Plastics *for* Environment

& Sustainable Development

Indian Centre for Plastics in the Environment

Central Institute of Plastics Engineering & Technology, Chennai

(Ministry of Chemicals & Fertilizers, Govt. of India)

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It is a nodal agency recognized by the Government of India to handle all issues related to Plastics and Environment in the country.

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An Eco-assessment *Study*

With contributions from :

Indian Institute of Technology, Bombay – Mumbai

National Chemical Laboratory – Pune

Indian Institute of Technology, Delhi – New Delhi

Indian Council for Medical Research – New delhi

Indian Institute of Packaging – Mumbai

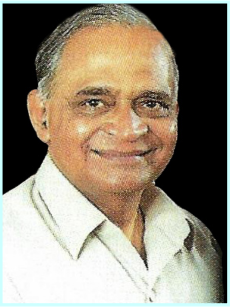
Defence Material and Stores Research and Development Establishment - Kanpur

The Automotive Research Association of India – Pune

Indian Institute of Technology, Kharagpur – Kharagpur

Central Institute of Plastics Engineering & Technology - Chennai

FOREWORD



Prof. M. M. Sharma (F.R.S.)

Padma Vibhushan

Dr. R. A. Mashelkar (F.R.S.)

Padma Vibhushan

Plastics have moulded the modern world and transformed the quality of life. There is no human activity where plastics do not play a key role, from clothing to shelter, from transportation to communication and from entertainment to health care. Plastics, because of its many attractive properties, such as lightweight, high strength and ease of processing, meet a large share of the materials needs of man. From practically zero in the fifties, human kind today consumes greater than one hundred and fifty million tons of plastics. We truly live in a 'Plastics Age'. Our daily lives would be very much poorer without these benign and environmentally friendly materials. Plastics possess a unique combination of properties. Plastics can be super tough, rigid as well as flexible, transparent as well as opaque and can allow selective permeation or act as a barrier material.

Nature has produced 'plastic' like materials for centuries. Silk and cellulose are example of natural polymers. Reference to Shellac, a thermoplastic can be found even in Mahabharatha !

Growing population and consumption in India has put severe pressure on our natural resources and fragile eco-systems. The material needs of our population are growing and plastics offer a cost effective alternative.

Plastics are employed in myriad applications where they actually conserve natural resources. For example, asceptic packaging of food in barrier packaging films will render refrigeration unnecessary, saving capital and energy. Edible oils and milk are packaged in flexible packages eliminating the use of tin and glass containers. Rigid HDPE barrels are used for bulk chemical storage instead of steel drums. Apart from conserving natural resources, use of plastics in these applications saves transportation fuel as plastics are substantially lighter than tin, glass or steel.

Safe drinking water packaged in PET bottles are a very common sight now-a-days. They provide confidence to consumer on the quality of water and help reduce water-borne diseases. Advanced polymeric membranes help purify water from viruses and bacteria. They also provide potable drinking water from sea and brackish water through a process of desalination.

The fact that plastics are made from hydrocarbons derived from petroleum, which is non-renewable, has raised questions concerning its sustainability. Nevertheless, the consumption of petroleum hydrocarbon for the production of plastics is less than 5%, the balance being consumed as fuels and energy source. Consequently, the concerns about sustainability of plastic materials is somewhat exaggerated. On the contrary, processing of many natural materials (glass, paper, wood, metals) consume far more energy and thus lead to greater consumption of fossil fuels. Additionally, research and development work currently in progress globally will provide future opportunities to make some of the plastics from biomass and other renewable resources. Thus, plastic manufacture will become even more sustainable in the years to come. It is fair to say that plastics replace several natural materials, which are either scarce, consume more energy for processing or cause damage to the eco-systems during their production. Thus use of plastics makes a positive contribution to the sustainability of earth's resources.

Another issue that is often discussed is whether because of their non-biodegradability, plastics will cause damage to our eco systems. The signature of all natural materials made by biological processes is that they are biodegradable and bio-assimilable. The long life and desirability of plastics, which have made them, a material of choice for many applications is seemingly a disadvantage when it comes to their disposal. However, when handled properly, plastics do little damage to our environment.

Plastics have the advantage that they can be easily reprocessed and recycled. In some cases, one can recover even the raw materials that were originally used in their manufacture. Plastics offer the unique advantage that one can recover the fuel value contained in the hydrocarbon polymer after its use. Plastics can also be made environmentally degradable, especially for packaging applications. There are expectations that in the near future plastics will be made even biodegradable and compostable so that waste plastics can be handled the same way as wet food waste and agricultural waste. The overall eco-friendliness of plastics become apparent when one evaluates the total 'life cycle' namely, an analysis of raw materials, energy, effluents, methods of disposal etc. of a material from its origin to its final disposal.

It is, therefore, very appropriate that the Indian Centre for Plastics in the Environment and Central Institute of Plastics Engineering and Technology are bringing about a monograph titled "Plastics for Environment and Sustainable Development". This monograph, which has chapters authored by several distinguished scientists and technologists from some of our leading R & D institutes will comprehensively address all issues concerning sustainability of plastics as materials and an assessment of the impact on environment. We do believe that the monograph will set to rest any lingering doubts about the sustainability of plastics as materials or their adverse impact on our environment and will lead to more enlightened discussion on the role of plastics in the armoury of materials used by men.

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PREFACE

Plastics, often described as one of the greatest inventions of modern age, occupy a unique position in the kaleidoscopic world of materials. Some of the greatest technological and societal developments in the 20th century and our accelerated journey into the knowledge driven new millennium have been truly made possible, to a great extent, due to the phenomenal contribution of plastics – almost a sine-quanon for modern society.

