

History and Significance of Polymers

What is a polymer? The most simple definition of a polymer is something made of many units. The units or "-mers" are generally hydrocarbons or derivatives joined together in distinct repeating patterns. Think of a polymer as a chain. Each link of the chain is the "mer" or basic unit, which is made of carbon, hydrogen, oxygen, and/or silicon. To make the chain, many links or "-mers" are hooked or polymerized together.

Polymerization can be demonstrated by linking strips of construction paper together to make paper garlands or hooking together hundreds of paper clips to form extended chains. Further investigation of the chemistry of polymers will come, but first a look into the history of these materials.

Some polymers are natural substances that come from vegetable and animal sources. They include horns of animals, tortoise shell from the hawksbill turtle, shellac from the secretions of an Asiatic insect called a lac, rosin from the sap of pine trees, asphalt from decayed plants and animals, and tar from the distillation of organic materials such as wood. Other natural polymers you may not be as familiar with include amber, which is the fossilized resin of trees, or lignin, which is the fibrous binding between wood cells. What makes these polymers unique is that they can be used or processed into usable articles by the application of only heat and/or pressure. Common uses of these natural polymers include fans and hair ornaments, which can be made from tortoise shell. Buttons, beads, knife handles, and jewelry can be made from horn and from amber. Bowlers, dancers, violinists, baseball players, and gymnasts all use the natural polymer rosin in their sport or profession.

Shellac was used by the Chinese as early as the fifteenth century to create beautiful artwork, although more familiar is shellac's use as a wood finish. A comb-making company that used natural polymers was probably the first polymer industry in the United States, dating back to 1760.

By the turn of the nineteenth century, a new development was about to occur that would change the infant polymer industry dramatically. The change occurred when natural polymers were processed or reacted with chemicals to make them useful substances. These polymers are called "modified natural polymers" or "semi-synthetic polymers." The first and most famous of these is vulcanized rubber. In 1839, Charles Goodyear discovered, after years of experimentation, that the sap of the hevea tree (latex) could be heated with sulfur to permanently alter the physical properties of the latex. Until this discovery, rubber had limited usefulness because it was brittle in the cold and melted when the temperatures became warm.

Additional natural source polymers include gutta percha, gun cotton, celluloid, casein, parkesine, and guayule. Gutta percha, the latex of the Malaysian gutta tree, was first used by George Montgomery for whip and knife handles. Because of its waterproof nature, gutta was then used to cover the first trans-atlantic cable in 1843. Today, gutta percha is the material dentists use to fill the canal of a tooth during a root canal. Wood pulp and cotton linters are the natural source for many plastics, such as gun cotton (a Civil War explosive), parkesine and celluloid (plastics very similar to ivory that were developed in the 1860s), cellulose acetate (used for films and fibers), and many others. Milk is the natural source for casein, which has been used for buttons, moldings, and adhesives. The latex of the guayule bush, which is very similar to the latex of the hevea tree, was investigated as a replacement for hevea latex in rubber production in the 1940s. Not only were the scientists of the 1800s developing modified natural polymers, they were also trying to duplicate the structure of natural substances, in hopes of producing synthetic counterparts.

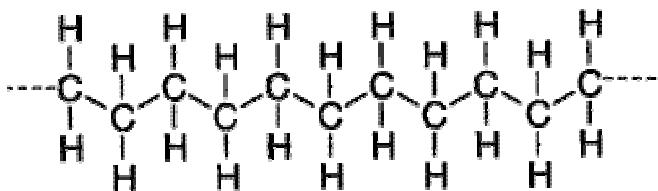
Leo Baekeland successfully introduced the first semi-synthetic polymer in 1909, which he called "Bakelite." Soon after, in 1911, the first semi-synthetic fiber, rayon, was developed as a substitute for silk. Organic chemistry began to flourish and many discoveries were made. The fact that polymers were large molecules and not colloidal aggregates was first proposed by Staudinger in 1920, but the concept was not fully accepted until the work of Carothers, the inventor of nylon, in 1929. In the decade of the 1930s, several

