Journal of Advances in Science and Technology

Vol. III, No. VI, August-2012, ISSN 2230-9659

THE STUDY OF PLASTIC CHEMISTRY

www.ignited.in

Journal of Advances in Science and Technology
Vol. III, No. VI, August-2012, ISSN 2230-9659

The Study of Plastic Chemistry

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***Abstract:* The term "plastics" covers a range of synthetic or semi-synthetic polymerization products. They are composed of organic condensation or addition polymers and may (often) contain other substances to improve performance or economics. There are few natural polymers generally considered to be "plastics". Plastics can be formed into objects or films or fibers. Their name is derived from the fact that many are malleable, having the property of plasticity. Plastics are designed with immense variation in properties such as heat tolerance, hardness, resiliency and many others. Combined with this adaptability, the general uniformity of composition and light weight of plastics ensures their use in almost all industrial segments.**

"Plastic" may also refer to any material characterized by deformation or failure under shear stress- see Plasticity (physics) and ductile.

Plastics can be classified in many ways but most commonly by their polymer back-bone (vinyl{chloride}, polyethylene, acrylic, silicone, urethane, etc.). Other classifications include thermoplastic vs. thermoset, elastomer vs. engineering plastic , addition or condensation, and Glass transition temperature or T_g.

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INTRODUCTION:

Many plastics are partially crystalline and partially amorphous in molecular structure, giving them both a melting point (the temperature at which the covalent bonds dissolve) and one or more glass transitions (temperatures at which the degree of cross-linking is substantially reduced.)

Plastics are polymers: long-chains of atoms bonded to one another. These chains are made up of many repeating molecular units, or "monomers". The vast majority of plastics are composed of polymers of carbon alone or with oxygen, nitrogen, chlorine or sulfur in the back-bone. (Some of commercial interest are silicon based.) The back-bone is that part of the chain on the main "path" linking the multitude of monomer units together. To customize the properties of a plastic different molecular groups "hang" from the back-bone (usually they are "hung" as part of the monomers before linking monomers together to form the polymer chain). This customization by pendant groups has allowed plastics to become such an indispensable part of 21st Century life by fine-tuning the properties of the polymer.

FINDINGS:

The development of plastics has come from the use of natural materials (e.g. chewing gum, shellac) to the use of chemically modified natural materials (e.g. natural rubber, nitrocellulose) and finally to completely man-made molecules (e.g. epoxy, polyvinyl chloride, polyethylene).

NATURAL POLYMERS

People have been using artificial organic polymers for centuries in the form of waxes and shellacs. A plant polymer named "cellulose" provides the structural strength for natural fibers and ropes, and by the early 19th century natural rubber, tapped from rubber trees, was in widespread use.

Eventually, inventors learned to improve the properties of natural polymers. Natural rubber was sensitive to temperature, becoming sticky and smelly in hot weather and brittle in cold weather. In 1834, two inventors, Friedrich Ludersdorf of Germany and Nathaniel Hayward of the US, independently discovered that adding sulfur to raw rubber helped prevent the material from becoming sticky.

In 1839, the American inventor Charles Goodyear was experimenting with the sulfur treatment of natural rubber when, according to legend, he dropped a piece of sulfur-treated rubber on a stove. The rubber seemed to have improved properties, and Goodyear followed up with further experiments, and developed a process known as "vulcanization" that involved cooking the rubber with sulfur. Compared to untreated natural rubber, Goodyear's "vulcanized rubber" was stronger, more resistant to abrasion, more elastic, much less sensitive to temperature, impermeable to gases, and highly resistant to chemicals and electric current.

Vulcanization remains an important industrial process for the manufacture of rubber in both natural and artificial forms. Natural rubber is composed of an organic polymer named "isoprene". Vulcanization creates sulfur bonds that link separate isoprene polymers together, improving the material's structural integrity and its other properties.

CELLULOSE BASED PLASTICS: CELLULOID AND RAYON

All Goodyear had done with vulcanization was improve the properties of a natural polymer. The next logical step was to use a natural polymer, cellulose, as the basis for a new material.