Unfortunately these important materials of construction have been much misunderstood and pilloried more on emotive grounds rather than an epistemic analyses based on scientific rationale & objective evaluation.

Indian Centre for Plastics in the Environment (ICPE), which itself is one of a select few institutions of its kind globally, has taken the initiative to publish a promethean monograph addressing the multifaceted issues and dimensions of plastics concerned with environment and sustainable development. Such an initiative is unparalleled in the lexicon of industrial communications in our country. The initiative is also unique as it has brought on a single platform - nine autonomous institutes of global repute to address specific topics. The volume, dedicated to the nation, encapsulates the summarized dissertations from luminary contributors, cutting across the broadcast spectrum - from business & industry to scientists & technologists, from research & development to academia and from environmental experts to sector specialists.

We do hope that t his volume will kindle the spirit of scientific temperament, broaden the knowledge horizon for public-at-large, facilitate sustainable development and assist those who formulate and guide the policy and regulatory regimes in the country. ICPE plans to bring out in the next phase detailed encyclopedic monographs on each of the issues.

This would be ICPE's humble contribution to a raison d'état.

ICPE

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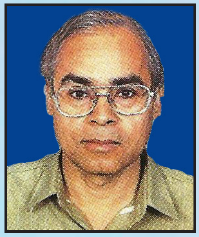

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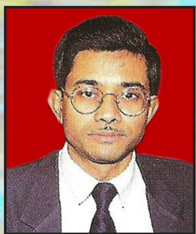

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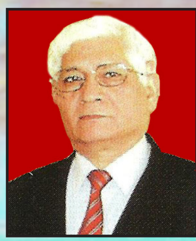

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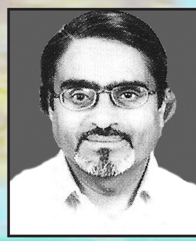

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Importance of Plastics in Modern Society

Prof. Ashok Misra

Indian Institute of Technology, Bombay
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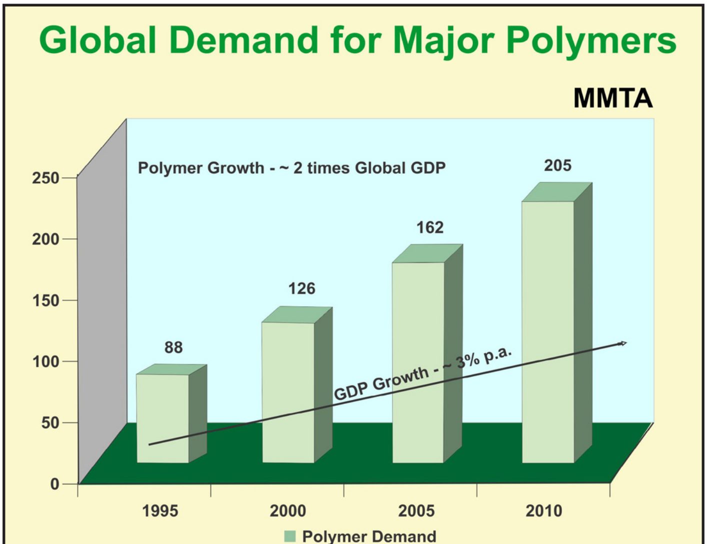
IMPORTANCE OF PLASTICS IN MODERN SOCIETY

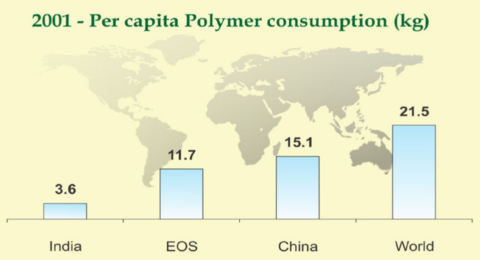
Plastics are a subset of materials known as polymers. These are composed of large molecules formed by joining many smaller molecules together (monomers). Other kinds of polymers are fibres, films, elastomers, surface coating and biopolymers, such as cellulose, proteins and nucleic acids. Plastics owe their name to their ability to be shaped to form articles of practical value by various conversion and forming processes. There are some peculiar properties of plastic materials, which make them unique so that products can literally be tailor-made out of these materials.

In fact, plastics have permeated every facet of human life viz. agriculture and water consumption, building construction, communication, small and bulk packaging, education, medicine, transportation, defence, consumer durables to name a few. One of the reasons for great popularity of plastics is due to tremendous range of properties exhibited by them because of their ease of processing. Hence, the demand for plastics has been increasing in modern living. Since last six decades the Plastic Industry has grown world wide with present consumption of more than 130 MMTPA.



Source : Chem Systems

The Polymer/Plastic growth worldwide has been steady around 6% per annum which is much higher than the GDP growth rate of 3.3%. The higher growth sectors or demand drivers for plastics consumption are consumer and bulk packaging, plasticulture, building construction, electrical and electronics, automotive, consumer goods, medical, telecommunication, furniture and household applications. The output value of commodity, engineering and high performance polymers was US $ 115 billion, accounting for about 7% of total chemical output value globally.



Low per capita polymer cosnsumption -
a pointer to promising demand growth in future
Source : Chem Systems POPS 2001

In India, however, the consumption of major plastics in only 3% of global consumption i.e. about 4 million tons annually. This is very low as compared to global levels as shown in adjoining figure.