important new polymers were developed, including polyolefins, polystyrene, polyvinyl chloride, thiokol, neoprene, and nylon. However, it was not until World War II that a significant change took place in the polymer industry. The technology to produce synthetic polymers from chemicals was developing rapidly, but the applications were not always commercially feasible or profitable. Prior to World War II, natural substances were generally available; therefore, synthetics were not as necessary. Once the world went to war, our source of latex was cut off and synthetic rubber became a necessity. Natural fibers such as silk were no longer available for parachutes so nylon became the solution. Since then, the polymer industry has grown, changed, and diversified into one of the fastest growing industries in the United States and in the world.

By 1983, the use of polymers in the United States had surpassed the use of aluminum and steel and this trend continues. In 1996, the plastics industry had total shipments of \$274.5 billion, a 55 percent increase since 1991. The Society of the Plastics Industry, Inc. (SPI) indicates that in 1996, there were 1,337,700 employees working in the plastics industry. U.S. plastics industry employment has been growing at a healthy pace at a time when employment in all manufacturing has been declining.

The Structure of Polymers

Many common classes of polymers are composed of hydrocarbons. These polymers are specifically made of small units bonded into long chains. Carbon makes up the backbone of the molecule and hydrogen atoms are bonded along the backbone. Below is a diagram of polyethylene, the simplest polymer structure.



There are polymers that contain only carbon and hydrogen (for example, polypropylene, polybutylene, polystyrene, and polymethylpentene). Even though the basic makeup of many polymers is carbon and hydrogen, other elements can also be involved. Oxygen, chlorine, fluorine, nitrogen, silicon, phosphorous, and sulfur are other elements that are found in the molecular makeup of polymers. Polyvinyl chloride (PVC) contains chlorine. Nylon contains nitrogen and oxygen. Teflon contains fluorine. Polyesters and polycarbonates contain oxygen. Vulcanized rubber and thiokol contain sulfur. There are also some polymers that, instead of having carbon backbones, have silicon or phosphorous backbones. These are considered inorganic polymers. One of the most famous silicon-based polymers is Silly Putty™.

Polymerization and Molecular Structure

The initial compound that is used to form polymers is the "mer" or monomer. Monomers are chemically joined together in one of two ways: addition polymerization or condensation polymerization.

Addition polymerization is comprised of three basic steps: initiation, propagation, and termination. For example, during the initiation phase of the polymerization of polyethylene, the double bonds in the ethylene "mers" break and begin to bond together. A catalyst or promoter may be necessary to begin or speed up the reaction. The second phase, propagation, involves the continued addition of monomers together into chains.

The final step is termination. During termination all monomers may be used, causing the reaction to cease. A polymerization reaction can cease by quenching the reaction. Similar to quenching someone's thirst, water can be used to quickly cool a reaction. Polymers formed by addition polymerization include acrylic, polyethylene, and polystyrene, to name a few.

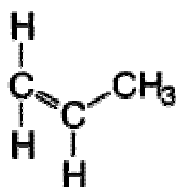
Very simply, addition polymerization describes the process of "mers" joining by each one adding on to the

end of the last "mer." A simple visual of the process is paper clips joined together to form a long chain. Polymers formed by addition polymerization are often thermoplastic in nature. Thermoplastics are like hot melt glue sticks that can be heated and made soft and then become hard when cooled. Thermoplastic polymers are easily processed and reprocessed or recycled. The majority of polymers used today are thermoplastics.