Inventors were particularly interested in developing synthetic substitutes for those natural materials that were expensive and in short supply, since that meant a profitable market to exploit. Ivory was a particularly attractive target for a synthetic replacement.

An Englishman from Birmingham, named Alexander Parkes developed a "synthetic ivory" named "pyroxlin", which he marketed under the trade name "Parkesine", and which won a bronze medal at the 1862 World's fair in London. Parkesine was made from cellulose treated with nitric acid and a solvent. The output of the process hardened into a hard, ivory-like material that could be molded when heated.

However, Parkes was not able to scale up the process to an industrial level, and products made from Parkesine quickly warped and cracked after a short period of use. An American printer and amateur inventor named John Wesley Hyatt took up where Parkes left off. Parkes had failed for lack of a proper softener, but Hyatt discovered that camphor would do the job very nicely.

Hyatt was something of an industrial genius who understood what could be done with such a shapeable, or "plastic", material, and proceeded to design much of the basic industrial machinery needed to produce good-quality plastic materials in quantity. Since cellulose was the main constituent used in the synthesis of his new material, Hyatt named it "celluloid". It was introduced in 1863.

One of the first products were dental pieces, and sets of false teeth built around celluloid proved cheaper than existing rubber dentures. However, celluloid dentures tended to soften when hot, making tea drinking tricky, and the camphor taste tended to be difficult to suppress.

Celluloid's real breakthrough products were waterproof shirt collars, cuffs, and the false shirt fronts known as "dickies", whose unmanageable nature later became a stock joke in silent-movie comedies. They didn't wilt and didn't stain easily, and Hyatt sold them by trainloads. Corsets made with celluloid stays also proved popular, since perspiration didn't rust the stays, as it would if they had been made of metal.

Celluloid proved extremely versatile in its field of application, providing a cheap and attractive replacement for ivory, tortoiseshell, and bone, and traditional products that had used these materials were much easier to fabricate with plastics. Some of the items made with cellulose in the 19th century were beautifully designed and implemented. For example, celluloid combs made to tie up the long tresses of hair fashionable at the time are now jewel-like museum pieces. Such pretty trinkets were no longer only for the rich.

Celluloid could also be used in entirely new applications. Hyatt figured out how to fabricate the material in a strip format for movie film. By the year 1900, movie film was a major market for celluloid.

However, celluloid still tended to yellow and crack over time, and it had another, more dangerous defect: it burned very easily and spectacularly, unsurprising given that mixtures of nitric acid and cellulose are also used to synthesize smokeless powder.

Ping-pong balls, one of the few products still made with celluloid, sizzle and burn if set on fire, and Hyatt liked to tell stories about celluloid billiard balls exploding when struck very hard. These stories might have had a basis in fact, since the billiard balls were often celluloid covered with paints based on another, even more flammable, nitrocellulose product known as "collodion". If the balls had been imperfectly manufactured, the paints might have acted as primer to set the rest of the ball off with a bang.

Cellulose was also used to produce cloth. While the men who developed celluloid were interested in replacing ivory, those who developed the new fibers were interested in replacing another expensive material, silk.

In 1884, a French chemist, the Comte de Chardonnay, introduced a cellulose-based fabric that became known as "Chardonnay silk". It was an attractive cloth, but like celluloid it was very flammable, a property completely unacceptable in clothing. After some ghastly accidents, Chardonnay silk was taken off the market.

In 1894, three British inventors, Charles Cross, Edward Bevan, and Clayton Beadle, patented a new "artificial silk" or "art silk" that was much safer. The three men sold the rights for the new fabric to the French Courtald company, a major manufacturer of silk, which put it into production in 1905, using cellulose from wood pulp as the "feedstock" material.

Art silk became well known under the trade name "rayon", and was produced in great quantities through the 1930s, when it was supplanted by better artificial fabrics. It still remains in production today, often in blends with other natural and artificial fibers. It is cheap and feels smooth on the skin, though it is weak when wet and creases easily. It could also be produced in a transparent sheet form known as "cellophane".