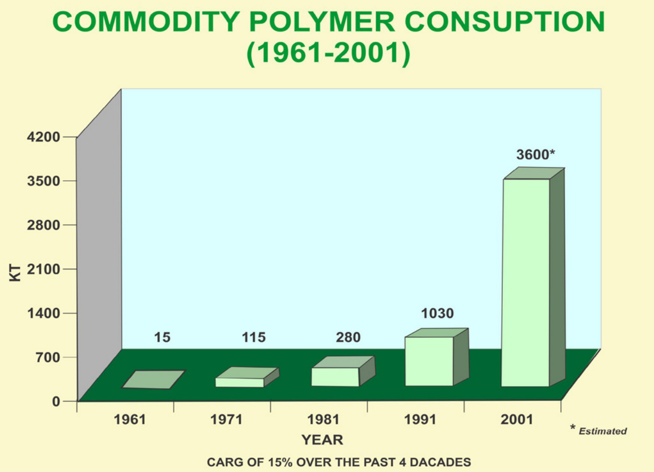
Despite a double digit polymer growth rate in India, the growth pattern is much higher in Chin which has emerged as the largest consumer of plastics in Asia as shown in table below.

Demand for Polymers India vis-a-vis China

Polymer growth & GDP (%)	1990 – 00	2000 – 10
India		
All polymers	14.3	14.0
PE/PP	16.3	15.1
GDP	6.0	~6.0
China		
All polymers	18.5	8.8
PE/PP	19.5	9.4
GDP	10.3	~6.1

Source : Chem Systems

However, in India, the consumption of plastics has been trebling every decade and from a consumption level of 61 KTA in 1960. The present Consumption has grown upto more than 4 million kilo tons and is likely to go up to 12 million kilo tons in 2010.



Consumption Trebling Every Decade
Source : CPMA

Plastics have a very strong correlation with economic growth. The Central Statistical Organisation (CSO) and NCAER **have analyzed various industry sectors for the Input-Output Matrix (for 1993-94) to study the effect of growth of various sectors on GDP growth. Out of 115 sectors analyzed, the Plastic Resin and Synthetic Fibres sectors ranks a high 37.** The importance of this sector can be gauged from the fact that one unit increase in the output value for the plastics sector reflects an increase of 2.38 units in the economy. **Over the years the demand elasticity of polymer growth in comparison with GDP growth has been about 2.4 which is in line with the NCAER study.**

The growth of Plastic consumption worldwide as well as in India is inevitable and desirable, because multiple advantages that these materials provide. Some examples are given below as illustrations.

- **Plastics help improve quality of life:** The Internet, globalization, increased speed of communication, faster means of transportation, the advance of surgical medicine – all these would not be possible without plastics. Continuous technological innovations by the plastics industry means that ever more efficient, lightweight and adaptable forms of plastics are being developed for an increasing range of uses. It is these advances that allow plastics to play an important role in the pursuit of sustainable development, by bringing innovative solutions to the full range of challenges facing society as we begin in the new millennium.

- **Preserve land, water and forest resources :** Plastics have been providing help to tackle the world's water distribution crisis, with affordable, easily constructed piping providing solutions to clean water shortages for 5.5 million people in Asia, the Middle East and Africa. The future may see not only increased distribution thanks to plastics – but also safer water. Also the use of plastics drastically reduced the use of traditional usage of wood and other forest products thus resulting in reduction of deforestation.

- **Enable efficient use of non-renewable energy resources :** It is estimated that the use of plastics as a whole actually saves more oil than is needed for their manufacture. At end-of-life, plastics can be a valuable alternative energy source in their own right. Plastics recycling continues to increase in world while energy recovery is a responsible use of our oil resources, diverting waste from landfill and helping to preserve fossil fuels. Some 2.5 billion people throughout the world are not supplied by a national electricity transmission system but could find help through alternative energy supplies. Tapping the sun and wind is already bringing clean and efficient energy to people world-wide and is greatly facilitated by the use of plastics that constitute major parts of the cells and turbines.

- **Possess a more favourable cost-benefit ratio:** Continuous improvements in the material itself and recovery technologies mean that, in the future, packaging will become even lighter and more resource-efficient. The recently introduced Smart Car – largely made of plastics – is a sign of things to come.

- **Has a very versatile range of Applications:** Plastics have proved to have a wide range of applications in a large number of field and their applications are increasing due to advantage of low cost, high durability and easy availability.

Plastics are treated as versatile materials since the properties of these materials can be tailored to meet specific demands by varying molecular weight, molecular weight distribution and side chain branching. Further making copolymers and polymer blends and alloys provide on mechanism for providing a synergism in properties and tailor making materials for specific applications.

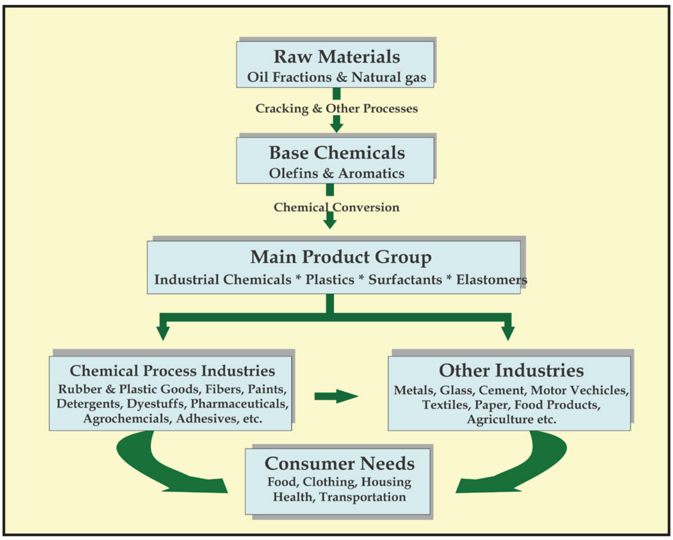
An important sub division between the thermoplastic groups of materials is related to whether they have crystalline (ordered) or amorphous (random) structure. None of the plastic materials are completely crystalline or amorphous. Some plastics, such as polyethylene and nylon can achieve a high degree of crystallinity. Other plastics such as, acrylic or polystyrene are always amorphous.

