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INTRODUCTION

THE PRIMARY FUNCTIONS of a package are containment, protection, information and utility-of-use (convenience). All these functions are provided at a cost of about 7% of the price that consumers pay for any given product [1].

Containment simply means that the package provides a means of carrying or holding a product. Most products in a modern society require some type of containment, or they would be of little use. It is difficult to imagine cereal without a box, milk without a jug, or flour without a bag. It is even more difficult to imagine carrying these products home and storing them on the shelf, refrigerator or freezer without some form of package. So, containment is the first function of packaging.

Protection and preservation, taken together, constitute the next function. Protection and preservation, exemplified by the canning process, furnishes high quality, uncontaminated foods on a year-round basis. Canning has been supplemented by high quality frozen foods and, more recently, by other innovative packaging and preservation technologies. These include aseptic packaging, to provide shelf-stable milk and juices, and controlled and modified atmosphere packaging

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that permits fresh entrees, pastas, cooked meats and similar foods to remain fresh in the cooler for weeks.

Protection extends beyond protecting the packaged product from the hazards of the environment and the distribution system. Sanitation, to ensure the purity of packaged foods, is the norm in modern food systems. Food is packaged in government-approved processing plants and is protected from contamination from insects, rodents or humans until it is ready for use in the home. In another area of product protection, tamper resistant and tamper evident packaging (common in drug packaging) is now becoming commonplace in food packaging to help assure consumers that the foods they select are free from tampering.

Information lets the consumer know what is in the package. The can without a label is a clear example of a package without information. Modern food packages convey far more information than simply telling the consumer what is inside. Through pictures or transparent packages, the consumer is informed about the appearance of the packaged product. Through printed information the consumer is informed about the ingredients and, often, the nutritional value of a packaged food. Through print, color and shape a package conveys images of brand and quality to the consumer.

Utility-of-use (convenience) is the fourth packaging function. Packages make it easy to use the product. A recent popular innovation in food packaging is the squeeze bottle for ketchup which, in many ways is more convenient (has greater utility) than the glass bottle it replaced. It is resistant to breakage and is lighter and easier to carry. It is also squeezable, eliminating the struggle to initially get the ketchup to flow from the bottle (and to get it to stop). The choice of package sizes, ranging from "large economy" to individual portion, is an example of utility-of-use to satisfy needs of the individual, the large family or the institutional customer. Microwave packaging and cook-in, eat-in packages are other examples of how packaging makes products easier to use.

Industrial/Institutional Packaging and Retail Packaging

Packages can be categorized into those that consumers see and use (retail packages) and those that the consumer generally does not see or use (industrial/institutional).

Improvements in industrial/institutional packages in recent years have increased efficiency and lowered costs in many service industries. Perhaps the best example is the delivery of health and medical services. Sterile supplies and medicines, prepackaged in needed amounts, have simplified and reduced the risk during many hospital and medical office procedures.

For example, surgical kits holding all the equipment and materials needed for a particular surgical procedure in a protected sterile condition are used in hospital operating rooms. Prepackaged sterile laboratory equipment is used in hospital and research laboratories to simplify and speed up laboratory analyses and to assure quality control. Flexible bags for blood and intravenous solutions provide for sterility and easier storage, and greatly reduce the risk of breakage in emergency situations. Liquid unit doses (LUD) of medicines are routinely used in hospitals and other medical care facilities to ensure proper dosages and minimize the possibility of error.

Just as these examples typify medical packaging, similar examples could be given of packaging's key role in numerous other industrial and institutional applications, such as bag-in-box pouches for milk dispensing in restaurants and for bulk shipment of fruits. However, since this paper is intended to review packaging benefits and discuss current issues of direct interest to the consumer, it will focus primarily on retail packaging.

FOOD PROTECTION AND PRESERVATION

Nowhere is the role of retail packaging more visible to the consumer than in the delivery of food in a safe and wholesome condition. Food and beverage account for the greatest proportion—approximately two-thirds—of the $70 billion packaging industry in the U.S. [2]. Also, food packaging more closely touches our lives than other branches of packaging. New technologies and trends often appear first in the food sector and then find their way into other packaging branches.

In a modern U.S. supermarket, where most of our food for home consumption is purchased, all but the fresh produce is generally packaged, either by the manufacturer, distributor or retail outlet. And the purchases are again packaged in paper or plastic bags for the trip home.

Food is our most perishable commodity, subject not only to spoilage from the moment of harvest, slaughter or manufacture, but also vulnerable to attack from a vast array of living things ranging from microbes to vermin and rodents. Packaging has helped limit food spoilage in the U.S. to less than 3% for processed food and 10–15% for fresh food [3]. In lesser developed countries, food spoilage frequently reaches 50% due to inadequate or nonexistent packaging, storage and transport systems [3].

The food preservation practices of drying and salting used in antiquity were the main methods of food preservation available until the past century. In the early 1800s in response to a challenge by Napoleon, who desired a higher quality diet for his far-flung armies, the process of canning was developed. The approach is the same as that used in today's canned goods.

Even well into this century people in many regions of the U.S. usually ate fresh foods only when they were in season, and dried or salted much food before storing for use at other times of the year. Losses due to spoilage and vermin were high. Preservation processes were somewhat haphazard, and consumption of "high" or partially spoiled meats and other foods was common in even the best of circles.