BAKELITE (PHENOLIC)

The limitations of celluloid led to the next major advance, known as "phenolic" or "phenol-formaldehyde" plastics. A chemist named Leo Hendrik Baekeland, a Belgian-born American living in New York state, was searching for an insulating shellac to coat wires in electric motors and generators. Baekelund found that mixtures of phenol (C_6H_5OH) and formaldehyde ($HCOH$) formed a sticky mass when mixed together and heated, and the mass became extremely hard if allowed to cool and dry.

He continued his investigations and found that the material could be mixed with wood flour, asbestos, or slate dust to create "composite" materials with different properties. Most of these compositions were strong and fire-resistant. The only problem was that the material tended to foam during synthesis, and the resulting product was of unacceptable quality.

Baekelund built pressure vessels to force out the bubbles and provide a smooth, uniform product. He publicly announced his discovery in 1909, naming it "bakelite". It was originally used for electrical and mechanical parts, finally coming into widespread use in consumer goods in the 1920s. When the Bakelite patent expired in 1927, the Catalin Corporation acquired the patent and began manufacturing Catalin plastic using a different process that allowed a wider range of coloring.

Bakelite was the first true plastic. It was a purely synthetic material, not based on any material or even molecule found in nature. It was also the first "thermoset" plastic. Conventional "thermoplastics" can be molded and then melted again, but thermoset plastics form bonds between polymers strands when "cured", creating a tangled matrix that cannot be undone without destroying the plastic. Thermoset plastics are tough and temperature resistant.

Bakelite was cheap, strong, and durable. It was molded into thousands of forms, such as radios, telephones, clocks, and, of course, billiard balls. The U.S. government even considered making one-cent coins out of it when World War II caused a copper shortage.

Phenolic plastics are still in widespread use. For example, some electronic circuit boards are made of sheets of paper or cloth impregnated with phenolic resin.

POLYSTYRENE AND PVC

After the First World War, improvements in chemical technology led to an explosion in new forms of plastics. Among the earliest examples in the wave of new plastics were "polystyrene" (PS) and "polyvinyl chloride" (PVC), developed by the I.G. Farben company of Germany.

Polystyrene is a rigid, brittle plastic that is now used to make plastic model kits, disposable eating utensils, and similar knicknacks. It would also be the basis for one of the most popular "foamed" plastics, under the name "styrene foam" or "Styrofoam". Foam plastics can be synthesized in an "open cell" form, in which the foam bubbles are interconnected, as in an absorbent sponge, and "closed cell", in which all the bubbles are distinct, like tiny balloons, as in gas-filled foam insulation and floatation devices.

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styrene monomer   polystyrene polymer ("<bzr>" is a benzene ring)

PVC has side chains incorporating chlorine atoms, which form strong bonds. PVC in its normal form is stiff, strong, heat and weather resistant, and is now used for making plumbing, gutters, house siding, enclosures for computers and other electronics gear. PVC can also be softened with chemical processing, and in this form it is now used for shrink-wrap, food packaging, and raingear.

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vinyl chloride monomer polyvinyl chloride polymer

Nylon

The real star of the plastics industry in the 1930s was "polyamide" (PA), far better known by its trade name, "nylon". Nylon was the first purely synthetic fiber, introduced by Du Pont Corporation at the 1936 World's Fair in New York City.

In 1927, Du Pont had begun a secret development project designated "Fiber66", under the direction of a Harvard chemist named Wallace Carothers. Carothers had been hired to perform pure research, and not only investigated new materials, but worked to understand their molecular structure and how it related to material properties. He took some of the first steps on the road to "molecular design" of materials.

His work led to the discovery of synthetic nylon fiber, which was very strong but also very flexible. The first application was for bristles for toothbrushes. However, Du Pont's real target was silk, particularly silk stockings.

