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**Abstract:** Examines the problems and progress in the field of plastics recycling. Statistics on plastic packaging disposal; Advances in plastic recycling; The initial start; The next stage, packaging production; Aid from manufacturers; The wide variety of resins; Design modifications; A recycling innovation that works; Separating different plastics; Resin recovery systems; Chemical processes; Government policies needed. INSET: Red herrings..

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# RECYCLING THE PLASTIC PACKAGE

**Recent technological advances could allow most plastic to be recycled. But progress will be limited without government policies to enhance industrial demand. _PI_** _b_

Asked to name a symbol of our throw-away society, most Americans would undoubtedly say packaging, which is the largest component of our solid waste stream, accounting for almost one-third of municipal solid waste. And the packaging material that's usually considered the worst offender is plastics. After all, plastics have been the fastest growing packaging material by far and now account for 11 percent of packaging waste by weight. They also constitute a disproportionately high volume of municipal solid waste-- approximately 20 percent--which drives up the cost of transporting and landfilling it. But most important, plastics are generally viewed as unrecyclable. Only about 2 percent of plastic wastes in the United States are presently recycled, while the recycling rates for the other major materials used in packaging--paper, glass, and metals--all exceed 15 percent.

The fact of the matter is that it doesn't have to be that way. To be sure, plastics recycling does present some difficult technical problems. But these obstacles are no longer so formidable: advances in plastics recycling have been taking place at a truly astounding rate, perhaps comparable to the pace of innovation in computer technology. As a result, it's now technically feasible to recycle the bulk of the plastic used in packaging, and in most cases it's economically viable as well--or could be, given the proper institutional arrangements and market incentives.

Interestingly, too, formal economic arrangements and the coordinated efforts of corporations, consumers, and government have proven highly important; many of the significant advances in plastics recycling stem from these critical steps rather than from some scientific or engineering breakthrough. And the annual number of refinements--incremental innovations--is enormous. It's worth noting as well that techniques to facilitate plastics recycling are occurring at every stage in the lifecycle of the material, not just when bags and bottles are recovered.

## Auspicious Beginnings

At the very start of the plastics lifecycle, virgin resin can be tailored to overcome the effects of future reprocessing. Plastics degrade with repeated heating or mechanical stress, and recycling imposes an additional thermal history, so that the material's durability and dimensional stability often suffer. But additives such as antioxidants can retard thermal degradation and thus help preserve a plastic's desirable properties.

Also, high-density polyethylene (HDPE) can be more successfully recycled in containers for detergents and cleansers if manufacturers use a type of resin in which one part has a high molecular weight and the rest has a low molecular weight. This is one example of a strategy to increase the material's "environmental stress crack resistance" (ESCR), which means that harsh chemicals will be less likely to damage it, even after it has been reprocessed and subjected once more to the stresses of being shaped into a container. The aforementioned HDPE resin increases ESCR by more than 100 percent.

At the next stage in the material's lifecycle, packaging production, packaging can be designed to enable an increase in its recycled resin content. A common technique is to make a plastic container with several layers, some of which incorporate recycled plastic. For example, Procter & Gamble offers many of its detergents in three-layered HDPE bottles that contain 20 to 30 percent recycled plastic. The recycled resin is placed in the central layer only, so that it cannot come into contact with the harsh, crack-promoting contents of the bottle or spoil the bottle's appearance. A second approach is to make single-layer plastic containers using a blend of virgin and recycled polymers with acceptable ESCR properties. Sonoco Graham, for instance, manufactures motor oil containers using this method.

Manufacturers can also aid recycling by using a single resin formulation to produce each item, since homogeneous plastic waste is relatively easy to recycle. The resin-production and plastics-processing industries have, for decades, recycled their industrial scrap, which is relatively uncontaminated and of a narrow and well-known composition. Similarly, the most successfully recycled plastic packaging has been soft drink bottles made of pure polyethylene terephthalate (PET), which are diverted from the solid waste stream in states with bottle return laws. In the bottle-bill state of Massachusetts, for example, some 80 percent of PET bottles are recycled.

