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Contribution of Plastics to the Standard of Living

Technology is the main source for increasing the standard of living[1]. Technological advances increase the rate and efficiency of production of goods and services. During the 20th century, one significant advance was the development of useful and mass-produced synthetic polymers often called plastics. The importance of plastics in today's economy is indicated by their ubiquity: nearly every product uses plastic in some way, perhaps as an intricate part, or for packaging. Table 1 shows the use of plastic by various industries. This wide use follows from plastics' desirable properties.

Table 1. Sale of Plastics in the US in 2011 [1]

Market	Sales in 2011 (millions of pounds)
Transportation	2649
Packaging	25302
Building and Construction	11036
Electrical	1618
Furniture	1818
Consumer (e.g. toys)	1473
Industrial (e.g. machine parts)	781
Adhesives	801
Other	1206
Exports	14858
Total	74811

[1]For a particular socioeconomic class, the standard of living is the amount of goods and services available to that class.

Desirable properties of polymers include low density, high strength per unit mass, easy processing, chemical inertness, and adjustable properties via additives. Most plastics are made from easily available raw materials, such as crude oil. The useful properties of plastics derive from their molecular structure; most polymer molecules are long chains of hydrocarbons or hydrocarbon derivatives. Because the long intertwining chains create strong intermolecular forces, polymers are strong for their weight. A variety of additives can be added to the molecular chains, bonded onto or between chains, or mixed in as a nonvolatile solvent. These additives modify properties such as color, rigidity or flexibility, fire resistance, and chemical activity[2]. When made from hydrocarbons, polymers have a low density relative to other materials such as metals or ceramics. Table 2 shows densities for various plastics and metals.

Table 2. Density of various metals and plastics [2] [3] [4]

Material	Density (g/cm^3)
Aluminum	2.712
Lead	11.34
Iron	7.85
Acylonitrile Butadiene Styrene (ABS)	1.04
Ultra-Low-Density Polyethylene (ULDPE)	0.904-0.912
High-Density Polyethylene (HDPE)	0.930-0.977
Ethylene Chlorotrifluoroethylene (ECTFE)	1.67-1.68

[2] One well-known additive is BPA, Bisphenol A, $(CH_3)_2\ C(C_6H_4OH)_2$, used as a plasticizer (a class of additives that increases flexibility in plastics) and sometimes as a polymerization initiator. However, recent studies suggest that this additive may be a health hazard.

Most plastics are formed using chain polymerization reactions, where monomers are chemically bonded end to end in repeating patterns. These reactions can be controlled using several variables, such as pressure, temperature, reaction time, and concentration of additives, to change the final composition of the plastic. Since most monomers are fluids, while polymers are soft solids, most plastics can be easily molded, extruded, or machined into a desired form with little energy.

Plastics came into prominence during the early-mid 20th century, although some plastics date back to the late 1800s. One of the first plastics was celluloid, made from nitrocellulose and camphor; it was first sold in the 1860s as a replacement for costly ivory in billiard balls. More modern uses for cellulose include photography film and ping-pong balls.

The first thermosetting[3] plastic was Bakelite[4], created in 1907 by Dr. Baekeland, and brought to market in 1920 as "the material of 1000 uses". Developed to replace resin extracted from beetles, it is produced by a condensation reaction between phenol and formaldehyde. It was used in the electrical and car industries due to its high chemical and heat resistance, as well as its electric-insulating properties. Bakelite can be used in many miscellaneous products, such as the outside of appliances, whistles, and the handles of rifles and pistols. Today, it has been mostly replaced by easier-to-synthesize plastics, except in industrial applications that require specific properties, such as high heat resistance.

[3] Thermosetting polymers cure irreversibly, usually shaped before curing and molded into its final shape. Heating a thermoset will decompose it, as opposed to a thermoplastics that becomes liquid.
[4] Bakelite is polyoxybenzylmethylenglycolanhyride

However, some of the most ubiquitous plastics emerged during the mid 1900s. Nylon was first created in 1938 for use in toothbrush bristles by DuPont, and was then more famously used in women's stockings in 1940 and parachutes in World War II. Styrofoam, also known as expanded polystyrene foam, was created in 1941 by Dow. Originally used for insulation and life rafts, it can now be commonly seen in disposable cups.

The plastic industry has evolved to where custom plastics can be created for a variety of specific applications by varying polymerization times and conditions that affect the length of a molecular chain and the degree of branching. Additive can provide flexibility, flame resistance, and chemical resistance.

One of the key uses for polymers is packaging. Polymers have excellent properties for making shipping and packaging materials: low density, inertness, impermeability, and they are easily colored. Also, these plastics are inexpensive. Polymers can be made with very low density, important for shipping and packaging materials, to keep shipping costs low. For example, it requires 2 pounds of plastic to deliver 1300 ounces of liquid, as opposed to 3 pounds of aluminum, 8 pounds of steel, or 40 pounds of glass [1]. In addition, the flexibility of some plastics prevents fracture during transport, as opposed to glass bottles that can shatter. Many plastics are inert and impermeable, preventing the degradation of products, increasing shelf-life and the distance goods can be transported. Packaging experts estimate that each pound of plastic used in food packaging reduces food waste by 1.7 pounds [1]. Also, the production of plastic requires less energy (a large source of production costs), as shown by the energy costs of

different packaging materials listed in Table 3. Thus, plastic packaging reduces the cost of shipping products[5].