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nylon polymer chain

It took Du Pont twelve years and $27 million USD to refine nylon and develop the industrial processes for bulk manufacture. With such a major investment, it was no surprise that Du Pont spared little expense to promote nylon after its introduction, creating a public sensation, or "nylon mania". Nylon mania came to an abrupt stop at the end of 1941, when America entered World War II. The production capacity that had been built up to produce nylon stockings, or just "nylons", for American women, was taken over to manufacture vast numbers of parachutes for fliers and paratroopers. After the war ended, Du Pont went back to selling nylon to the public, engaging in another promotional campaign in 1946 that resulted in an even bigger craze, triggering off "nylon riots ".

Nylon still remains an important plastic, and not just for use in fabrics. In its bulk form it is very wear-resistant, and so is used to build gears, bearings, bushings, and other mechanical parts.

SYNTHETIC RUBBER

Another plastic that was critical to the war effort was "synthetic rubber", which was produced in a variety of forms.

Practical synthetic rubber grew out of studies published in 1930 written independently by Carothers and the German scientist Hermann Staudinger. These studies led in 1931 to one of the first successful synthetic rubbers, known as "neoprene". Neoprene is highly resistant to heat and chemicals such as oil and gasoline, and is used in fuel hoses and as an insulating material in machinery.

In 1935, German chemists synthesized the first of a series of synthetic rubbers known as "Buna rubbers". These were "copolymers", meaning that their polymers were made up from not one but two monomers, in alternating sequence. One such Buna rubber, known as "GR-S" ("Government Rubber Styrene), is a copolymer of butadiene and styrene, became the basis for US synthetic rubber production during World War II.

Worldwide natural rubber supplies were limited, and by mid-1942 most of the rubber-producing regions were under Japanese control. Military trucks needed rubber for tires, and rubber was used in almost every other war machine. The US government launched a major (and largely secret) effort to develop and refine synthetic rubber. A principal scientist involved with the effort was Edward Robbins .

By 1944 a total of 50 factories were manufacturing it, pouring out a volume of the material twice that of the world's natural rubber production before the beginning of the war.

After the war, natural rubber plantations no longer had a stranglehold on rubber supplies, particularly after chemists learned to synthesize isoprene. GR-S remains the primary synthetic rubber for the manufacture of tires.

Synthetic rubber would also play an important part in the space race and nuclear arms race. Solid rockets used during World War II used nitrocellulose explosives for propellants, but it was impractical and dangerous to make such rockets very big.

During the war, California Institute of Technology (Caltech) researchers came up with a new solid fuel, based on asphalt fuel mixed with an oxidizer, such as potassium or ammonium percholorate, plus aluminum powder, which burns very hot. This new solid fuel burned more slowly and evenly than nitrocellulose explosives, and was much less dangerous to store and use, though it tended to flow slowly out of the rocket in storage and the rockets using it had to be stockpiled nose-down.

After the war, the Caltech researchers began to investigate the use of synthetic rubbers instead of asphalt as the fuel in the mixture. By the mid-1950s, large missiles were being built using solid fuels based on synthetic rubber, mixed with ammonium perchlorate and high proportions of aluminum powder. Such solid fuels could be cast into large, uniform blocks that had no cracks or other defects that would cause nonuniform burning. Ultimately, all large military rockets and missiles would use synthetic rubber based solid fuels, and they would also play a significant part in the civilian space effort.

PLASTICS EXPLOSION: ACRYLIC, POLYETHYLENE, ETC

Other plastics emerged in the prewar period, though some wouldn't come into widespread use until after the war.

By 1936, American, British, and German companies were producing "polymethyl methacrylate" (PMMA), better known as "acrylic". Although acrylics are now well-known for the use in paints and synthetic fibers, such as "fake furs", in their bulk form they are actually very hard and more transparent than glass, and are sold as glass replacements under trade names such as "Plexiglas" and "Lucite". Plexiglas was used to build aircraft canopies during the war, and it is also now used as a marble replacement for countertops.

Another important plastic, "polyethylene" (PE), sometimes known as "polythene", was discovered in 1933 by Reginald Gibson and Eric Fawcett at the British industrial giant Imperial Chemical Industries (ICI). This material evolved into two forms, "low density polyethylene" (LDPE), and "high density polyethylene" (HDPE).