On the other hand, the wide variety of resins used in packaging cannot be recycled interchangeably, since they all have different physical and chemical properties and all react differently to reheating. Indiscriminate mixing of resins, or even of different grades of the same resin, generally has serious adverse consequences for the material's properties.

Heinz kept this single-resin principle in mind while it was developing its new squeezable ketchup bottle. Originally, the company had introduced a bottle that was perceived as difficult to recycle, since it had a seven-layer wall of different resins glued together. But the recently designed five-layer bottle consists of 98 percent PET and 1.5 percent ethyl vinyl alcohol and can be easily recycled using current PET recycling procedures. The ethyl vinyl alcohol, which is included to control oxygen diffusion, is less than ideal from a recycling standpoint, yet because such a small amount of it is used, it is not a problem.

Another set of packaging design modifications focuses on adhesives. Some adhesives, such as those typically used to affix the HDPE base cup to a PET soft drink bottle, can discolor or chemically degrade the resin during recycling. However, new "hot melt" adhesives, which are chemically inert and thermally stable, do not create these undesirable effects.

Paper residues, even in minute amounts that might remain after washing, can lead to a degradation of resin properties. Thus the conventional paper labels on polyethylene containers are being replaced by polyethylene labels that are part of the mold used to make the container itself. The use of the plastic label not only results in a higher grade of recycled plastics, but it also simplifies the packaging production process by combining container labeling with container manufacture. It makes recycling easier as well, since the problem of washing out paper labels and the adhesives used to affix them is eliminated.

An entirely different kind of packaging feature is the voluntary code developed by the Society of the Plastics Industry: the by-now familiar arrows that follow one another around in a triangle and are accompanied by numbers and letters. Six of these designate the most common container resins and a seventh designates mixed waste, including other plastics, alloys, and multilayer products.

Here we have a clear example of a recycling innovation that works largely because of coordinated efforts--in this case, cooperation across an entire industry. And trivial as the idea of a code may seem, it's crucial to recycling, since it permits plastic wastes to be sorted manually by resin type. Just as sticking to one resin during manufacturing helps make a product easier to recycle, so does keeping that one resin unmixed with other resin types. Once discarded materials are commingled, they are difficult and expensive to separate, and they risk becoming contaminated.

The coordinated activity of different members of society is also responsible for many recycling advances arising at the stage in the material lifecycle when solid waste is collected and recyclables are separated out. For example, cooperation is key to the success of bottle return programs, polyethylene-bag collection programs at grocery stores, and polystyrene-food-container collection programs for high-volume commercial and institutional users. State and local governments are beginning to play an important role as well--by enacting bottle deposit legislation, requiring some recyclables to be separated from the stream of solid waste, and providing curbside collection of such materials.

Incremental technical advances have aided collection, too. For instance, redesigned collection vehicles facilitate the loading of recyclables and allow workers to store them separately and compact them on board. Another noteworthy innovation is the reverse vending machine, which, by ingesting empty PET bottles and returning the bottle deposit, offers convenient, automated bottle return.

### Closing the Loop

During the next stage in the material's lifecycle, recyclable plastic that has not been separated from the stream of solid waste is extricated from other material and purified. Actually, even plastic that has been separated out needs to be washed and rinsed to eliminate gross impurities such as food that can cause the material's properties to degrade significantly. Other undesirable matter can be removed at the same time. For example, in wet reclamation systems, PET bottles are shredded, paper from the label is removed by air filtration, and the remaining material is separated by water floatation. PET and aluminum sink, and HDPE from the basecup floats to the top and is removed. After drying, the aluminum and the PET are separated electrostatically: the PET and aluminum chips are charged by a high-voltage electrode, but only the PET chips hold the charge.

One especially innovative technology used in sorting out commingled plastics relies on centrifugal force, which segregates materials of different densities. This is useful in separating out "polyolefins"--in other words, polyethylenes and polypropylene--which are lighter than other plastic waste. And although polyvinyl chloride (PVC) and PET, which have similar specific gravities, cannot be separated using such a technique, that problem has not proven insurmountable, at least as long as the PVC and PET are not somehow fused together. PVC-PET separation systems have been developed based on electromagnetic scanning techniques that detect the chlorine in PVC. Robots or other mechanical devices can then be used to separate the two different kinds of plastic.

