Plastics—solution, or pollution

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There are many different processes used to recycle plastics--some more successful than others. Are the containers we place in the recycle bin are recycled back to make the original product, or is recycling just another station on the way to the landfill?

All traditional plastics are derived from either crude oil or natural gas. The process begins by refining of crude oil or natural gas and then “cracking” it using high temperature furnaces. Ethylene and propylene can then separated from the gas phase, after which they may be used as monomers or go through a subsequent chemical reaction to produce other kinds of monomers. Monomers are joined together in a chemical reaction to form long chains of repeating monomers called polymers. Properties of the polymer depend on the combinations of monomers used [3,4].

However, plastic is more than just a polymer; additives can be included to give the plastics certain desired characteristics. Plasticizers, for example, function as a solvent to allow the segmental mobility that makes plastics flexible. Other ingredients can add toughness, color, and durability. After the additives are added, the polymer mix is melted and pushed through an extruder, which operates in a similar fashion to a pasta maker, producing continuous lengths of plastic sections. The plastic sections are then cooled and fed to a pelletizer that cuts the product into small pellets referred to as resin [7].

Resins can be processed by a variety of methods depending on the desired product. For example, narrow-mouth containers, such as plastic bottles and detergent jugs, are produced by blow molding. Blow molding is a process whereby the plastic is shaped by blowing compressed air into a mold, similar to blowing air into a balloon. Tub-shaped or cup-shaped plastics, like yogurt tubs, are produced by injection molding, whereby the plastic is “stamped” into its shape [5].

Eventually, plastic products will reach their end use and be discarded. Because plastics are synthetic, neither microorganisms nor natural forces can break them down easily. As a result, plastics do not rot or rust like wood or iron, and they keep their strength and shape for long time. This is one of the greatest advantages of plastics, but it is also their greatest drawback. It takes plastics hundreds of years to break down in the environment [1]. One solution to this problem is recycling. Recycling plastics could reduce or eliminate plastic waste and also decrease the amount of oil used to manufacture plastics.

how it works

Today there are three common approaches to recycling plastics. Mechanical means convert the plastic waste into a resin that can be processed to manufacture new plastic products. Chemical means convert plastic waste into monomers that can be used in plastic manufacturing. Thermal means convert plastic waste into oil or synthesis gas that can be used as fuel or to produce new plastic products.

mechanical recycling

Currently, recycling plastic by mechanical means is by far the most commonly used method [8]. The mechanical recycling process is quite simple. Different methods are used for different resins and by different companies, but most involve the following steps: collection, sorting, and baling by resin type, color, or both. At the recycling factory, the bales are broken apart and ground into small flakes of about 3/8 of an inch (1 cm). Various methods are used to remove contaminants; most commonly, washing and floating the plastic removes heavy (sinkable) contaminants, like pieces of label, foil, or glue, from the flakes. The flakes are then melted and pushed through an extruder, then cooled and fed into a pelletizer, which cuts the product into small pellets (similar to plastic manufacturing from virgin feedstock). The pellets are then used as resin to form a new product [6,7].

The different kinds of plastics used to make packaging can be classified as either thermoplastics, plastics that melt before they decompose, or thermosets, plastics that degrade prior to softening. Therefore, in theory, all packing plastics can be recycled by mechanical means into the original product (primary reprocessing). In reality, primary reprocessing is relatively rare. Secondary reprocessing is much more common, where plastics are not recycled into the original products but into different products that usually cannot be recycled again [9].

There are two main reasons primary reprocessing is difficult. The first is that plastics are very susceptible to contamination, which can lead to defects in structure, which can cause inferior mechanical properties and in some cases, total breakdown of the polymer structure. Contamination can come from various sources, including residual chemicals from the previous use of the plastic that have not been removed in the cleaning process. The most severe problems occur when the contamination comes from mixing several kinds of resins. For example, even small amounts of PVC can lead to a breakdown in the structure of polyethylene (the plastic used to make water bottles) [10].