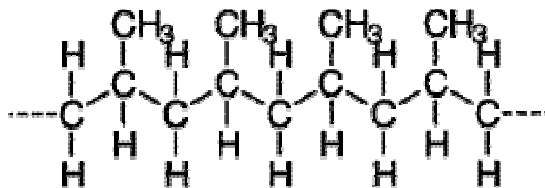
The other group of polymers are formed by condensation polymerization. During the chemical reaction of condensation polymerization, a small molecule is eliminated as the monomers join together. Common polymers in this group include nylons, some polyesters, urea formaldehyde, and urethanes. These polymers can be thermoplastic in nature or thermosetting. Once a thermoset polymer is formed, it cannot be melted and reformed. All plastics flow at some time during their processing and are solid in the finished state, but once a thermoset is processed, it is dramatically different and cannot be reformed.

The means of polymerization will affect the heat reaction of the formed polymer; likewise, the arrangement of the "mers" within the molecule will affect the physical characteristics of the formed polymer. "Mers" joined together in long chains have a linear configuration very similar to a paper clip chain, even though in actuality tetrahedral bonds give the molecule a zigzag arrangement. During polymerization, if the "mers" not only form straight chains but also form long side chains off the main backbone, the resulting configuration is described as branched, like a tree branch or grape stem. A third configuration is achieved by the long chains being chemically linked together. An example would be natural rubber (isoprene) being reacted with sulfur. The sulfur bonds the chains to form a giant meshwork molecular structure that is known as vulcanized rubber. This is a cross-linked configuration.

Polyethylene has the simplest "mer" structure. Even though the backbone of other polymers will be similarly formed by a broken bond between two carbons, the remaining carbons in the "mer" will form a functional group whose orientation about the backbone will affect the physical nature of the resulting polymer. For example, propylene is the "mer" that will form polypropylene:



Polymerization will be initiated by the double bond breaking and the "-mers" joining together. Therefore, the methyl group on the propylene "-mer" has the potential to be located at various points along the backbone. If the methyl group (CH₃) is oriented repeatedly on one side of the chain on alternating carbons, it is called isotactic.



Ninety to nine-five percent of all polypropylene polymers have this configuration.

Molecular Arrangement of Polymers

Think of how spaghetti noodles look on a plate. This is similar to how polymers can be arranged if they are amorphous. An amorphous arrangement of molecules has no long-range order or form in which the polymer chains arrange themselves. Amorphous polymers are generally transparent. This is an important characteristic for many applications such as food wrap, Plexiglas, headlights, and contact lenses.

Controlling and quenching the polymerization process can result in amorphous organization.

Obviously, not all polymers are transparent. The polymer chains in objects that are translucent and opaque are in a crystalline arrangement. By definition, a crystalline arrangement has atoms, ions, or, in this case, molecules in a distinct pattern. You generally think of crystalline structures in salt and gemstones, but not in plastics. Just as quenching can produce amorphous arrangements, processing can be controlled to produce the degree of crystallinity desired. The higher the degree of crystallinity, the less light can pass through the polymer. Therefore, the degree of translucence or opacity of the polymer is directly affected by its crystallinity. Crystallinity also affects the melting point of a polymer. The more crystalline the pattern of the molecules, the more energy is needed to cause the molecules to separate, melt, and flow. Amorphous polymers, on the other hand, will have lower melting points. Care must be taken to retain the degree of crystallinity in a polymer. Reprocessing, recycling, overheating, fabricating, machining, UV light, or heat in service use or storage can potentially affect the crystallinity of a plastic. As a polymer becomes more crystalline, its melting point and strength increase. However, its strength can increase to the point that the polymer becomes brittle and loses characteristics it was originally made to have.

By manipulating factors on the molecular level that affect the final polymer produced, engineers continually are challenged to produce better-suited materials for a wide variety of old and new applications designed to improve our quality of life. Manufacturers and processors introduce various fillers, reinforcements, and additives into the base polymers, expanding product possibilities.

Characteristics of Polymers

The two major groups of polymers are thermoplastics and thermosets. Thermoplastic and thermosetting nature is based on the heat response of polymers. The light transmittance of polymers includes the description of materials as being transparent, translucent, or opaque. Transparent polymers are those that you can see through, translucent are those that you cannot see through but allow light to pass through, and opaque polymers are those that you can neither see through nor allow light to pass through. Light penetration qualities are dependent on the degree of crystallization of the polymer and the presence of additives.