The development of a whole host of new materials and packaging forms in the latter part of the 1800s and the first decades of this century opened the door to today's modern packaging systems. After World War II, the pace accelerated with the rise of the modern supermarket (with the parallel need for each package to "sell itself" to the consumer) and widespread use of freezing as an alternative preservation method to canning. The growth of television in this period led to one of the most famous of modern food packages—the TV dinner tray.

In parallel, food distribution channels changed dramatically as the country moved from a rural to an urban society. Distribution distances for food products changed from a few miles (e.g., New Jersey to New York) to thousands of miles (e.g., California to the East Coast and overseas).

The 1960s and '70s saw an acceleration of the trend to single-person and two-income families, leading to a demand for convenience foods, carry-outs and smaller individual portions. The 1980s were marked by a continued trend to convenience, coupled with a concern for health that resulted in a demand for natural foods, and fresh and freshly prepared foods. These trends were accelerated and complemented by advances in food preparation technologies, especially the microwave oven. Microwave technology alone has been responsible for whole new families of packages that are microwave compatible or microwave enhancing.

Today's consumer can choose from a vast array of food products in serving sizes compatible with their needs. Fresh, frozen, canned, condensed and dried foods are readily available. All of this is made possible through the combination of modern food processing and food packaging technologies.

Packaging is an essential component of the distribution system in the United States. Without protective packaging, the distribution system in the United States would cease to exist. One entire area of packaging development is devoted to developing and testing packages to ensure that they can withstand the rigors of the distribution system and protect goods on their way to the final consumer.

For many products, package/product combinations have been developed that resulted in revolutionary changes in the way goods are distributed. Examples of such combinations follow.

Vacuum-Packed Beef

Today's consumers take for granted that the local supermarket will have whatever cut of beef they wish to buy. This is true even though consumers, as a whole, do not want to buy cuts of beef in the proportions that nature provides. Consumer preferences also vary weekly in response to weather, holidays and other factors.

Vacuum packaging of subprimal cuts of beef (e.g., whole tenderloins) in barrier films at the slaughterhouse is an important aspect of the distribution system responsive to the consumer. Vacuum packaging prolongs the quality life of the meat by preventing oxidation. If the supermarket finds its display case depleted of a certain cut of meat, extra cuts can be obtained readily from an inventory of vacuum-packed subprimal cuts. The waste normally resulting from larger inventories is avoided because vacuum packaging allows longer storage while retaining quality. In fact, vacuum packaging in barrier films allows the beef to improve by aging without losses due to dehydration and oxidation.

Chicken in Modified Atmosphere Packages

The age-old problem of who gets the white meat and who gets the dark meat when a family gathers for a chicken dinner has been eliminated by changes in poultry distribution and packaging. Supermarkets now offer packages of chicken legs, packages of chicken breasts, and other choices ranging up to the traditional whole chicken.

The inventory problems associated with selling chicken parts have been lessened by the use of packaging methods which extend the shelf-life of poultry. The packaging methods involve the use of barrier films and special atmospheres to surround the chicken in place of air. The combination of packaging and atmosphere preserves the quality of the chicken at a high level for a longer time.

Using this new modified atmosphere packaging, poultry suppliers also now offer cooked chicken parts which taste as good as fresh chicken when reheated at home.

LIFESTYLE PRIOR TO PACKAGING

As recently as 1920, more than 30% of Americans lived on family farms [4]. To a great extent, each family farm raised the variety of foods needed to survive. These foods included grains for bread, meats, dairy products, fruits and vegetables. Each family would preserve fruits and vegetables by home canning and storing. Other products had to be consumed in the limited time before they would spoil or could be processed into more durable foods. Meats would be salted, dried or smoked. Cream would be churned into butter and stored in a cool place.

The quality of foods consumed on the family farm ranged from excellent to barely edible. Even today, the quality of a freshly killed chicken or a just-picked tomato is unbeatable. However, in a winter following a poor harvest, diets would be reduced to staples or less.

People in cities and towns relied on locally grown fresh fruits and vegetables produced within a short distance of town. Animals were slaughtered locally to provide fresh meat. (During the Civil War, soldiers stationed in Washington converted the open spaces around the Washington Monument into an abattoir where sheep and cattle were slaughtered to provide fresh meat for the army.) Like their country cousins, city folk canned foods, used root cellars, and salted, dried and smoked meats. Many city dwellers, and most in small towns, kept gardens, chickens and smaller meat animals such as pigs.

The local weekly marketplace was the major form of distribution in the U.S.—into this century for rural areas, and it is still the key part of the distribution system in many developing countries. Families living within walking distance of a small town gather one day each week at the town marketplace. Each family brings surplus goods it has produced to exchange for needed articles that are surplus to another family.

In the marketplace system, producers transfer their products directly to consumers. Very little packaging is required. One farmer may bring live chickens to market in small cages. The consumer may also take live chickens home in cages, or dead chickens slung over a shoulder. Consumers will often bring cloth sacks or baskets to the market and fill them with their purchases or trades.

Obviously, the marketplace system of distribution has a great many deficiencies. It is worth reflecting on these in order to appreciate the advantages of a modern distribution system. Some of the obvious deficiencies include:

1. Limited storage life—perishable meats, fruits and vegetables must be consumed within their natural quality time limits.