Plastics, therefore, clearly form a material choice in a large number of commercial applications. The demand of Plastics will be further driven by :

- Population growth and urbanization
- Opening of Rural Markets
- Explosive Indian middle class
- Effective Media Network
- Increased Purchasing Power
- Higher Disposable Incomes
- Successful Marketing
- Brand Awareness
- Rising Aspirations

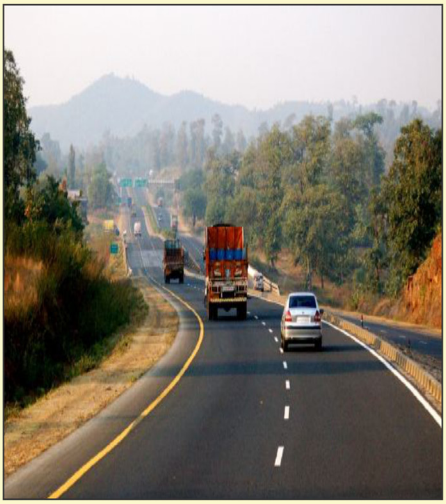
Keeping the above facts in view, it has become virtually impossible to imagine 'Life without Plastics." Plastics are mostly derived from fossil fuels viz. crude oil & natural gas. Only 4% of these fuels consumed go to make the plastics; The rest 96% being used for other human needs like transport and heating. It is this small portion of The resource, which helps in contributing towards social and economic development on the one hand, and, protection and conservation of environment on the other. In subsequent discussions, these issues have been addressed keeping in view the contribution to society, economy, and environment.

Flow Diagram from Oil to Polymer Products



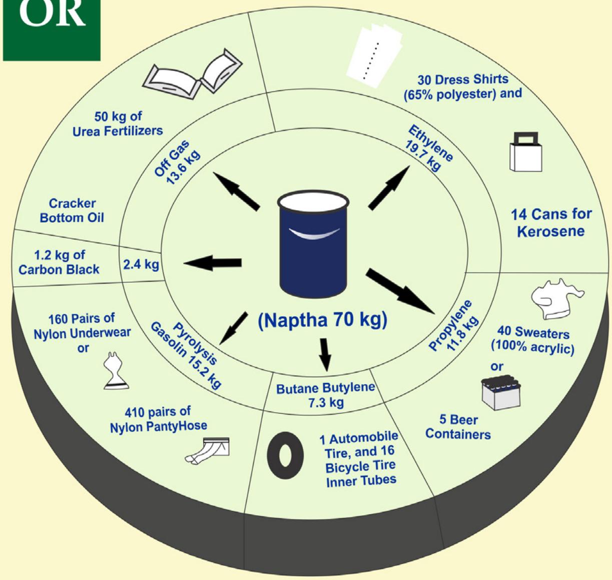
A Small qty. of Neptha provides value-added Products, improving the quality of life

1 Barrel of Naptha



A Car trip from Mumbai to Ahmedabad

OR



Manufacture of Plastics & Products

Polymers were regarded as colloids but Herman Staudinger (1920) showed that a polymer is a macromolecule consisting of several repeating units. In 1928, Carothers synthesized linear polyesters and polyamides. In 1950s, Ziegler and Natta worked on anionic coordination catalysts for synthesis polymers or plastics that led to the development of PP, HDPE and other stereo specific. There are basically three ways by which polymers or plastics can be produced synthetically from simple starting materials. These techniques are referred to as addition polymerization, condensation polymerization and rearrangement polymerization. During polymerization, the monomer units join together to form a macromolecule. The number of repeating units in a molecule is called as degree of polymerization. The most important feature in distinguishing polymers from low molecular weight compounds is the existence of a distribution of chain lengths, and degrees of polymerization and molecular weights.

Plastics are made from oil, natural gas, coal and salt. The major feedstock is oil. The petrochemical industry supplies the monomers for plastic production and manufactures a wide range of additives to modify their behavior. Plastics are produced by polymerization, the chemical

Bonding of monomers into polymers. The size and structure of the polymer molecule determines the properties of the plastic material. In their basic form, plastics are produced as powders or granules. The application of heat and pressure to these raw materials produces the final plastic product for specific end use application.

Plastics are classified as thermoplastic or thermosetting resins. Thermoplastic resins, when heated, soften and flow as viscous liquids, when cooled they solidify. The heating and cooling cycle can be repeated many times without much loss of specific properties. This property makes them suitable for recycling. Thermosetting resins liquefy when heated and solidify with continued heating. The polymer undergoes permanent cross-linking and retains its shape during subsequent heating cycles. Thermoset plastics cannot be reheated and remoulded; however, thermoplastics can be reprocessed by melting, and hence, readily recycled.

Manufacturing process of Plastic raw materials

Plastic raw materials are produced by polymerization of small chemical unit called monomer. Thermoplastics (PE, PP, PS, PVC etc.) are generally made as an addition to the polymerization process whereas Thermosets (Nylon, Polyester etc.) are manufactured by condensation of the polymerization process. Some examples of synthesis of plastics are given below.