Table 3. Energy required to manufacture packaging products [5] [6] [7]

Product	Mega-joules of Electricity
1L Plastic Bottle	3.4
12oz Aluminum Can	7.45
12 oz Glass bottle	3.9
Paper bag	2.62
Polyethylene bag of equal capacity	0.763

As transportation costs decrease, production can be consolidated, providing economies of scale. Production is often located in less-developed countries where the cost of labor is low, bringing an influx of capital to the country and creating more consumers. Cheap labor and economies of scale lower prices and increase sales. A prime example of this is the shift of production facilities to China in recent decades.

Synthetic polymers would not be useful unless they were easily and widely available. Fortunately, polymers are cheap to produce and process compared to alternatives, as shown in Table 4 that gives the market price of plastic and other materials.

[5] Plastics also help reduce the weight of transportation vehicles by replacing heavier materials, further decreasing transportation costs.

Table 4. Average market price of common materials and various plastics. [8] [9] Pricing is by weight, making dense metals seem cheaper. Steel is roughly 8 times denser than most plastics.

Material	Average Price, Oct 2012 ($/lb)
Aluminum	0.85
Steel	0.16
Lead	0.92
Tin	9.05
Low-Density Polyethylene	0.67
High-Density Polyethylene	0.66
Polypropylene	0.66

Plastics are produced primarily from crude oil. As most of the demand for oil is driven by fuel needs, the plastics industry benefits from advances in crude oil production. 254 million barrels of oil are used annually in US plastics production. However, this was only 3.6% of the total US oil consumption. [1]

Synthetic polymers are not made from plants or animals (as opposed to silk, natural rubber, shellac), leading to wider and reliable availability. This increases economies of scale, and allows for a wider market. Also, because polymers are synthetic and not made from animal or plant materials, they exhibit fewer inconsistencies compared to other materials like wood. The consistent availability of plastics streamlines supply lines, eliminating costly inventory surplus or shortages. Table 5 shows US annual production of a variety of plastics.

Table 5. US Usage of Different Plastics in 2011 [1]

Type	Abbreviation	Chemical Formula	Example Uses	Total US use, 2011 (millions of pounds)
Thermosetting Plastics				13692
Low-Density Polyethylene	LDPE	$(C_2H_2)_n$	Films and plastic bags	6744
Linear Low-Density Polyethylene	LLDPE	$(C_2H_2)_n$	Packaging	13574
High-Density Polyethylene	HDPE	$(C_2H_2)_n$	Packaging	17245
Polypropylene	PP	$(C_3H_6)_n$	Lids, bottle tops	16425
Polystyrene	PS	$(C_8H_8)_n$	Insulation	5514
Nylon (Polyamide)		$(COC_4H_8CON\text{-}HC_6H_{12}NH)_n$	Clothing	1110
Polyvinyl Chloride	PVC	$(C_2H_3Cl)_n$	Tubes	14447
Other Thermoplastics				16033
Total Thermoplastics[6]				91092
Total Plastics				104784

Because of their low cost, plastics have replaced other materials, often resulting in lower durability and "disposable" products. For example, mechanical pencils and safety razors can be purchased for approximately 10 and 25 cents, respectively. Without plastics to form the body and mechanical parts, such as the razor-blade hinge, prices would not be in the disposable range. In addition, the relative ease of shaping and controlling polymers provides improvements in rapidly constructing prototypes for new products. This has enabled more frequent redesigns of products to stimulate sales of products as trends come and go. For example, toys now experience yearly or seasonal redesigns and more complex parts, as opposed to the simpler toys from the mid-twentieth century. In addition, the low density, low cost, ease of dyeing, and ease of shaping makes plastics attractive for the outside casing of

[6] Thermoplastics are plastics that can be reshaped after formation by heating them to a glass transition temperature, where they can then be reshaped.

products. Miscellaneous goods all use plastic cases, such as computer mice, pens, kitchen appliances, and vacuum cleaners. Plastic allow lower prices, replacing more expensive materials like steel or difficult-to-shape materials like wood. Plastics have increased the trend toward more fashion or novelty-oriented goods that are not needed. The low cost of plastics encourages the creation and consumption of otherwise cost-prohibitive goods. This trend has played a large part in the economic growth the US has seen over the last century.

In addition to being a major scientific advance, the low cost and versatility of plastics make them a major part of today's economy, and also make them a part of the consumer culture of excess buying of low-cost goods. The increased consumption enabled by plastics stimulates the economy through higher production of goods. However, the disposal of discarded plastic has become an increasingly pressing issue. Typical plastics are chemically resistant to the reactions that break down most trash. New research is required to produce biodegradable plastics that can decompose in natural conditions.

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