2. Limited availability—only goods produced in a local region are available and only in the season of their harvest.
3. Quality limitations—if the region produces good potatoes, the potatoes are good; if not, the potatoes are bad.
4. Sanitation—few precautions are taken to protect foods from contamination by flies and human handling.

The disposal of food wastes and other wastes in cities was often grossly inadequate. Streets and alleys often were filled with garbage; rain would turn them into sewers. Rats, flies and other vermin feasted on the wastes and proliferated to spread disease. Municipal sanitation departments were established to minimize the problems. The departments were not misnamed since sanitation was and is their primary function [5].

THE MODERN DISTRIBUTION SYSTEM

In complete contrast to local production and consumption of goods, the modern distribution system produces finished goods in a limited number of locations and ships them regionally, nationally and internationally. Often the manufacturer does not ship directly to retail outlets, but instead utilizes distributors or warehouses as a means of inventorying goods and shipping them to retail outlets.

One effect of packaging in modern distribution systems has been its direct linking of the producer and consumer. Producers retain responsibility for their products by putting brand names on the package. Consumers quickly learn to rely on particular brands for the quality they want. The intermediaries between the producer and the consumer, the wholesalers and retailers, do not determine the quality of the product if the packaging is suitable.

Products which are packaged, but unbranded, are taking up a smaller and smaller portion of supermarket shelf space. Fresh poultry is now almost universally branded. Branded fresh fruits and vegetables are becoming the norm. Other products such as fresh red meats and fish are now also appearing as packaged, branded products.

Today, less than 3% of Americans live and work on farms [4]. The fact that these few Americans feed more than 240 million Americans and millions more overseas is the result of the successful development of agricultural technology *and* the development of the distribution systems and packaging necessary to avoid spoilage and waste.

In the majority of families with both spouses working, each is employed for 35 or more hours per week [4]. Although appliances help with housework and maintenance, cooking and marketing chores still require considerable time. With this pattern of living, conveniently packaged foods are essentials, not luxuries. Further, they are cost effective. A study at the University of Maryland [6] showed that convenience packaged foods are slightly less expensive than prepared-from-scratch fresh foods, *without accounting for the savings in food preparation time!*

But packaging saves on more than meal preparation time. Packaging allows replacing the daily shopping trip with one weekly shopping trip. In a one- or two-hour period on a convenient evening or weekend, a family can stock up on all the food needed for the week ahead. The consumer selects the quality and quantity of food needed simply by taking packages from the shelf, cooler or freezer. Each package tells the consumer about its contents without the need to speak to a salesperson.

Many hours are saved in shopping for packaged goods. And, while food packaging can give excellent illustrations of this point, with other packaged goods ranging from razor blades to light bulbs the consumer can quickly select a purchase based on the information on the package. The hours saved can be converted to a dollar amount, which, when compared to the cost of packaging, is a great bargain.

In addition to the hours of work eliminated, a second great advantage of using packaging is the scheduling flexibility allowed. Microwaveable meals present a wide selection of foods that are immediately available. The microwave oven can be operated and the meal prepared by a child old enough to read the instructions on the package or by any person to whom a conventional gas or electric range might present a hazard. Conveniently packaged microwaveable food products support the lifestyles of families of the types that are increasing their proportionate share of the U.S. population: older, smaller families, single parent households, and singles.

PACKAGING AND THE ENVIRONMENT

With few exceptions, the environmental issues faced by the packaging industry relate to the problem of solid waste generation and disposal. Although the environment is certainly not the only issue that will be challenging the industry during the 1990s, environmental issues represent a common thread of concern that uniquely challenges the packaging industry. In fact, many in the packaging industry believe that the environment will present *the* industry challenge during the 1990s. For this reason, we will highlight the main environmental issues that the industry is now facing and will face for the foreseeable future.

Municipal Solid Waste

The term "municipal solid waste" (MSW) is somewhat misleading. The term actually refers to refuse that is routinely collected from households, commercial institutions, offices and light industry by municipal or private haulers, or refuse from these sources hauled to dumpsters or disposal sites by individuals.

The amount of MSW generated in the U.S. is also subject to some confusion. Generally accepted numbers have been developed for the U.S. Environmental Protection Agency and these figures are shown in Table 1 [7]. The significant numbers are generation, discards after materials recovery, and discards after materials recovery and combustion. The generation figures include all waste materials generated by individual households and commercial establishments. See Table 1 for a summary of these data for the years 1960–1988 and 1995 (projected).

The data from the U.S. Environmental Protection Agency (EPA) [7] indicate that containers and packaging make up the largest single category of MSW on an as-generated basis. This category comprised 31.6% of the total (on a weight basis) in 1988. The percentages of products discarded into the waste stream on a weight basis are given in Figure 1.

An area of contention is the "weight vs. volume" argument, where it is implied that if volume were measured, packaging would make up a far greater proportion of MSW. While it is true that some packaging materials such as plastics are very light, others such as glass or steel are heavy. The EPA has estimated the makeup of MSW on a volume basis [7]. These estimates conclude that packaging represents about 29.6% of the volume of MSW discarded in 1988.