Polyethylene

This polymer is made by mainly free radical, coordination (Ziegler Natta catalyst system) or more advanced complex coordination (Metallocene catalyst) process. Ethylene monomer joins to form a long hydrocarbon chain of polyethylene in the presence of heat, pressure and a suitable catalytic system.

$$\mathbf{H_2C{=}CH_2} \longrightarrow \mathbf{-(CH_2 - CH_2)_n -}$$

Ethylene monomer → Polyethylene

Polypropylene

The polypropylene manufacturing process is also similar to the polyethylene process except for the monomer (propylene) and processing conditions and the catalytic system.

$$\mathbf{H_2C{=}\underset{\mid \atop CH_3}{CH}} \longrightarrow \mathbf{-(CH_2\text{-}\underset{\mid \atop CH_3}{CH}\text{-}\ CH_2)_n -}$$

Propylene → Polypropylene

Polyvinyl Chloride

PVC manufacturing process is somewhat different from the PE and PP processes but polymerization occurs by the same addition mechanism of vinyl chloride monomer (VCM).

$$\mathbf{H_2C{=}\underset{\mid \atop Cl}{CH}} \longrightarrow \mathbf{-(CH_2\ \text{-}\underset{\mid \atop Cl}{CH})_n\text{-}}$$

Vinyl chloride → Polyvinyl chloride

Polystyrene

Polystyrene is manufactured mainly by a free radical process. The other processes are the cationic, anionic and coordination systems (Ziegler-Natta).

$$\underset{\text{Styrene}}{\underset{\displaystyle C_6H_5}{H_2C{=}\underset{|}{CH}}} \longrightarrow \underset{\text{Polystyrene}}{\underset{\displaystyle C_6H_5}{-(CH_2-\underset{|}{CH})_n-}}$$

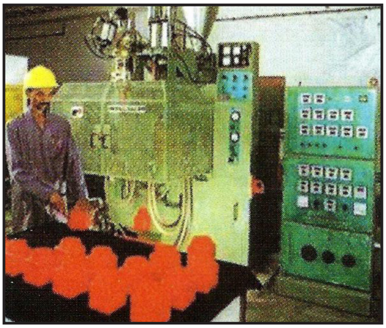
Almost 85% of all resins produced are thermoplastics and over 70% of the total volume of thermoplastics is accounted for by the resins; polyethylene, polypropylene, polystyrene and Polyvinyl Chloride (PVC) They are made in a variety of grades, and, because of their low cost, are the first choice for a large number of applications. A variety of processing and shaping methods are available to form the desired products from these processes; extrusion and injection moulding are the most common.

Plastics are manufactured in World Scale Plants of Avg. 2-5 lac MTA size. The major raw material manufacturers are Reliance Industries, Gas Authority India Limited, Indian Petrochemicals Ltd., Haldia Petrochemicals Ltd., Supreme Industries, BASF India, Bayer ABS and Finolex Industries etc. A typical plastic manufacturing plant (PE/PP) is shown in figure below.

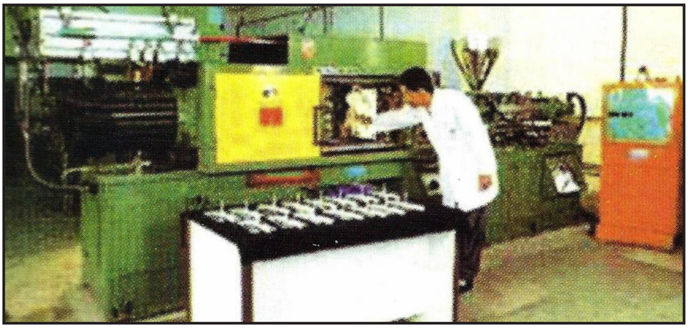
Polyethylene resin Manufacturing Plant (Courtesy : RIL, India)

Compared to the basic plastic raw material manufacturing plants; plastic processing units are comparatively smaller. Presently, there are approximately 22,000 units across the country in small/medium sectors.

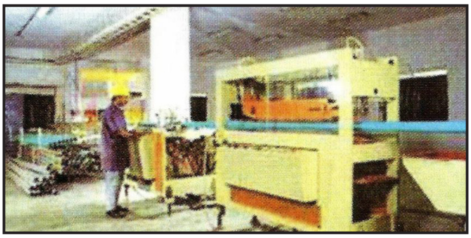
The main Plastic processing units are in extrusion, Blow moulding, Injection, film-extrusion, woven sacks, pipes, etc.



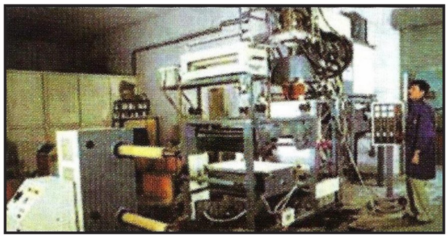
Blow Moulding Machine



Injection Moulding Machine



PVC Pipe Plant



TQPP Film Plant

Plastics - Contribution to Daily Life

Versatility of Plastics Application

Plastics help in improving life and living around the world

Unique combinations of the properties of plastics have helped mankind in improving life in numerous ways while a few examples suffice.

Over 1 billion people lack routine access to water and around 35 per cent of the deaths in the developing world are due to contaminated water. Plastic pipes and filters are helping to improve that situation by supplying clean drinking water in many parts of the world where water borne disease cause irreparable harm to human life.

In many areas, optimizing water usage and increasing agricultural output is the key. Plastic films help farmers grow high yield rice on stretches of desert land. The plastic film is used to line 20-cm deep furrows into which the rice is planted. The process saves 60-80 per cent of desert water and increases crop yield by between 1500 kg – 3000 kg per hectare.

In all parts of the world, large water losses occur because of leaks in the distribution systems. Because of reduced number of joints and overall mechanical properties, plastic pipes reduce such water loss.