Eastman Chemical has recently developed a technology for automatically sorting all plastics according to resin type--they would be electronically scanned for organic marker compounds that manufacturers would incorporate into the virgin resin. Though potentially very useful for automating the separation process, such a technology would require industrywide cooperation to be really effective: if many companies failed to incorporate the marker compounds into their resins, the electronic scanner would be able to read only part of the plastics stream, and the separation process would be undermined.

Perhaps the most powerful set of resin recovery systems to be developed are based on chemical processes. These allow achievement of the elusive and highly desirable goal of "closing the loop" in plastics recycling. That is, they make it possible to use recycled resins in the same application as they were used originally. One example is depolymerization systems, whereby heat and pressure are applied to plastics in the presence of specific chemicals such as methanol. That causes the polymer chains to break down into their monomeric constituents, which can then be repolymerized to produce virgin resins. Goodyear, DuPont, and Hoechst Celanese have already used this principle to develop processes that depolymerize PET flakes into the basic monomers ethylene glycol and terephthalic acid. Other depolymerization processes are under development to allow polyolefins, polystyrene, and polyvinyl chloride to be broken down into their constituent parts.

A second set of methods based on chemical processes leaves the polymers intact but separates them out from one another even if they are commingled. These methods rely on the principle that different polymers dissolve in different solvents, or even in the same solvent, at different temperatures. For instance, in one process developed at the Rensselaer Polytechnic Institute, a plastic mixture is exposed to a solvent at a certain temperature to dissolve one of the types of plastic. The solvent stream is then quickly evaporated to recover the dissolved polymer and the pure solvent, and after that, the cycle begins again--with the difference that the temperature goes up and a different type of plastic is dissolved. In each successive loop of the cycle, as the temperature of the solvent is raised higher and higher, still other polymers in the resin mix are dissolved. This allows the recovery of most common plastics.

The majority of systems based on chemical processes, including the one from Rensselaer Polytechnic Institute, are still in the experimental stage, but if they turn out to be commercially viable, they would advance recycling efforts substantially. Not only would they allow recovery of nearly pure polymers or their constituents from a mixture of wastes, but the reaction conditions destroy contaminants, so that the recovered material could, with the approval of the Federal Drug Administration, be used to store food. And in fact, this has already started to happen: the FDA recently allowed Hoechst Celanese to make Coca-Cola bottles containing 25 percent PET recovered by depolymerization.

In the last stage in the material lifecycle, plastics reformulation and reprocessing, products and packaging are manufactured using recovered plastics. Plastics reprocessing has benefited from the myriad incremental innovations in reprocessing equipment. Just one small example is special agitators to facilitate material flow. The plastic that gets reprocessed in a recycling facility is full of irregular edges and odd outcroppings, and in the past, pieces of it would get caught on the reprocessing machinery, so that the flow would become clogged. But if the material is agitated a little, it doesn't have as much of a chance to get caught.

Post-recovery plastics reformulation has been improved primarily through the technologies used for developing high-value virgin plastics--in other words, additives that enhance the material's mechanical properties. These include "block copolymer compatibilizers," which are soluble in more than one polymer resin and therefore allow such resins as PET and HDPE to be blended. This can result in alloys such as super-tough PET/HDPE blends formed from the components of soft drink bottles. Another class of additives that is beginning to find applications in reprocessed plastics is "impact modifiers." Among these are "reactive" impact modifiers that chemically bind onto matrix polymer chains; in commercially available varieties, for example, this ability can lead to an increase of up to 1,000 percent in the strength of reprocessed nylon under impact.