The data on MSW generation in the U.S. do not support the banner headlines of "Garbage Glut" and "Solid Waste Crisis". In fact, with projected increases in materials and energy recovery, the discards to landfill or other disposal are expected to decline [7]. Of even more significance, the percentage of containers and packaging in MSW has been declining since the 1970s [7].

The Role of Food Packaging in Waste Reduction

The best quality peas available to consumers are those grown in their own gardens. Unfortunately, not everyone has time or space for a gar-

Table 1. Generation, materials *recovery, composting, combustion, and discards of municipal solid waste [7].*

	Millions of Tons							
	1960	1965	1970	1975	1980	1985	1988	1995
Generation	87.8	103.4	121.9	128.1	149.6	161.6	179.6	199.8
Recovery for Recycling	5.9	6.8	8.6	9.9	14.5	16.4	23.1	38.8
Recovery for Composting	0.0	0.0	0.0	0.0	0.0	0.0	0.5	9.5
Total Materials Recovery	5.9	6.8	8.6	9.9	14.5	16.4	23.5	48.3
*Discards after Recovery**	81.9	96.6	113.3	118.2	135.1	145.2	156.0	151.5
Combustion with Energy Recovery	0.0	0.2	0.4	0.7	2.7	7.6	24.5	45.0
Combustion without Energy Recovery	27.0	26.8	24.7	17.8	11.0	4.1	1.0	0.5
Total Combustion	27.0	27.0	25.1	18.5	13.7	11.7	25.5	45.5
*Discards to Landfill, Other Disposal***	54.9	69.6	88.2	99.7	121.4	133.5	130.5	106.0

*Does not include residues from recycling/composting processes.
**Does not include residues from recycling/composting, or combustion processes.
Detailed may not add to totals due to rounding.

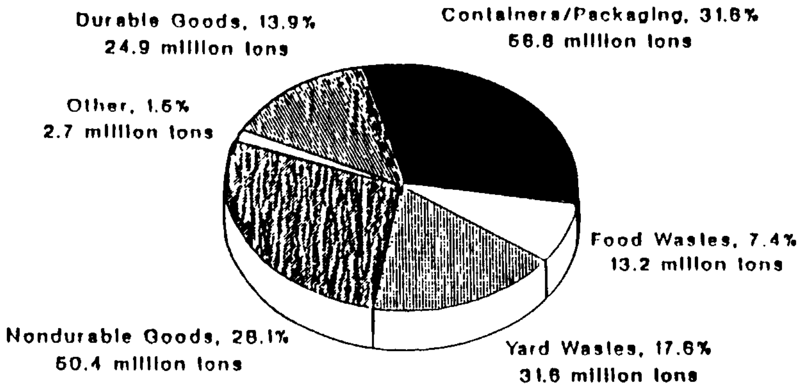

Figure 1. Products generated in MSW by weight, 1988 [7].

den, and even gardens (in the Northern Hemisphere) cannot provide peas in January.

Arguably, the best quality peas, second to garden-grown, are frozen peas available year-round in the supermarket. Frozen peas are economically packaged in plastic bags or paperboard cartons. A typical bag for one pound of peas weighs about one ounce. It is worth comparing the amount of waste material one is left with for peas grown in the garden and frozen peas purchased in the supermarket.

Garden-grown peas come with pods and assorted stems which are comparable in weight and volume to the peas themselves. In fact, only 38% by weight of the pea in the pod is edible matter. The home gardener, at best, may use the waste for compost; at worst, it is added to MSW and is landfilled. The same "waste" parts from the food processing plant are usually converted into by-products, such as animal feed, and are not wasted at all. Table 2 lists nine common vegetables, their annual production and the percentage of production that is inedible [8].

The vegetables in Table 2 are available to the consumer both as fresh and as packaged foods. Typically, 47% of purchases are in fresh form, 20% are canned and 33% are frozen. If all of the annual production was listed in the fresh form, these nine vegetables would contribute three million tons of MSW per year [9]. In New York City alone, the use of packaging for these vegetables annually eliminates the need to dispose of over 100 thousand tons of MSW [9].

A recent study [10] compared the food wastes generated by households in Mexico City with those typical of U.S. households. Mexico City was chosen because little of the food consumed there is packaged/ processed food. For example, a Mexican family is much more likely to squeeze orange juice from fresh oranges, rather than use reconstituted frozen orange juice. *The study found that the average household in Mexico City discards 40% more refuse each day than the average U.S. household.* Food waste in U.S. household refuse is only about half that in Mexico City refuse.

Chicken provides another good example of the way packaging reduces the amount of MSW that would be otherwise generated. Typically, 1,000 chickens produce about 1,650 pounds of waste feathers, viscera, heads and feet [11]. The use of about 15 pounds of packaging for 1,000 chickens allows the 1,650 pounds of waste to be available for byproduct uses.

Studies have been conducted that show this relationship on a more general statistical basis. For example, as shown in Figure 2 for data worldwide, as paper and paperboard, metal, and glass packaging waste increases in solid waste, food waste declines. Even more dramatic evidence is given in Figure 3 where the correlation shows that, as plastic wastes increase in the U.S., the amount of food waste decreases at an even greater rate [12].