Every polymer has very distinct characteristics but most polymers have the following general attributes.

- 1. Polymers can be very resistant to chemicals.* Consider all the cleaning fluids in your home that are packaged in plastic. Reading the warning labels that describe what happens when the chemical comes in contact with skin or eyes or is ingested will emphasize the chemical resistance of these materials.
- 2. Polymers can be both thermal and electrical insulators.* A brief trip through your house will reinforce this concept, as you consider all the appliances, cords, electrical outlets, and general wiring that are made of or covered with polymeric materials. Thermal resistance is evident in the kitchen with pot and pan handles made of polymers, with the foam core of refrigerators and freezers, and with insulated cups, coolers, and microwave cookware. The thermal underwear that many skiers wear is made of polypropylene, and the fiberfill in a winter jacket can be made from polypropylene or polyester fiber.
- 3. Generally, polymers are very light in mass with varying degrees of strength.* Consider the range of applications from a dime store toy to the frame structure of space stations, or from delicate nylon fiber used to make pantyhose to Kevlar®, which is used in bulletproof vests.
- 4. Polymers can be processed in various ways to produce thin fibers or very intricate parts.* Plastics can be molded into bottles or the body of a car, or can be mixed with solvents to become an adhesive or paint. Elastomers and some plastics stretch and are very flexible. Other polymers can be foamed, like polystyrene (Styrofoam®) and urethane, to give just two examples.

Polymers are materials with a seemingly limitless range of possible characteristics, and colors. Polymers have many inherent properties that can be enhanced by a wide range of additives to broaden their use and

application. The ability to design or engineer the polymer for each specific application makes plastics unique among basic material types.

Each polymer resin can be identified by fundamental identification tests. Melting point, burning properties, solubility, relative density, and halogen tests can identify resins in a lab. When testing the resins, be sure to use safety goggles and perform the tests in a lab fume hood.

Of the most common resins, polyethylene (PE) and polypropylene (PP) both have a translucent, waxy texture, and are the only non-foam plastics that float in water. The burning properties will discriminate between these two resins. PE burns rapidly, drips flames, smells like candle wax and, when extinguished, will produce a white smoke. PP, on the other hand, burns more slowly, smells like burning fuel, and does not drip flames while burning. PE is impervious to chemical solvents while PP will dissolve in hot toluene.

Other common plastics can be identified by their burning properties. Polyvinyl chloride (PVC) can be ignited but will self-extinguish as soon as the fire source is removed. PVC has a very acidic odor when burning because hydrogen chloride is a burning by-product. (A halogen test can be performed to identify the presence of chlorine in PVC. A copper wire is heated in a laboratory burner flame to incandescence and then touched to the PVC. When the wire is returned to the burner, a brilliant green flame is produced.) Rigid PVC will become rubbery in the presence of benzene or will dissolve in methyl ethyl ketone. Polystyrene (PS), on the other hand, burns rapidly, has a strong gas odor, and produces tremendous amounts of soot. PS will swell readily in acetone.

These identification tests are not conclusive determinations for polymer content, but are a solid guideline. Polymers with colorants, additives, and stabilizers will naturally have somewhat altered behaviors. Infrared spectrophotometry, gas chromatography, and X-ray are some of the analytical identification tests that can be performed to positively identify polymeric materials. Elastomers are unique polymers, which include rubber, synthetic rubber, and thermoplastic elastomers, and are characterized by their elasticity and flexibility. Elastomeric materials stretch and have the ability to recover with limited permanent set or distortion. These materials are generally thermosetting and can be distinguished by similar basic identification tests like the plastics previously mentioned. However, commercial products are usually compounded with more than one base elastomer, making identification by analytical instrumentation a necessity.