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ethylene monomer polyethylene polymer

PEs are cheap, flexible, durable, and chemically resistant. LDPE is used to make films and packaging materials, while HDPE is used for containers, plumbing, and automotive fittings. While PE has low resistance to chemical attack, it was found later that a PE container could be made much more robust by exposing it to fluorine gas, which modified the surface layer of the container into the much tougher "polyfluoroethylene ".

Polyethylene would lead after the war to an improved material, "polypropylene" (PP), which was discovered in the early 1950s by Giulio Natta. It is common in modern science and technology that the growth of the general body of knowledge can lead to the same inventions in different places at about the same time, but polypropylene was an extreme case of this phenomenon, being separately invented about nine times. It was a patent attorney's dream scenario, and litigation wasn't resolved until 1989.

Polypropylene managed to survive the legal process, and two American chemists working for Phillips Petroleum of the Netherlands, J. Paul Hogan and Robert Banks, are now generally credited as the "official" inventors of the material. Polypropylene is similar to its ancestor, polyethylene, and shares polyethylene's low cost, but it is much more robust. It is used in everything from plastic bottles to carpets to plastic furniture, and is very heavily used in automobiles.

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propylene monomer polypropylene polymer

Polyurethane was invented by Friedrich Bayer & Company of Germany in 1937, and would come into use after the war in blown form for mattresses, furniture padding, and thermal insulation. It is also used in non-blown form for sports wear as "lycra".

In 1939, I.G. Farben Industrie of Germany filed a patent for "polyepoxide" or "epoxy". Epoxies are a class of thermoset plastic that form cross-links and "cure" when a catalyzing agent, or "hardener", is added. After the war they would come into wide use for coatings, "adhesives", and composite materials.

Composites using epoxy as a matrix include glass-reinforced plastic, where the structural element is glass fiber, and "carbon-epoxy composites", in which the structural element is carbon fiber. Fiberglass is now often used to build sport boats, and carbon-epoxy composites are an increasingly important structural element in aircraft, as they are lightweight, strong, and heat-resistant.

Two chemists named Rex Whinfield and James Dickson, working at a small English company with the quaint name of the "Calico Printer's Association" in Manchester, developed "polyethylene terephthalate" (PET or PETE) in 1941, and it would be used for synthetic fibers in the postwar era, with names such as "polyester", "dacron", and "terylene".

PET is more impermeable than other low-cost plastics and so is a popular material for making bottles for Coca-Cola and other "fizzy drinks", since carbonation tends to attack other plastics, and for acidic drinks such as fruit or vegetable juices. PET is also strong and abrasion resistant, and is used for making mechanical parts, food trays, and other items that have to endure abuse. PET films, tradenamed "Mylar®", are used to make recording tape.

One of the most impressive plastics used in the war, and a top secret, was "polytetrafluoroethylene" (PTFE), better known as "teflon", which could be deposited on metal surfaces as a scratchproof and corrosion-resistant, low-friction protective coating. The polyfluoroethylene surface layer created by exposing a polyethylene container to fluorine gas is very similar to teflon.

A Du Pont chemist named Roy Plunkett discovered teflon by accident in 1938. During the war, it was used in gaseous-diffusion processes to refine uranium for the atomic bomb, as the process was highly corrosive. By the early 1960s, teflon "non-stick" frying pans were a hot consumer item.

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F      F            F   F   F

tetrafluoroethylene monomer      teflon polymer
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Teflon was later used to synthesize the miracle fabric "Gore-Tex", which can be used to build raingear that in principle "breathes" to keep the wearer's moisture from building up. GoreTex is also used for surgical implants; teflon strand is used to make dental floss; and teflon mixed with fluorine compounds is used to make "decoy" flares dropped by aircraft to distract heat-seeking missiles.

After the war, the new plastics that had been developed entered the consumer mainstream in a flood. New manufacturing were developed, using various forming, molding, casting, and extrusion processes, to churn out plastic products in vast quantities. American consumers enthusiastically adopted the endless range of colorful, cheap, and durable plastic gimmicks being produced for new suburban home life.