Traditionally, recycled plastics--often commingled reclaimed polymers--have been able to compete favorably with virgin resins only in low-performance uses. And low-end markets--for products such as flowerpots, drainage tiles, corrugated pipes, trash cans, trash bags, fiberfill, and plastic lumber--have been expanding rapidly. Still, the inherently low value of such products does not provide enough of an economic incentive to spur widespread recycling efforts. Furthermore, these markets represent only a minuscule fraction of total plastic use and hence only a limited commercial outlet for recycled resins. If plastics recycling is ever to become commercially successful on a large scale, recycled resins must become competitive with virgin resins in markets where products meet high standards and command a high price. Thus in our opinion, the most pivotal technical developments in plastics recycling are those that make this possible. Advances such as depolymerization and solvent-based polymer separation are especially important, although the significance of innovations at all the other stages of the plastics lifecycle is not to be denied.

## The Need for Demand

Although these widespread advances suggest a promising future for plastics recycling, serious impediments remain to all kinds of recycling--not just plastics--and they are not purely technical but also economic and political. This may seem odd considering the advantages of recycling. Not only does the practice represent an alternative to incinerating and landfilling solid waste, but it also provides manufacturers with additional material. Moreover, taking into account both the market costs of recycling and what is gained by avoiding solid waste disposal, the benefits of recycling packaging material are enormous. We have calculated that in our home state of Massachusetts, for example, the net social benefits amount to approximately $231 per ton (see the chart on the opposite page).

Unfortunately, most of these benefits do not figure in market transactions. Part of the reason is that private markets do not reflect the social costs of the environmental harm they cause. Also, the way in which solid waste collection and disposal costs are financed presents a problem. In most cases, the local government assumes responsibility, and draws on general tax revenues. Thus, even though the total costs of solid waste collection and disposal are substantial, the marginal cost directly confronting those responsible for the waste is typically zero or very close to it. That fact affects decisions at all stages of a material's lifecycle. For example, a company considering whether to use virgin or recycled resins in its packaging does not have to include in its calculations the cost of disposing of the materials once their useful life is over, since society can be counted on to take care of that. The result is insufficient industrial demand for recycled materials.

State and local governments throughout the United States have tried to stimulate recycling through programs aimed at developing a recycling infrastructure. For instance, they have required recyclables to be separated from other waste, implemented curbside collection of these materials, and established material recovery facilities. But until the recovered materials are actually used--until they are converted into new products and sold to new customers--no meaningful recycling can be achieved. To be effective, government policies must widen their scope to enhance the demand for recycled materials.

One approach might be to introduce charges or taxes that would make it more expensive to forego recycling. These could be household charges for solid waste disposal, point-of-sale taxes on unrecyclable packaging, or taxes on virgin materials, for example.

Another strategy would be for the government to institute procurement policies. That is, the government could, in effect, increase its own demand for recycled or recyclable materials, perhaps by requiring that a certain percentage of the products it purchases be made of them. Or the government might simply decide, for instance, that it is willing to pay as much as 10 percent more for products containing recycled materials. The shortcoming of such policies is that in many areas, including packaging, government purchases constitute only a minute percentage of the market for a material.

A third government mechanism that could enhance demand for recyclable materials is recycling standards. These are already in place in some states: governments have required that local newspapers contain a certain percentage of recycled paper. Recycling standards have been applied more broadly still in other countries like Germany, where under a new law, 64 percent of packaging materials must be recycled by 1994. Even the American plastics industry, typically opposed to government regulation, has begun to recognize the need for such measures; this is evidenced from the editorial in the February 1992 issue of Plastics Engineering, which calls for demand-enhancing recycling standards with mandatory rates and deadlines for compliance.

Recycling standards should be distinguished from the unconditional bans on plastic materials that some state and local governments have implemented. We do not support such bans. They eliminate the preferred option of recycling plastics and do not increase the demand for recovering the material that replaces them. Moreover, the substitute material may itself be unrecyclable to a large extent, as in the case of paper packaging contaminated with food, and the ban may actually exacerbate the solid waste problems it is attempting to alleviate. For example, the substitute packaging may result in more food spoilage. Finally, unconditional bans have historically been applied in a relatively unsystematic manner, making them appear arbitrary and unfair.