Today, plastics are widely used in the automotive industry to create increasingly fuel-efficient cars. It is estimated that 12 million tons of oil is saved each year by using lightweight plastic vehicle components instead of traditional materials. Plastics help reduce fuel consumption and CO_2 emissions.

A major contributor to CO_2 emissions is domestic heating. An innovative project has shown that plastics can reduce the annual fuel consumption for a $100m^2$ apartment, from 2000 liters to 300 liters.

Plastic house wraps is applied to the exterior of house just behind the brick or siding. This wrap creates barriers to airflow or infiltration, which reduces the amount of air-leaking through the seams and openings in our house's exterior walls into our house. This ultimately means that our total fuel consumption is reduced and as a result fewer greenhouse gases emitted (Approximately 50% of our energy consumption in heating is used to heat infiltrations air.) a recent study looked into the amount of greenhouse gases emitted during the production of plastics, air barriers and their use (from the time the oil is first extracted from the ground through to the production of the product). Results found that with the reduced energy consumption made possible via the air barriers, there was a significant overall net reduction in CO_2 emission.

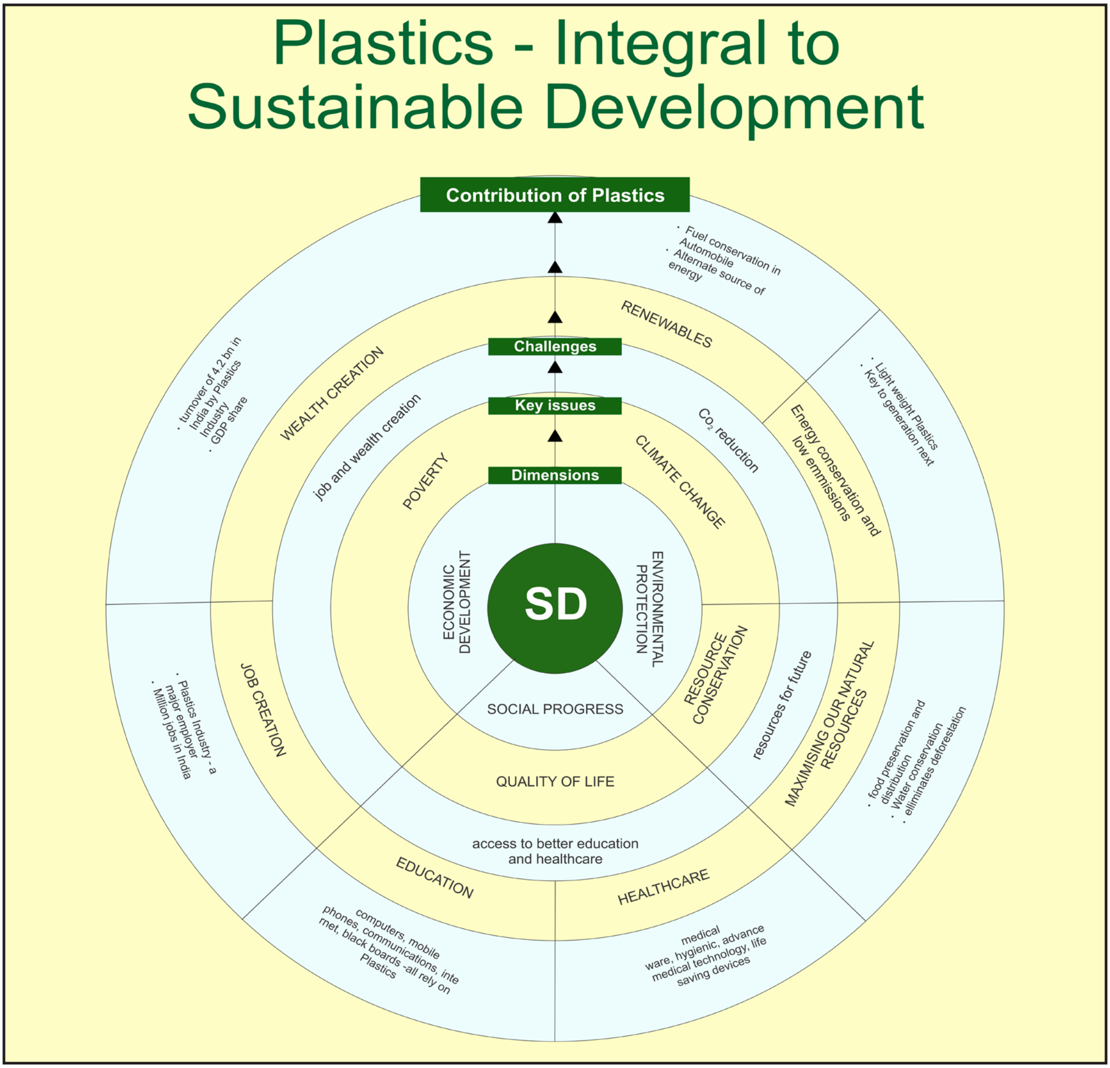
Infact, CO_2 emissions drop from six tons to one tone by replacing traditions building components with equivalent plastic components. For instance, triple-glazed PVC window frames and polymeric window coatings not only reduce heat loss but also allow solar gain. This further saves oil consumption by use of plastics.