It is sometimes claimed that municipal solid waste can be substantially reduced by consumers if they would buy only large portions and "large economy sizes" of food and other consumer goods. This practice is desirable, and should be encouraged. Changing lifestyles and demographic trends, however, point toward the need for *smaller* portions and individual servings for many consumers. Individually wrapped slices of cheese may appear to be overpackaged. But, for the small family or sin-

Table 2. Vegetable production and wastes [8].

Vegetable	Annual Production (million pounds)	% Inedible Refuse	Total Refuse (million pounds)
Lima Beans	172	60	103
Snap Beans	1775	12	213
Broccoli	376	39	147
Carrots	2309	41	967
Cauliflower	295	61	180
Sweet Corn	5411	64	3463
Green Peas	1145	62	710
Spinach	409	28	115
Brussel Sprouts	662	10	66
Totals	12,554		5944

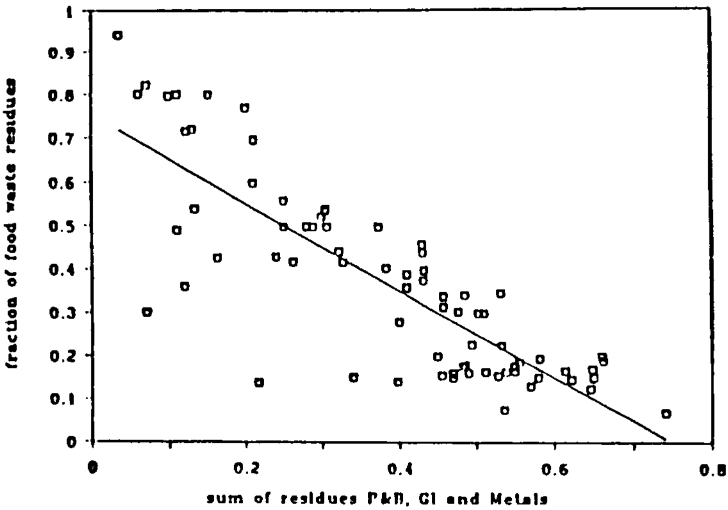

Figure 2. Correlation between the fraction of food waste and sum of fractions of wastes from paper and board, metals and glass. Data from 78 locations, worldwide. Data points and regression line are given [12].

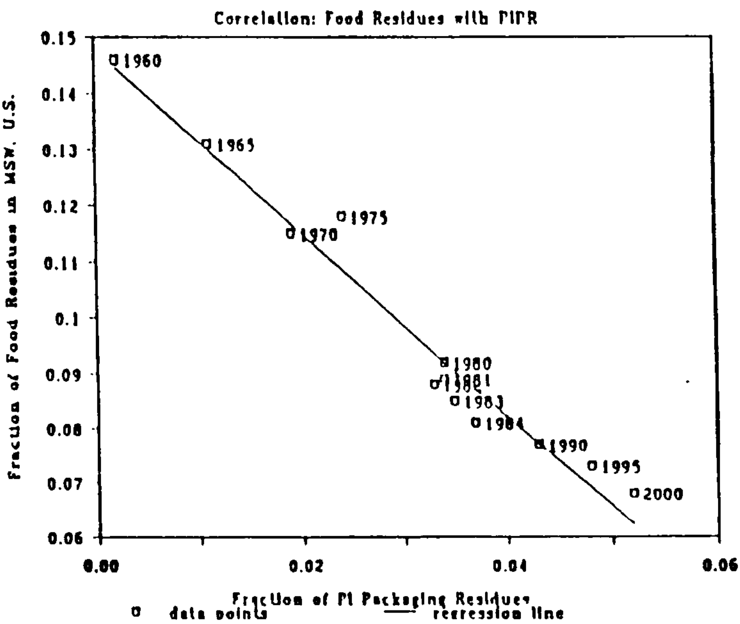

Figure 3. Correlation for fraction of food waste and fraction of plastics packaging wastes. Both data points (year marked) and correlation line are given [12].

gle consumer, this form of packaging can reduce spoilage and staling at home, be cost effective, reduce the waste of an expensive food product, and, not incidentally, reduce the amount of solid waste that would be generated if much of the cheese was discarded due to spoilage.

Overpackaging

One of the current issues (and a charge that the packaging industry has faced from the beginnings of the environmental movement) concerns "overpackaging". This is the perception that packaging is used where none is needed or that extra packaging is used. Often the motive associated with "overpackaging" is consumer deception. The breakfast cereal box is sometimes used as an example of deceptive "overpackaging": the box is only 60–80% full when the consumer opens it. As explained on some cereal boxes, the box was "full" when it was shipped. The cereal has settled in transit. This is not deceptive to the consumer because the contents of cereal boxes are sold by weight, not by volume.

It is important to note that cereal manufacturers would save the expense of extra paperboard and inner liners if they could find a means to better settle cereal in their filling lines. While some in-line settling systems have been developed, methods to eliminate the problem while not crushing the cereal have not yet been found.

Before reaching a conclusion that something is overpackaged, it is important to remember that packaging is multi-functional (see the section on food protection and preservation). The reasons that a product is put into a package often go beyond strictly utilitarian product protection. For example, blister packs for hardware and other products can be cost effective by reducing clerical time in the retail store and limiting shoplifting. A package in this case takes the place of a sales clerk, so its size, shape, color and print must also sell and often explain the proper use and installation of the product. Product suppliers and retailers use the most cost effective package.