Forms of Plastics

After "mers" are polymerized together, thermoplastics are extruded into strings of plastics that are chopped into pellets. These pellets can be mixed with colorants and additives that are then remelted into other shapes. The extrusion process is customarily designed to make a variety of common objects. Plastic pellets are fed into an extruder through the hopper. The plastic travels into a heated barrel where one or two screws turn continuously, mixing, blending, and melting the plastic. The screw also moves the plastic through the barrel to the end where the die is located. Depending on the shape of the die, a variety of objects are developed. Some common extruded products include drinking straws, molding strips, hose and tubing, seamless gutters, window frames, and vinyl siding.

A process similar to extrusion is the production of sheeting. Plastic is extruded and fed through two hot rollers producing sheets, which continue to be fed through hot rollers to produce the desired thickness. The process of material being fed through a series of hot and/or cooled rolls is called calendaring. Sheetting has a final thickness of 0.25 mm or more; whereas film, which can also be produced by this method, is less than 0.25 mm in thickness. Film is also produced by a blown or tubular extrusion process. A tube of plastic is extruded from a vertical die and air is blown into the center of the tube, cooling and orienting the polymers in the film. The air-filled tube resembles a hot air balloon. The diameter of the die and the rate at which the extruded tube is pulled determine the final diameter of the product. Trash liners are commonly produced utilizing this process. The film is then fed through a series of rollers where the material is finally wound on a reel. Plastic films have revolutionized the food packaging industry. Frozen foods, dry goods, meat and vegetable wrap, boil-in-bags, and microwave wrap are examples where filmed polymers are used and contribute to the health and safety of your household.

Fibers and filaments are also extruded through multiple openings of a spinneret die. The specially shaped strands of molten plastics are cooled, then drawn and stretched by passing through a series of rollers. The drawing process will orient the molecule chains to produce the desired strength, while the shape of the fiber will affect other characteristics. All natural fibers have distinguishing cross-sections that fiber producers mimic to create a synthetic that resembles a natural fiber.

Plastic pellets are also used to produce injection molded products. The majority of plastic objects you would customarily think of are products of the injection molding process. The process is very similar to extrusion except the melted plastic is forced under pressure into a closed mold. After the mold is filled it is cooled, the two parts of the mold open, and the object drops out.

Another similar process is blow molding. The molten plastic is extruded as a large tube and the tube is clamped into a mold. Air or another inert gas is forced through the tube of plastic, which forces the material against the walls of the mold. Blow molding can also be done using a preform. A preshaped object is molded and then is reheated, clamped in the mold and air forced into the mold, finalizing the desired shape. Two-liter soft drink bottles are often made by this method.

Another molding process requires plastic pellets to be ground into a fine powder. The powdered plastic is easily melted and used for injection or rotational molding. Rotational molding is used to make large toys and lawn mower catchers. This is becoming a more popular form of molding and is characterized by the object being hollow. The powdered plastic is placed into a half mold and the upper part of the mold is bolted to the bottom. The mold is placed into a heating chamber and rotates, which causes the plastic to coat the walls of the mold. After a specified time, the mold is shifted to another chamber where it is cooled by spraying the outside of the mold with water. Then the top of the mold is removed and the molded part is removed and allowed to cool.

Elastomeric polymers like rubber are mixed in a machine called a Banbury. All the compound ingredients are placed into the machine, and blades inside knead and mix the components. This process is temperature critical, since most compounds mixed by this process are thermoset. Temperature needs to be monitored and controlled to minimize cross-linking, which can cause the material to be permanently set. After mixing in the Banbury, the mixture drops onto a two-roll mill where the rollers turn toward each other forcing the plastic or elastomer between them. The mixed rubber is then cut off the mill and stripped into long continuous sheets until it is ready to be extruded into various shapes and cured into a final product.

These explanations are extremely simplified. In reality, technicians who operate molding machinery have to understand the plastic they are molding as well as complex computer-operated machinery. Their jobs generally include inspecting the quality of the materials being made and correcting problems as they arise in the machine and the polymer.