The second reason that primary reprocessing is difficult is that plastics are sensitive to heat and handling. The building blocks of plastics, polymers, are long flexible molecules, and when they are subjected to heat and stress during the extrusion process their structure changes. Some of the polymer molecules interconnect and stiffen, and the plastic becomes weaker and more brittle. Each time the plastic is reprocessed its mechanical properties will deteriorate resulting in a weaker and more brittle plastic. In contrast, glass or aluminum, which are composed of short molecules, are not as sensitive to heat and handling and therefore can be reprocessed almost infinitely [10].

chemical and thermal recycling

Recycling plastics by chemical or thermal means is a significant technical advancement in plastics recycling, in comparison to conventional mechanical recycling, as thier products are, after purification, identical to the virgin feedstock used to produce new plastics. The problem is that they are both energy intensive and demand high initial capital investment. Both the thermal and the chemical methods produce products that have similar, or even greater, cost than virgin feedstock. Both methods have only reached the semi-commercialization level and still need to be further developed. However, this cost analysis was based on oil prices of 1999; if oil and gas prices keep rising there will be more opportunities for chemical and thermal recycling commercialization [8].

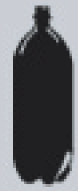
Thermal and chemical recycling methods work by breaking polymers into shorter chains, individual monomers, or in some cases into hydrogen and carbon monoxide (often referred to as synthesis gas). These products can be used to remake the original product, feedstock, or fuel [3]. Chemical recycling methods usually breaks down the polymer monomers. The most common chemical methods are methanolysis, glycolysis, and hydrolysis, none of which can process mixed plastic waste feedstock. They are most often practiced in PET recycling (plastic resin used to make water bottles). In most chemical methods, the polymer is heated to moderate temperatures (around 250C) under pressure, resulting in de-polymerization of the polymer molecule. The products are then purified by methods like distillation and re-crystallization to make a feedstock that can be used to generate a resin of similar quality to virgin resins.

The most common method of thermal recycling is pyrolysis, which can easily handle mixed streams of plastic wastes. In pyrolysis, the plastic waste (or any other organic waste) is rapidly heated to 450 - 600°C in absence of air. The heavy vibrations at this temperature break the polymer molecule apart, producing organic vapors and charcoal. The vapors are then condensed to give bio-oil, which has a similar composition to naphtha. Yields are normally around 70-75%. This bio-oil can be used as fuel or as feedstock for the petrochemical industry. Other thermal processes result in turning plastic waste into synthesis gas, a common feedstock in many industrial processes [8,11].

what do the numbers mean?

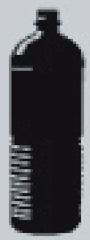
The recycling process is greatly influenced by the type of plastic, which is identified by means of a numbering system initiated in 1988 by the Society for Plastics Industry. Plastics are categorized as seven different types and identified by the code number that is usually found inside a chasing arrows symbol (commonly known as the

PETE (Polyethylene Terephthalate)
*Common uses: 2 liter soda bottles, cooking oil bottles, peanut butter jars



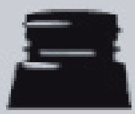
HDPE (High Density Polyethylene)
*Common uses: detergent bottles, milk jugs

PVC (Polyvinyl Chloride)
*Common uses: plastic pipes, outdoor furniture, shrink wrap, water bottles, salad dressing and liquid detergent containers



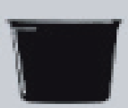
LDPE (Low Density Polyethylene)
*Common uses: dry cleaning bags, produce bags, trash can liners, food storage containers

PP (Polypropylene)
*Common uses: bottle caps, drinking straws



PS (Polystyrene)
*Common uses: packaging pellets or "Styrofoam peanuts," cups, plastic tableware, meat trays, to-go "clam shell" containers

Other
*Common uses: certain kinds of food containers and Tupperware



"recycling symbol") on the bottom of plastic containers. Plastics #1-#6 account for 96% of all packaging plastics. However, the presence of the "recycling symbol" does not indicate that the plastic can actually be recycled. In addition, it was developed by the plastic manufacturing industry, not by the recycling industry. Although two plastics may have the same number, they may not necessarily be able to be recycled together. A good example is a #2 HDPE yogurt tub (wide-mouth) and #2 HDPE milk jug (narrow-mouth). Yogurt tubs are "injection molded," and milk jugs are "blow molded." Both resins are made out of HDPE, but because the different processing methods require different material characteristics, each resin contains different additives. Each of the resins cools and melts at a different temperature, and therefore, they cannot be reprocessed together [5,10].