Some products that utilize a large amount of packaging (e.g., single service portions of condiments, individually wrapped cheese slices) prevent wasting food and preserve quality for the occasional user. There are also packages that are "oversized" to meet legal requirements for label and print size, for example, for some over-the-counter drugs.

Examples of true overpackaging are rare exceptions in the marketplace. Competitive pressures will always move toward less rather than more packaging for any particular application. The Institute of Packaging Professionals has recently published guidelines [13] to assist packagers in avoiding overpackaging (and also to select other environmentally desirable features among available choices). Efforts such as this, together with greater emphasis on packaging education at the university level, will bring even greater sophistication and environmental awareness to packaging design and purchasing among packaging professionals.

Environmental Protection Agency Hierarchy of Methods to Solve the MSW Problem

In 1989, the Environmental Protection Agency (EPA) issued its recommendations concerning methods to solve the MSW problem. For the packaging portion of MSW, the EPA recommended a hierarchy of solutions, in the following order:

1. Source reduction
2. Recycling
3. Incineration (waste-to-energy)
4. Landfill

The following four sections will explain these solutions. They will describe how packaging suppliers have always used source reduction and have already developed extensive recycling capabilities. They will also describe how the packaging portion of MSW enhances the incineration of MSW and how it has actually diminished the total amount of MSW which would have been landfilled.

Source Reduction

From a packaging perspective, source reduction is the concept of minimal packaging. Historically, source reduction, in many instances, meant not making a package at all (for example, carrying the French bread totally unwrapped or bringing a bag from home to the grocery store). From an environmental perspective, these are examples of ideal packages, "packages that weigh nothing and take up zero space". Real world packages, which meet the functional requirements of a package, will always represent some compromise with the ideal.

Prior to the 1980s virtually no package designer would have made a packaging choice with the sole motivation of lessening the amount of packaging waste. In the traditional packaging choices between cost and consumer convenience, or between package volume and consumer convenience, a decision favoring consumer convenience has generally been the one that would increase or maintain sales. However, as an historical part of doing business, it has always been in the interest of both the product manufacturer and the consumer to avoid the extra costs of excess packaging. The package user (i.e., the producer of goods) is in business to sell a product, not to purchase unneeded packaging.

Historically, manufacturers of packaged products have devised means to lower the costs of their packaging, including very small changes that are imperceptible to the consumer. In the case of nationally marketed packaged goods, a savings of 1/10 of a cent on each package can amount to millions of dollars a year in increased profits. Package users and producers must reduce packaging costs wherever possible for competitive reasons. The major ways to do this are to increase the speed of the packaging fabricating/filling machines and to reduce the materials used.

An example of a series of incremental, almost imperceptible changes in packaging which have occurred over a period of years is the 12-ounce aluminum beverage can. Over the years, the thickness of the aluminum can body has been diminished primarily by the use of new designs that retain strength while reducing metal required. In another innovation, the top of the can has been necked in—first one, then two, three and four times. Each successive necking down of the end reduced the area of the relatively thick end and reduced can weight. Between 1972 and 1989, the average weight per can has been lowered from 0.046 lbs. to 0.034 lbs., a decrease of about 26% [14,15].

A similar progression of incremental changes, lowering the amounts of material, has occurred in the packages that compete with the 12-ounce beverage can. These changes have all occurred because the production and sale of packaging is a highly competitive business. The competition is among suppliers of the same materials and among different materials and designs (e.g., flexible films and semi-rigid materials competing with rigid packages).

In the case of the PET bottle, the weight reduction has been 25% over a period of 14 years [16]. This has been carried out by process changes. In the case of the 16-ounce glass bottle, the weight reduction has been 30% over a period of 10 years [17]. The major part of this change has been accomplished by a basic change in manufacturing technology.

Another type of packaging change to reduce weight and volume is the switch from one kind of package to another of totally different design. A recent example is the switch from the steel coffee can to the aluminum foil composite flexible vacuum pack. The flexible package weighs 90% less than the metal can, it occupies 20% less space on the supermarket shelf, and, most important from an environmental viewpoint, when discarded it takes up far less space.

Recycling

Recognizing the need to address environmental concerns about plastics, an intensive multidisciplinary effort has begun in the United States to develop the technology and infrastructure for recycling plastic packaging materials. Major technological efforts pointed toward recycling have been mounted at universities, by major resin suppliers, and others. Some efforts are in conjunction with large users of certain plastics (such as foamed plastics for fast foods) to develop both the technology and the business systems to recycle plastics.

Plastics, however, enjoy other environmental advantages since they are generally light weight and crushable (thus suited for waste reduction objectives) and, because of their high heating value, make good feed stock for waste-to-energy systems.

Historically, recycling programs depend on the development of a system of collection and buy-back of recyclables from scrap dealers or from recycling centers developed specifically for the material involved. Another type of recycling/collection activity is rapidly developing on the American scene—homeowner separation of recyclables, coupled with curbside pickup.