Polymers are used as adhesives that bond materials together. Cement is one type of adhesive that, by definition, is a liquid plastic in a solvent base. As the solvent evaporates, the cement hardens, which is commonly called drying. Many types of adhesives and cements are generally referred to as "glue." Probably the most familiar adhesive is a suspension of polyvinyl acetate in a water base, better known as white glue. By our definition, white glue is a cement. The solvent (water) evaporates, resulting in the polyvinyl acetate hardening. Adhesives such as this form mechanical bonds between materials. A mechanical bond is characterized by the interlocking of surfaces by secondary bonds. A stronger bond can be made with chemical bond adhesives. A chemical bond results when the adhesive causes the molecules of the two materials to flow together. Welding or heating form chemical bonds, as well as some cements. Using a cement with a solvent that can dissolve the plastic causes the intermingling of molecules between the two surfaces forming the bond. Plastic can also be polymerized between two materials, causing the intermeshing of surface molecules. Some examples of solvent-based cements that form chemical bonds include epoxy and acrylic adhesives. A local hardware store will provide a better understanding of the number and variety of adhesives available.

Other polymers are rising in popularity as effective mechanical adhesives. Hot melt adhesives that are applied with a glue gun are used in some areas because of easy application. The plastic is melted and

extruded into place, bonding two materials together or filling and sealing cracks and seams. The molten plastics can be controlled so that a thin or heavy stream is formed depending on the specifications. As the plastic cools, the bond is formed instantly.

Other types of adhesives, which are applied in similar fashion to hot melts, are caulking, sealants, and putty compounds. These come in squeeze tubes or in a tipped cartridge. The cartridge is inserted into an extruder gun and the substance is forced through a tip. These compounds are used to fill cracks or produce a seal between two materials such as a joint, window edge, or bathroom fixture. The main purpose of these adhesives is to keep out moisture and air.

An equally common use is adhesive-backed tape or labels. These adhesives include masking tape, invisible tape, duct tape, Post-it™ notes, Band-Aids™, pressure sensitive labels, and stickers. Heat sensitive patches or iron-on patches are also included in this group. In each case, the adhesive is on the back of a substrate such as paper, film, or fabric and can be adhered to another surface by pressure, moisture, or heat.

Polymers in suspension are also in the family of coatings. Paint, wood finishes, and vinyl-coated tool handles are examples of this form of polymers. Coatings are permanently applied to a substrate. Polymeric dispersions, used to fill a mold are considered castings. Casting is another term applied to the various pressure molding processes already discussed, as well as to embedments, which are molds filled without pressure.

Various additives broaden the spectrum of forms that polymeric materials can take. Fillers and reinforcements added to polymeric material constitute composites. Fillers are usually small particles or flakes of organic or inorganic material that are added to polymers to extend the material, lower the costs, and improve the physical properties. For example, application of metallic flake to PVC has brought the development of electrically conductive plastics to the marketplace.

Reinforcements are classified as fibers, additives that improve physical properties, especially the tensile and impact strength of the material. Glass fiber is a common reinforcement used to fill plastics. Mats or yarns of polymer or metal are additional examples of reinforcements used in the industry. Fillers and reinforcements are not only dispersed through the polymer, but can be layered, forming composite structures more commonly called laminates. Laminate structures are used in aircraft and car bodies, foam-backed carpet, and Formica® counter tops.

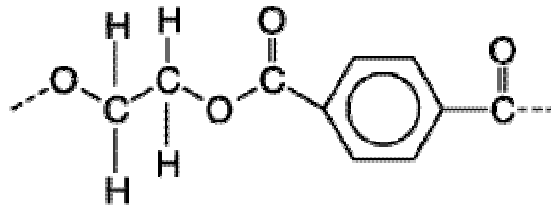
Additives are also used to stabilize the final polymeric material produced or to aid the processing of the material. Additives are available to curtail the effects of oxidation, ozone, or ultraviolet radiation. Anti-static agents are used to prevent the buildup of electro-static charge on the surface of the polymer. Synthetic fiber clothing is a common example of static charge building up on material, causing the fabric to cling to other materials. Fabrics, such as children's sleepwear and carpet, are often stabilized with flame retardants.