Packaging is the most visible use of plastics. Previously, packaging was heavy, often fragile and costly. Plastics have revolutionized packaging by providing light, strong, flexible-packaging materials. Plastics packaging reduces overall packaging consumption. In fact, without plastics, overall packaging weight would increase 300 per cent. In our country, about 28 to 30% of the consumption of plastics goes for packaging. Packaging applications will certainly grow manifold in the years to come. PET bottles, Olefin mouldings and pouches have almost changed our lifestyle. PET bottles are extensively used world wide for packaging of beverages and drinking water. Whether at home or at public places, there is a constant demand for pure drinking water. The drinking water packaging industry with an investment of about Rs. 700 crores and over 200 manufacturers have seen a significant development during the last 5 years. The quality of water and the sealing of the bottle for any pilferage or adulteration were questionable. The mandatory BIS certification and that of prevention of food adulteration act have brought in the quality assurance to the customer that the packed drinking water is trust worthy. It is estimated that 800 million liters of bottled water are marketed in India and demand will continue to grow further. Bottled water in turn reduces the risk of water borne diseases hence provide an improvement in the health sector.

Plastics packaging also helps preserve food. Wastage in Europe is kept to around two per cent – due in part to plastics packaging – compared to between 30 – 50 per cent in the developing world. The traditional materials, jute, paper, sisal, wood, cardboard, tinplate, aluminium and glasswares were widely replace with the advent of plastics due to many inherent advantages. Some of them are :

- Plastics Packagings are light in weight - 0.2 to 0.3 times of conventional materials.
- Plastics have wide design freedom in the manufacturing of packaging product.
- Plastics provide better aesthetic appeal, colourability, permeability and transparency.
- Plastics Packaging Products are non-toxic, non-corrosive, resistant to chemicals & water.
- Plastics packaging can be sterilisable which is an important requirement for packaging in medical field.
- Plastics consume low energy while converting from raw materials into product.
- Plastics protect food, pharmaceuticals, detergents due to good barrier properties.

In the healthcare sector, plastics based technologies, make life-saving and life-enhancing surgery possible, for example heart valves and hip joint replacement. Plastics also play a vital role in fundamental medical care, such as blood bags, disposable syringes, hygienic medical instruments, etc. helping make better and longer lives for the whole society all over the world.



Plastics: Contributing to Economic Development

The plastics industry and its products make a significant contribution to responsible economic development. Since the first synthetics were created around a century ago, and particularly since the 1950s, the use of plastics has increased enormously. They now take many shapes and forms and are used in a huge number of ways - from the simple plastic bag or ballpoint pen, to high tech. high performance structural components in automobiles and spacecraft. One of the impacts of this growth has been on economic development, with the establishment of small and medium-sized companies to convert plastics into useful products for all major sectors of the economy.

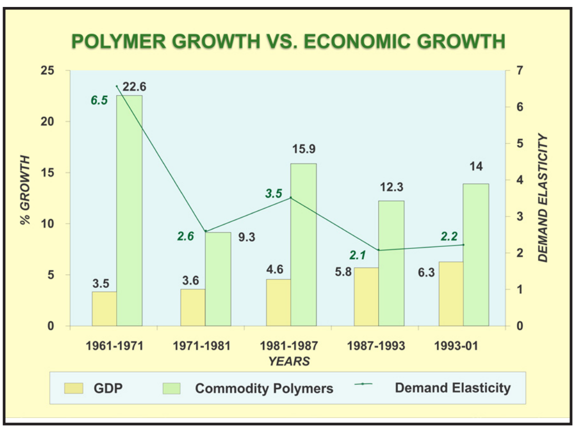
In employment terms, the industries directly linked to plastics production – such as converters and machinery manufacturers – as well as the polymer producing industry, are significant employers in many parts of the world. For example, in India around three million people are employed by the wider industry chain (approximately in the plastics manufacturing industry). This broader plastics industry has an annual turnover of around 4.2 billion. The plastics manufacturing industry invests million in R&D annually.

Along the supply chain, from raw material processing to the manufacture of products that rely on plastics, the industry adds value to the economy through the wealth and employment it generates. This makes it a major contributor to economic development in many areas of the world.

In India, around 11 major companies produce the basic polymer which is sold to around 22,000 small and medium sized companies. These, in turn, convert the polymer into products for use in many sectors, for example, packaging, automotive parts, electric & electronic equipment, medical products, etc.

The industry chain can best be seen in emerging markets where the growth of the converting industry to produce for local consumption and export precedes the construction of large polymer production plants.

Another way of looking at the contribution the plastics industry can make to economic development is by examining the relationship between plastics' growth rate and GDP. Plastics consumption generally outpaces GDP in most countries with the difference being most marked in developing world and emerging markets where this can be by a factor of up to five. This is largely a result of the natural growth of consumer demand in developing markets for products and services which rely on plastics, for example, in communication, technology, healthcare packaging and convenience goods. The graph below shows how plastics consumption has outpaced GDP in India.



However, it is not just in terms of economic wealth and job creation that such markets can benefit from the plastics industry. New technologies for plastics production and processing are being adopted to "leapfrog" ahead of older technologies. In doing so, this allows developing nations the benefit of introducing modern technologies and facilities without having to go through the painful and time-consuming learning processes already undergone where the technology / product / production facility was first developed.

Plastics – Contribution to Social Progress

Plastics offer a range of benefits to society at large – helping in its advancement and better living standards.

Extending the global knowledge economy (ICE)

One of the main areas where plastics have come to play an increasingly significant role in recent years is the opening up of areas of Information, Communication and Education (ICE) to a far greater proportion of the world's population than previously thought possible.

Computer technology, the Internet and mobile communications are areas of exponential growth – never before has mankind been in a position to benefit from such easy access to information and knowledge. Equipment- such as computers and telephones – are becoming increasingly smaller, lighter and less expensive, thereby opening up the possibilities of access to a much greater number of people. The portability and affordability of much of the above hardware would be impossible without plastics.