Curbside separation programs are municipal refuse collection systems in which individual households separate their waste to facilitate recycling. There are two types of separation. In "commingled" separation, all recyclable materials are placed in a single container. In "multibin" separation, the households put each material in a separate container. Curbside separation programs, often mandatory, are rapidly being established throughout the country. The programs can tie in well with the handling systems already established by packaging materials suppliers for the return of used packaging materials.

There are limitations to curbside separation programs, particularly concerning the current difficulty in sorting plastics into separate resin categories, contamination of packaging materials with food, markets for the large amount of material potentially available from this source, and the willingness of households to participate over the long term [18].

Composting, currently considered a form of recycling by the EPA, is a process for converting organic waste materials to a soil conditioner through the action of microorganisms. Because many packaging materials are inherently nondegradable or may be made so through coatings or laminations, the applicability of composting to packaging waste is limited.

A recent study [7] has projected the effect that recycling, in all forms, will have on MSW by the year 1995. This study projects that the amount of material ending up in landfills will still be over 50% of generated MSW in 1995, even though recycling rates will increase (Table 1). The projections underline the fact that recycling is only part of the solution to solid waste, in general, and to packaging waste, in particular. It is also probable that recycling levels of 40–50% for packaging materials in general (as opposed to materials with high scrap value like aluminum) would require fundamental changes in MSW management [7].

Recycling cannot be promoted or represented as the total solution for the solid waste problem. Recycling is an attractive solution for several packaging materials, but it should be viewed as only one part of a system of solutions to the complex problem. Recyclability should never be regarded as the only criterion, or not necessarily the major criterion for judging the environmental acceptability of a package or packaging material.

Incineration (Waste-to-Energy Systems)

The traditional disposal method for solid waste in the United States (and throughout the world, for that matter) has been on the land, first by open dumping, and, later, by sanitary landfilling. Incineration is an attractive supplement to sanitary landfill. Incineration reduces the weight of incoming waste by about 75% and volume by about 90%. But a residue obviously remains that requires disposal. Thus, incineration should be viewed as a supplement to, not a replacement for, landfill. At its most efficient, incineration will *extend* the life of a landfill about 10-fold. It will not replace it.

Early incinerators in the U.S. were little better than open burning. With no air pollution control, and no attempt to regulate combustion temperatures, incinerators competed with open dump burning in their environmental unacceptability. However, as the sanitary landfill replaced the open dump, modern, controlled combustion incineration with energy recovery replaced early, uncontrolled incinerators.

Today's electricity or steam generating incinerators operate at high temperatures with excess oxygen to ensure complete combustion and to minimize the formation of harmful products of incomplete combustion such as dioxin. Air pollution control equipment, such as scrubbers and electrostatic precipitators, bring emissions well within EPA health-based limitations. But environmental acceptability has its price tag. While solid waste could be deposited in a now illegal open dump for $5–10 per ton, a properly run sanitary landfill may charge $25–30 a ton or more. Incineration, with energy recovery, may net out at more than $50 a ton, even after sale of steam or electricity is accounted for [19]. However, these costs do not include transportation to the disposal facility. For example, a waste-to-energy plant is likely to be near a population center and a landfill more distant. The overall costs can be similar.

In addition to high operating costs, energy recovery systems are expensive to build. A moderately sized waste-to-energy system can easily cost hundreds of millions of dollars.

Also, as pointed out above, waste-to-energy systems only *extend* landfill life; they do not replace it. The remaining material—10% by volume, 25% by weight—consists of ash that has concentrated all of the original materials, including potentially dangerous materials such as heavy metals.

Sanitary Landfills

In the 1960s, as much as 90% of MSW was disposed of on the land (the rest was incinerated or dumped at sea). At that time land disposal often meant a true "dump". Trash was dumped in the nearest depression or open spot. Significant volume reduction occurred through natural degradation, scavenging (animal and human) and open burning that reduced volume and thereby extended dump life. All of this changed with the passage of the nation's first solid waste law—the Solid Waste Disposal Act of 1965 (soon to be amended by the Resource Recovery Act of 1970 and subsequent Federal Acts), designed to ensure that MSW was disposed of in a manner consistent with public health. The result is that 75% of the MSW in the U.S. is now placed in sanitary landfills.

A sanitary landfill, by definition, is just that. Trash hauled to a landfill is continuously compacted into specially constructed "cells" and covered with dirt each day. Sanitary landfills are designed to minimize degradation (see section on biodegradability) and to prevent scavenging and fires. The final result is that the landfill fills three times faster than the dump that it replaced. Further, many existing sites cannot meet stringent new standards for eliminating groundwater pollution and methane gas generation.

This would not be a problem if we were opening new landfills or landfill capacity at the same rate we are closing them. But with the emergence of environmental movements, citizens began to challenge the need to site disposal sites in their neighborhoods. The situation was worsened by the fact that most MSW is generated in cities, where the people are, and must be disposed of in surrounding areas where the land is. Classic urban/rural conflicts resulted and continue to the present time.

The United States is a nation of vast land areas. The amount of land required for sanitary landfills for even the largest city (500 to 1000 acres per site) is infinitesimal compared to the available, unoccupied land within the country. The problem is political, not technical.

Biodegradable Packaging

No discussion of packaging and solid waste would be complete without mention of biodegradable packaging.