Polymers, especially those with plasticizers, are subject to microbial growth. Anti-bacterial or fungicidal additives, when incorporated into a polymer, will limit the growth of bacteria, fungus, or mildew on a shower curtain, in a water bed, or in tubing for medical applications. Processing additives range from accelerators and catalysts to retardants, which are critical in elastomer compounding. Waxes, lubricants, and plasticizers are additives that reduce friction in processing and result in flexible plastic or elastomeric materials. Blowing or foaming agents are additives that give polymers a specific form. Cellulose sponges and polystyrene are examples of the two different foams that are produced. Open-celled foams, like the sponge, hold water, and have cells or polymers that are not completely enclosed. Polystyrene is indicative of closed-celled foams that do not hold water and have completely encapsulated cells.

With the range of inherent characteristics of polymeric material and the possible modifications from fillers, reinforcements, and additives, the chemical and engineering potential of plastics and elastomers is limitless.

Common Plastic Resins Used in Packaging

Polyethylene Terephthalate (PET or PETE):



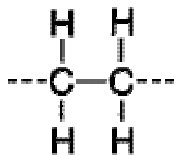
PET is clear, tough and has good gas and moisture barrier properties. The vast majority of this plastic ends up in soft drink bottles and blow molded containers, although sheet applications are increasing. In addition, a small volume of PET is now used outside the packaging industry for the production of injection molded components such as bicycle mud guards. Cleaned, recycled PET flakes and pellets are in great demand for spinning fiber for carpet yarns and producing fiberfill and geotextiles. Other outlets include strapping, molding compounds and both food and non-food containers.

Qualities: Clarity, strength/toughness, barrier to gas, resistance to grease/oil, stiffness, resistance to heat.

Uses: Plastic soft drink bottles, mouthwash bottles, peanut butter and salad dressing containers.

Recycled Products: Tote bags, dishwashing liquid containers, clamshells, laser toner cartridges, picnic tables, hiking boots, lumber, mailbox posts, fencing, furniture, sweatshirts.

High Density Polyethylene (HDPE):



HDPE is a relatively straight chain structure, but, as its name implies, exhibits a higher density. It is

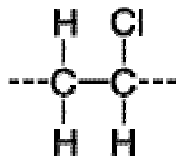
naturally milky white in appearance and finds wide application in blow molded bottles for milk, water and fruit juices. Copolymer HDPE, pigmented with a variety of colorants, is used for packaging toiletries, detergents and similar products.

Qualities: Stiffness, strength/toughness, low cost, ease of forming, resistance to chemicals, permeability to gas, ease of processing.

Uses: Milk, water and juice containers, grocery bags, toys, liquid detergent bottles.

Recycled Products: Recycling bins, benches, bird feeders, retractable pens, clipboards, fly swatters, dog houses, vitamin bottles, floor tile, liquid laundry detergent containers.

Vinyl (Polyvinyl Chloride or PVC):



In addition to its good physical properties, PVC has excellent transparency, chemical resistance, long-term stability, flammability resistance, good weatherability, flow and insulatory electrical properties. The diverse slate of vinyl products can be broadly divided into rigid and flexible materials. Rigid applications, accounting for 60 percent of total vinyl production, are concentrated in construction markets which include pipe and fittings, siding, carpet backing and windows. Bottles and packaging sheet are also major rigid markets. Flexible vinyl is used in wire and cable insulation, film and sheet, floor coverings, synthetic-leather products, coatings, blood bags, medical tubing and many more applications.