We expect that the most effective demand-enhancing policies would probably combine economic charges and recycling standards, perhaps with some secondary support from government procurement programs. The point, however, is that both demand-side and supply-government participation is needed. Those who object on ideological grounds to such government intervention should bear in mind that recycling provides significant social benefits and that without demand-enhancing recycling policies, manufacturers will not be economically motivated to do their share. It is also worth noting that the objective of these policies is to get government out of the business of disposing of solid waste and private industry into the business of recycling it.

PHOTO: Compacted plastic refuse.

PHOTOS (8): Recycling is simpler if different varieties of waste are kept separate, so new trucks for trash collection are made with several compartments (A). After the trucks are emptied (B), plastics at a state-of-the-art recycling facility--EnviroPlastics of Worcester, Mass.--are sorted by type and shredded into strips (C) that will be ground into half-inch flakes. The flakes then proceed to the "hydroclone" (D), which assures that even if an odd bottle is sorted incorrectly, the flakes from it won't be. When the tanks shown here are filled with water, some kinds of plastic will sink while others will float.

DIAGRAM: Innovations to enhance recycling can occur at any stage of the materials lifecycle, shown in this diagram. Note that just as consumers can recycle their waste, so can manufacturers.

The wide variety of plastics used in packaging all have different physical and chemical properties, and all react differently to reheating. Thus they have to be kept separate during recycling.

Types of Plastic Resin

| Resin | Major Types of Packaging | Typical Application |
|---|---|---|

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|---|---|---|
| Low-density polyethylene(LDPE) | Film, coatings | Grocery bag |
| High-density polyethylene | Bottles, film | Motor oil container |
| Polyethylene terephthalate(PET) | Bottles | Soda bottle |
| Polyvinyl chloride (PVC) | Containers, film | Shampoo bottle |
| Polystyrene (PS) | Containers | Food container |
| Polypropylene (PP) | Film, containers | Cereal box liner |

According to the author's calculations, recycling pays. Consider for example, avoided costs of landfilling and incineration. Some 30 percent of the waste stream would otherwise be landfilled, and at $209 per ton, the bill would come to $63. The remaining 70 percent would be incinerated, and that practice is even more expensive--$289 per ton--yielding a cost of $202.

The Social Benefits of Recycling

| Source of Benefit | $/Ton |
|---|---|
| Avoided subsidy to virgin materials | $3 |
| Avoided cost of incineration | $202 |
| Avoided cost of landfilling | $63 |
| Recycling revenues | $49 |
| Recycling costs | (-$86) |
| Total | $231 |

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By Robert F. Stone , Ambuj D. Sagar and Nicholas A. Ashford

Photographs by David Oxton

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The Economic Impacts of Recycling Standards for Packaging in Massachusetts and The Art of the Possible: The Feasibility of Recycling Standards for Packaging.

**RED HERRINGS**

Plastics recycling can sometimes become enmeshed with other environmental issues. For example, plastics manufacturers have historically used cadmium, lead, and other toxic heavy metals to make additives such as pigments and heat stabilizers. These additives have raised health concerns with regard to both recycling and disposal, and companies have had to face the technical problem of developing less hazardous replacement additives that do not compromise the performance of the virgin or recycled resins. Fortunately, they have been able to solve that problem. For instance,completely organic pigments have been developed to replace colorings that rely on heavy metals, and berium-zinc heat stabilizers are now available as replacements for cadmium-based formulations.

Another prominent environmental issue is biodegradability. In some cases, plastics manufacturers have modified synthetic polymers so that the molecules break down more easily upon disposal; in others, they have made resins that include natural materials such as starch that con be attacked and degraded by microorganisms in the natural environment. However, these plastics could actually impede recycling. For one thing, mixing degradable and nondegradable plastics would result in a recycled resin of unacceptable quality, so there would be the complication of keeping the two separate from each other and for the rest of the waste stream. Also, degradable plastics might require special reprocessing conditions. Otherwise, the stresses of the recycling process could compromise the physical properties of the resins.

In any case, the issue of biodegradability is something of a red herring, since even degradable plastics and substitutes for plastics, such as paper, do not degrade under current landfill condition: they fail to get the air and sunshine they need. In fact, many of so-called degradable plastics do not degrade completely even in the natural environment.

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