Biodegradable packaging (and to a lesser degree, photodegradable packaging) has been an environmental objective since the 1960s, the beginning of the modern era of environmental concern. Conceptually, degradability is somewhat incompatible with one of packaging's primary functions—that of protecting the product for often long periods of time. The way to make a package "smart enough" to protect the product during the product's life and then to degrade rapidly when the package is empty, is a challenge that, for the most part, has eluded material scientists and package developers.

Many environmentalists and packagers now believe that, given current waste management practices, degradability is not a major environmental advantage [20]. The technical reasons for such a switch in thinking are fairly straightforward and are based, in large part, on the generally recognized solid waste management technologies that will be employed for the foreseeable future.

The primary method of waste disposal in the U.S. is, and will be for some time, the sanitary landfill. Landfills present two primary areas of environmental concern—methane gas that can be a fire or explosion hazard and leachates that can contaminate groundwater. Both result from degradable materials although leachates can be caused by runoff, irrespective of degradation. Landfills, therefore, are designed to *minimize* degradability, so even highly degradable materials such as newspapers and food wastes remain intact for decades. Recent excavations at old landfill sites have confirmed this contention [20].

The other major waste disposal method is incineration (with, hopefully, energy recovery). Here the desired attribute is combustibility, not degradability.

Should composting of wastes reenter the picture as a major waste disposal tool, degradability may have to be reexamined. Composting is currently not on the EPA's hierarchical list of waste handling alternatives, but is included as a recycling alternative.

Degradability should not be thought of as a major help in litter control, since most degradable materials do not decompose fast enough to have a significant impact on urban or highway litter.

Degradability may have some positive benefits for items that may be discarded as litter in remote areas or at sea, or for packages that may end up in a biological process (such as a composting operation or a municipal sewage plant).

Government Actions and Proposed Solutions

Federal, state and local government agencies have been concerned about packaging and the environment for more than 25 years. It is not the purpose of this section to attempt to detail the many proposals to restrict packaging because of its perceived effect on the environment. Instead, the general thrust of the legislative proposals will be reviewed.

Governmental actions relating to packaging are almost exclusively directed at solid waste management and related issues such as litter. The vast majority of these are at the state and local government level. A reported 650 bills were introduced in state legislatures in 1989 which the sponsors claimed would correct some perceived environmental problem related to packaging. Numerous localities around the nation are involved in similar actions.

Many government actions are pointed toward reducing or controlling solid waste costs through reducing some part of the packaging component of waste. It is popular to give solid waste cost figures for a municipality or region and to state that a *cost* reduction can be achieved that is directly proportional to the *weight* or *volume* reduction that might be achieved through eliminating certain packages.

However, solid waste generation varies tremendously (50% or more) from day to day and from season to season in the same city or neighborhood [21].

Like other essential public services, the solid waste management system must be capitalized for and have sufficient personnel to handle the peaks in generation. Since *all* packaging makes up about 30% of MSW by weight or volume, elimination of whole categories of packaging waste would not likely be transferred into meaningful cost savings, and certainly not on a basis that is directly proportional to the weight or volume of the packaging eliminated.

A recent thrust by some states and localities is curbside separation—

requiring households to separate refuse into one or more categories of recyclable materials. These proposals have the support of some industrial segments since they represent a viable way to retrieve certain materials that are difficult to acquire by other means, most specifically, those materials of marginal cash value. The approach may have some success *as long as there is a viable market for the collected "recyclables".*

Alter [22] indicates that participation levels and other factors make a 25% reduction in waste by this approach (a low end projection by its proponents) an unachievable goal unless yard wastes are also recycled. The approach may also add rather than reduce total solid waste handling costs since the value of the recyclables may not cover the added cost of collection. These costs can be reduced, however, through disposal cost avoidance in high disposal cost areas or if, as expected, disposal costs increase.

A number of laws mandate certain recycled percentages in products, including packaging. These approaches often fail to recognize the complexities—technical, legal and financial—that such proposals entail. As one example, the aluminum can may be made from up to 100% recycled material. Aluminum foil, however, must be made almost entirely from virgin metal (or pure, in-plant scrap).

Some governmental incentives, such as requiring government agencies to buy products with a maximum percentage of recycled materials attainable with reasonable costs, can be positive steps. But mandatory recycled percentages, like mandatory recycling, do not recognize the technical, economic and legal requirements of the marketplace.

Taxes on packaging materials to pay the cost of disposal have been a popular discussion topic at the federal level for years. At least two such laws have been enacted (but not implemented) at the state level. Such laws raise several often unnoticed concerns. The laws would have to be fairly enforced on all components of waste, including durables and non-packaging items, such as newspapers. The tax would have to be set only to pay for waste management and not be used either as a new source of general revenue or try to redirect consumer buying habits. It is likely that such laws would create a costly new state or federal bureaucracy. Finally, there is an equity issue: who pays for what disposal? For example, it would be inequitable if a tax on packaging (or any other solid waste constituent, for that matter) were used to pay for the disposal of all wastes, including yard wastes.

Much of the proposed and enacted legislation directed against packaging has been extremely narrow, pointing toward some particular type of package or promoting some particular environmental attribute perceived to be desirable. Each legislative proposal should be examined from the standpoint of the effect it will really have on municipal solid waste management and at what cost.

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