One of the most visible parts of this plastics invasion was Earl Tupper's "tupperware", a complete line of sealable polyethylene food containers that Tupper cleverly promoted through a network of housewives who sold Tupperware as a means of bringing in some money. The tupperware line of products was well thought out and highly effective, greatly reducing spoilage of foods in storage. Thin-film "plastic wrap " that could be purchased in rolls also helped keep food fresh.

Another prominent element in 1950s homes was "Formica®", a plastic laminate that was used to surface furniture and cabinetry. Formica was durable and attractive. It was particularly useful in kitchens, as it did not absorb, and could be easily cleaned of stains from food preparation, such as blood or grease. With formica, a very attractive and well-built table could be built using low-cost and lightweight plywood with formica covering, rather than expensive and heavy hardwoods like oak or mahogany.

Composite materials like fiberglass came into use for building boats and, in some cases, cars. Polyurethane foam was used to fill mattresses, and styrofoam was used to line ice coolers and make float toys.

Plastics continue to be improved. General Electric introduced "lexan", a high-impact "polycarbonate" plastic, in the 1970s. Du Pont developed "kevlar", an extremely strong synthetic fiber that was best-known for its use in bullet-proof vests and combat helmets. Kevlar was so remarkable that Du Pont officials actually had to release statements to deny rumors that the company had received the recipe for it from space aliens.

THE ENVIRONMENT

Although plastics have had a remarkable impact on our culture, it has become increasingly obvious that there is a price to be paid for their use.

Plastic was almost too good, as it was durable and degraded very slowly. In some cases, burning it could release toxic fumes. Also, the manufacturing of plastics often created large quantities of chemical pollutants, and required use of the Earth's limited supply of fossil fuels. However, it should be noted that plastics only consume 4% of world's oil production. Furthermore, it can be claimed that the use of plastics helps the environment by saving water and oil. For example, plastics make cars lighter, thus saving oil and reducing CO_2 emissions.

By the 1990s, plastic recycling programs were common in the United States and elsewhere. Thermoplastics can be remelted and reused, and thermoset plastics can be ground up and used as filler, though the purity of the material tends to degrade with each reuse cycle. There are methods by which plastics can be broken back down to a feedstock state.

To assist recycling of disposable items, the Plastic Bottle Institute of the Society of the Plastics Industry devised a now-familiar scheme to mark plastic bottles by plastic type. A recyclable plastic container using this scheme is marked with a triangle of three "chasing arrows", which enclose a number giving the plastic type:

Plastics type marks

1. PETE - Polyethylene Terephthalate, Commonly found on: 2-litre soft drink bottles, cooking oil bottles, peanut butter jars.

2. HDPE - High Density Polyethylene, Commonly found on: detergent bottles, milk jugs.

3. PVC - Polyvinyl Chloride, Commonly found on: plastic pipes, outdoor furniture, shrink wrap, water bottles, salad dressing and liquid detergent containers.

4. LDPE - Low Density Polyethylene, Commonly found on: dry cleaning bags, produce bags, trash can liners, food storage containers.

5. PP - Polypropylene - , Commonly found on: bottle caps, drinking straws

6. PS - Polystyrene, Commonly found on: packaging pellets or "Styrofoam peanuts," cups, plastic tableware, meat trays, take away food clam shell containers

7. OTHER - This plastic category, as its name of "other" implies, is any plastic other than the named #1-#6, Commonly found on: certain kinds of food containers and Tupperware.

Unfortunately, recycling plastics proved difficult. The biggest problem with plastics recycling is that it is difficult to automate the sorting of plastic waste, and so it is labor-intensive. While containers are usually made from a single type and color of plastic, making them relatively easy to sort out, a consumer product like a cellular phone may have many small parts consisting of over a dozen different types and colors of plastics. As the value of the material is low, recycling plastics is unprofitable. For this reason, the percentage of plastics recycled in the US is very small, somewhere around 5%. Even so the American Plastics Council spends about 20 million dollars a year on an ad campaign that tries to convince the public that plastic recycling works.

