be used as a basis for developing a modern packaging supply industry, and the product range increased to include such materials as laminated board and high performance corrugated material from which precision die cut cases can be made.

7. ECONOMICS

Packaging is always part of a larger commercial activity, and for many product manufacturers it is seen merely as an on-cost. A famous figure (Ruben Rausing - responsible for the development of the Tetra Pak system) often said "A pack should always save more than it costs". The problem is that the direct cost is easily seen but the indirect savings which it may make possible (reduced insurance, damage rates, improved margins, better reputation, lower shipping costs etc. etc.) often occur at a position removed from the point at which the packaging is purchased.

For the manufacturers of packaging also, better performance from their products improves the economic viability of their customers and so the cycle is maintained. Packaging is not only about money, but this is the only completely standard unit in which cost performance can be analysed and compared.

8.. FUTURE TRENDS IN PACKAGING

Making prophecies is at best uncertain and at worst dangerous, but the following is a "best guess" in the light of present trends, taking into account some of the emerging influences.

Metal Packaging: A major move to reduce the amount of "mixed" metal packs is likely, based on aluminium, tinplate, and tin-free steel. In the longer term one or other of these will emerge as the dominant metal; the outcome dictated by cost and recycling developments. Lighter-weight cans for processed foods, using liquid gas internal pressurising methods will grow. Aerosol use will decline as alternative methods of dispensing products are adopted. There are many of these already available, ranging from finger pump dispensers to chemical gas generating and mechanical (spring or elastic sleeve) pressure dispensing systems. These are necessarily expensive and can be expected to find applications only for certain speciality uses.

Glass: No major breakthrough is expected and the material will consolidate its position in the high quality sectors for wines, spirits and toiletries. The parallel application as a very basic reusable container for liquid foods and drinks depends also very much upon the level of encouragement or preferential taxation it receives on "environmental" grounds. Protective sleeves are likely to become the norm for all carbonated liquids.

Paper Based: Its versatility, renewable source, and scope for being recycled will ensure a strong future for paper in all its forms, especially where it is used in combination with plastics components. Liquid-tight retail packs will grow, and their use for processed and other foods will expand significantly.

The corrugated case sector will remain at the present level in total while continuing to lose quantity to shrink or stretch wrapping and to the greater use of bulk units. Gains will come from continued replacement of wooden cases and crates and from higher volumes of smaller cases and trays for presentation packs e.g. for fresh produce, meat and fish. Paper sacks will decline, also due to greater use of bulk transport and substitution by plastics varieties.

Traditional cartons are to some extent "at risk" as they may be seen as non-essential for many food pack applications. Their growth will be a function of general prosperity - tempered by the environmental issue.

Plastics: The fastest changing sector and the only one which offers direct competition for virtually every other material. The greatest growth is likely to come from the flexible part especially for foods, as improvements in barrier, mechanical strength and heat seal quality continue to appear. These are seen as "effective use of resources" and with the exception of the occasional demand for degradability - are not felt to be at major risk on environmental grounds.

Rigid plastics bottles and containers face a mixed future. Optimum cost performance is achieved by combinations of materials but this inhibits direct recycling; lightweight flexible sachets offer economic savings; and bag-in-box offers a semi-bulk alternative.

Wide-mouth clear plastics jars, especially in PET, are likely to replace some metal, glass and composite forms for food. They are technically suitable for a minor part of the food range but polymer and processing developments can be expected to broaden this quite quickly to include hot-filled, pasteurised and oxygen sensitive foods. Polypropylene is likely to show the most sustained growth in the whole range of applications; PVC will undoubtedly suffer from the question marks over its chlorine content - with some substitution by PET although at higher cost. PET offers a very high potential indeed for food packaging - a major factor influencing this is likely to be the development of recycling programmes.

The "environmental" factor is the greatest unknown for plastics, which are singled out for disproportionate concern - largely, it would seem, on the grounds of their bright appearance and durability. It may be possible to overcome this "hostility" by helping to promote recycling operations within the industry where these are technically and economically feasible. Alternatively the use of waste plastics packaging can be exploited as a secondary fuel source in power generation. This is effectively recovering most of the energy content of the original petrochemical feedstock. With current incinerator designs there remain technical and environmental questions to the greater use of this material. Both are capable of solution but at a price which can make the operation not economically viable at present.