Qualities: Versatility, ease of blending, strength/toughness, resistance to grease/oil, resistance to chemicals, clarity, low cost.

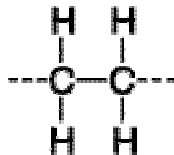
Uses: Clear food packaging, shampoo bottles.

Recycled Products: Air bubble cushioning, flying discs, decking, film, paneling, recycling containers, roadway gutters, snowplow deflectors, playground equipment.

Low Density Polyethylene (LDPE):



LDPE



A plastic used predominantly in film applications due to its toughness, flexibility and relative transparency. Because of its lower melting point at a given density, it is used in applications where heat sealing is easily accomplished. LDPE is the preferred resin on older unconverted film extrusion equipment due to its ease of extrusion. Typically, LDPE is used to manufacture flexible films such as those used for plastic retail bags and garment dry cleaning and grocery bags. LDPE is also used to manufacture some flexible lids, and it is widely used in wire and cable applications for its good insulatory electrical properties and processing characteristics.

Qualities: Ease of processing, barrier to moisture, strength/toughness, flexibility, ease of sealing, low cost.

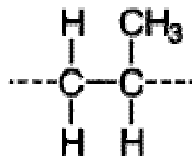
Uses: Bread bags, frozen food bags, grocery bags.

Recycled Products: Shipping envelopes, garbage can liners, floor tile, furniture, film, compost bins, paneling, trash cans, landscape timber, mud flaps.

Polypropylene (PP):



PP



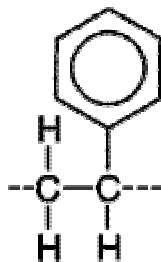
Polypropylene has excellent chemical resistance, is strong and has the lowest density of the plastics used in packaging. It has a high melting point, yet is readily heat-sealable. In film form it may or may not be oriented (stretched). It is also relatively inexpensive. PP is found in everything from flexible and rigid packaging to fibers and large molded parts for automotive and consumer products.

Qualities: Strength/toughness, resistance to chemicals, resistance to heat, barrier to moisture, low cost, versatility, ease of processing, resistance to grease/oil.

Uses: Ketchup bottles, yogurt containers and margarine tubs, medicine bottles.

Recycled Products: Signal lights, battery cables, brooms and brushes, ice scrapers, oil funnels, landscape borders, bicycle racks.

Polystyrene (PS):



Polystyrene is a very versatile plastic that can be rigid or foamed. General purpose polystyrene is clear, hard and brittle. On a per-pound basis, it is a very inexpensive resin. It is a rather poor barrier to oxygen and water vapor and has relatively low melting point. Typical applications include protective packaging, containers, lids, bottles, trays and tumblers.

Qualities: Versatility, insulation, ease of processing, low cost, clarity.

Uses: Videocassette cases, compact disc jackets, coffee cups, knives, spoons and forks, cafeteria trays, grocery store meat trays and fast-food sandwich containers.

Recycled Products: Thermometers, light switch plates, insulation, egg cartons, vents, desk trays, rulers, license plate frames, concrete.

Resin Identification Code

The Society of the Plastics Industry, Inc. (SPI) introduced its resin identification coding system in 1988 at the urging of recyclers around the country. A growing number of communities were implementing recycling programs in an effort to decrease the volume of waste subject to rising tipping fees at landfills. In some cases, these programs were driven by state-level recycling mandates. The SPI code was developed to meet recyclers' needs while providing manufacturers a consistent, uniform system that could apply nationwide. Because municipal recycling programs traditionally have targeted packaging—primarily containers—the SPI coding system offered a means of identifying the resin content of bottles and containers commonly found in the residential waste stream. Recycling firms have varying standards for the plastics they accept. Some firms may require that the plastics be sorted by type and separated from other recyclables; some may specify that mixed plastics are acceptable if they are separated from other

recyclables; while others may accept all material mixed together. Not all types of plastics are generally recycled, and recycling facilities may not be available in some areas.