Recently it was shown, however, that for post-consumer plastic waste, gasification offers a solution for the recycling of such material.

Research has been done on "biodegradable" plastics that break down with exposure to sunlight. Starch can be mixed with plastic to allow it to degrade more easily, but it still doesn't lead to complete breakdown of the plastic. Some researchers have actually genetically engineered bacteria that synthesize a completely biodegradable plastic, but this material is expensive at present. BASF make Ecoflex, a fully biodegradable polyester for food packaging applications. The disadvantage of biodegradable plastics is that the carbon that is locked up in them is released into the atmosphere as the greenhouse gas carbon dioxide when they degrade.

So far, these plastics have proven too costly and limited for general use, and critics have pointed out that the only real problem they address is roadside litter, which is regarded as a secondary issue. When such plastic materials are dumped into landfills, they can become "mummified" and persist for decades even if they are supposed to be biodegradable. In this regard though plastics are no worse than food or paper which also fails to degrade in landfills.

There have been some success stories. The Courtauld concern, the original producer of rayon, came up with a revised process for the material in the mid-1980s to produce "Tencel". Tencel has many superior properties over rayon, but is still produced from "biomass" feedstocks, and its manufacture is extraordinarily clean by the standards of plastic production.

PRICE AND THE FUTURE

One of the great appeals of plastics have been their low price, as compared to other materials. However, in recent years the cost of plastics has been rising dramatically. The cause of the increase is the sharply rising cost of petroleum, the raw material that is chemically altered to form commercial plastics. As the cost of plastic hinges on the cost of petroleum, should petroleum prices continues to rise, so will the cost of plastic. In 2004, the higher price of plastic drove a number of plastic toy manufacturers out of business.

Fears of dwindling petroleum supplies are becoming very real, with publications such as USA Today reporting that current oil reserves will only last 40 years. Alternate reserves such as oil shale and tar oil (tar sand) do exist, but the cost of production is much higher than with current sources. Thus, even if alternative sources are used, costs will continue to rise.

Scientists are seeking cheaper alternatives to plastic. Some plastic alternatives are: graphite, fiberglass, carbon fiber, graphene, carbon nanotubes, diamond, aerogel, carbon nanofoam, cellulose soybean plastic (bioplastic), and other carbon-based non-petroleum materials. Some of these alternatives are too expensive or not malleable enough, but can be used in some plastic applications. Some are many times the strength of plastic, but crack if made thin like cellophane. The most promising alternatives to plastic are graphene, carbon nanotube, and carbon nanofoam. All three of these are made of nanocarbons, products of the new nanotechnology. Nanocarbons are very cheap, 100 times stronger than steel, slicker than Teflon, lightweight, and can be made very thin, made to stretch, and built into any shape - all the things plastic can do. In addition, nanocarbon manufacturing is low- to non-polluting. Already bowling balls, golf balls, sports equipment, and water-proof cotton balls have been made of nanocarbons.

Common plastics and their typical uses

Polyethylene (PE) : wide range of uses, very inexpensive

Polypropylene (PP): food containers, appliances

Polystyrene (PS): packaging foam, food containers, disposable cups, plates and cutlery

Polyethylene terephthalate (PETE): beverage containers

Polyamide (PA) (Nylon): fibres, toothbrush bristles, fishing line

Polyester : fibres, textiles

Polyvinyl chloride (PVC): plumbing pipes, flooring

Polycarbonate : compact discs, eyeglasses

Acrylonitrile butadiene styrene (ABS) : electronic equipment cases (e.g. computer monitors, printers,

keyboards)

Polyvinylidene chloride (PVDC) (Saran): food packaging

SPECIAL PURPOSE PLASTICS

Teflon: heat resistant, low-friction coatings

Polyurethane: insulation foam, upholstery foam

Bakelite: insulating parts in electrical fixtures (strictly speaking not a plastic, but a ceramic material using a phenol formaldehyde resin binder)