the bottom line

In the 2000 plastic discards represented an estimated 9-10% by weight and up to 26% by volume of the municipal solid waste in the United States [2]. The U.S. EPA recovery rate for all plastics was 5.4% compared to 45.4% for paper/paperboard, 23% for glass, 34% for steel, and 30.1% average recovery rate for all materials. The plastic recycling industry is mainly focused on recycling #1PET and #2HDPE narrow-neck containers. PET and HDPE account for 95% percent of all narrow-neck containers, and their recycling rate in 2001 was 22.8%. There is a well-developed market for usage of these two types of recycled resins. Currently, the limiting factor in PET and HDPE bottle recycling is the collection rate. In states like California where there is a deposit on bottles, the recycling rate for #1 and #2 bottles was 35.5% in 2000, and expected to increase. Plastics #3 through #7 and wide-mouth #1 and #2 containers had a much lower recovery rate. This was a consequence of low collection rates (only 10% of curbside recycling programs collect these plastics), which made recycle them less economic, thus leaving markets for uses of those recycled resins undeveloped [2,3].

Between the years 1995 and 2000 total plastic recovery rates remained around 5%. By weight, the recovery rate increased significantly, but this was because of the massive increase in virgin plastics production in those years. For example, between 1995 and 1996 plastic recycling increased by 69 million pounds, and virgin plastic production increased by one billion pounds.

closing the loop: alternatives

The current total recycling rate of around 5% indicates that plastic recycling comes far short of solving the problem of plastic waste. The problem is worsened by the fact that only around 15% of recycled plastics are used to make the original product, and therefore, plastic recycling has only a small effect on the use of virgin feedstock. There are several ways to address this problem. One is to increase collection by making more laws like the bottle bill, which provides a deposit on returned bottles, and, by increasing recycling awareness through education. Another way is to allocate more resources to the development and commercialization of chemical and thermal methods of plastic recycling. Although these solutions would help increase the rate of plastic recycling, but would probably never close the plastic lifecycle loop.

A major problem with plastics is in their design. When the manufacturing industry designs plastics, it rarely considers how these plastics will be recycled, causing many problems in the recycling process. Even when only considering HDPE resins, several problems become apparent. Narrow-mouth HDPE containers need to be separated from wide-mouth ones, colored containers from uncolored ones. The bottle cap is made out of a different resin than the bottle itself; therefore they must be separated before recyling. Afterwards, the labels need to be removed and the adhesive needs to be extracted to contaminate the product. This could all be avoided by a good design. For example 3M has designed labels that are made out of PET and can be recycled with PET bottles.

Designing plastics to be recyclable can ease this process substantially. One possible approach is to make the plastics from recyclable resins that can easily be transformed into the same product. Also, there should be a means to recycle many different types of resins together. Another useful method for avoiding the arduous process of separating a large variety of plastics is composting. This approach is especially attractive with respect to film plastics, since thier high volume and low mass makes recycling them unaffective. Plastics could be derived from biomass and end their life in the compost bin with yard waste, decreasing the amount of waste in the landfill. This would also decrease the use of nonrenewable resources like oil. Although these design requirements may seem far-fetched, plastics satisfying these requirements already exist. One of the best examples is "NatureWorks" Polylactic Acid (PLA), a plastic manufactured by Cargill Dow. PLA is derived from corn or wheat sugar, and could, in the future, be made from biomass such as agricultural waste. PLA is already commercialized in packaging materials and fibers, which can be used to make clothing and carpets. All products made from PLA can undergo complete degradation within a few weeks under typical compost conditions. Alternatively, all products made from PLA could be readily hydrolyzed with wate, forming a lactic acid monomer that can be easily purified and used to remake a virgin grade polymer. This is similar to the chemical recycling discussed above, but the process is much simpler with PLA as feedstock [12].

There are many challenges for engineers to design more plastics like PLA. The federal government would need to catalyze this design revolution, such as through tax breaks for companies that produce plastics like PLA or higher taxes on plastics that are hard to recycle. With 100 billion pounds of plastics produced in the United States per year, and only a 5% recovery rate, such decisions to actively encourage improvement in our recycling practices will prevent a future overrun with landfills.

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