Computer hardware Systems

Plastics in Mobile Phones

Due to the rise of e-commerce in today's global economy, the amount of data to be transferred is increasing at the rate of 300% every year compared with just a five per cent increase for telephone calls. It is estimated that there are currently about 250 million internet users world wide with data exchange taking over from telephone calls in terms of importance in the current century.

While polymer optic fibres have been available for 30 years, their importance and use in enabling effective data flow is vital to this growth. They are flexible, unaffected by magnetic fields and cost efficient; providing essential lines which maintain communication across the world.

Telecommunication Network

Thousands of kilometers of these polymer fibre optic cables continue to be installed at the bottom of the world's oceans and seas in a bid to meet this surging demand. These cables will eventually link every corner of the world to the global information network. The Internet, globalization, increased speed of communication, faster means of transportation – all these things would not have been possible without plastics, which are mainly used for cladding of optical fibres.

The electrical and electronic (E & E) sector is an important and growing market for plastics. During 1995, Europe consumed almost 20% of its total polymer consumption in E&E applications. It is fair to say that the E&E industry would not have reached the current level of progress without plastics.

The versatility of plastics combined with durability, strength and cost effectiveness make it the ideal material for designers and manufacturers. From microwaves, washing machines, television sets and stereo systems to cables, computers and mobile phones, plastic provides practical benefits that other materials cannot match. All these innovations & inventions contribute to the upliftment of society at large.

Access to Improved Living Conditions

Longer life expectancy derives not only from remarkable pharmaceutical development of the twentieth century, but also from plastics-based technologies which make life-saving and life-enhancing surgery possible – for example, heart valves and hip joint replacement. Even fundamental medical care involved plastics – for instance in blood bags, disposable, hygienic medical instruments, safer spectacles, contact lenses and gradual delivery of medicines via capsules and patches. All these make better and longer lives a reality for both the rich and poor in society; in both, developed and developing nations.

Eradicating disease in the developing world

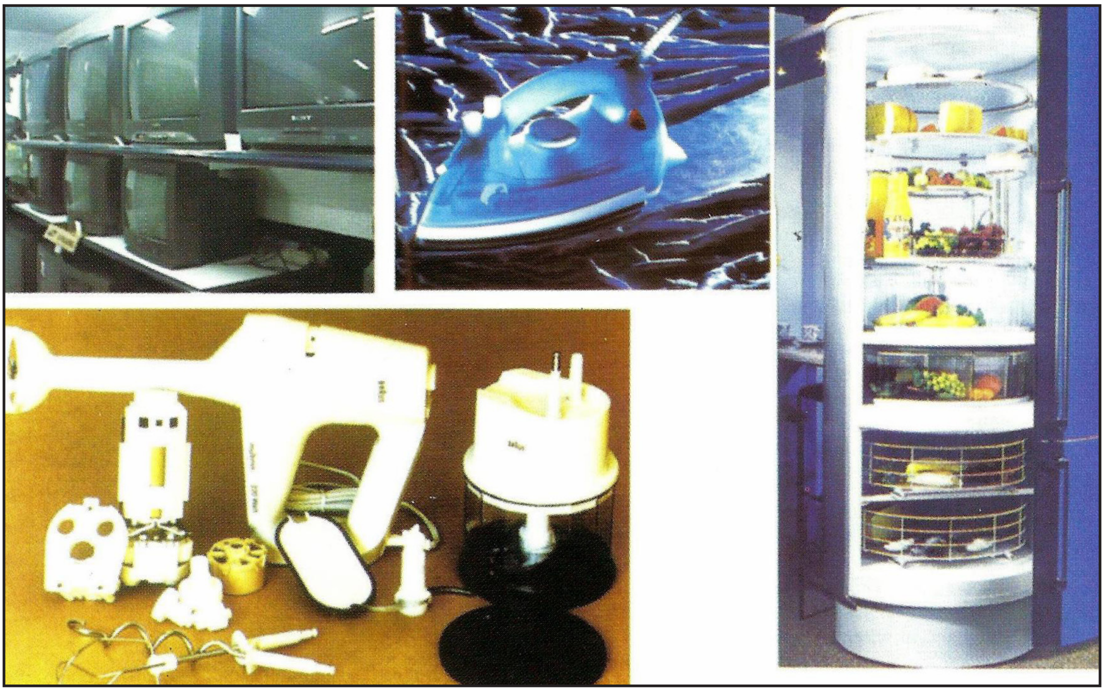
The use of Plastic filter cloth is helping in the World Health Organization's (WHO) effort to wipe out infectious diseases worldwide by 2030 by directly targeting one of them - Guinea

Single use disposable PP syringes hold the key to prevention and spread of dreadful and contagious diseases like AIDS etc.

worm disease (dracunculiasis). For example, a special nylon monofilament cloth filters out Guinea worm larvae from drinking water and millions of square feet are now in use in Asia and Africa. As a result, Guinea worm disease is poised to become only the second disease in the history of the world to be eradicated (smallpox was the first). The Carter Centre, responsible for administering this scheme, claims that the annual incidence of Guinea worm disease has been reduced by more than 95 percent. Fifteen years ago, it was estimated that more than 3.2 million cases of Guinea work disease occurred, and more than 100 million people were at risk of infection. Today, only about 15,000 cases remain in the world.

Affordability of consumer goods

Plastics are the heart of virtually every technological advance. Modern lifestyles in the world involve the use of goods and technologies which would not be affordable, and, in many cases, not possible to mass produce, were it not for plastics. In emerging markets and the developing world, plastics are starting to enable the provision of cleaner and more sanitary living conditions through the supply of affordable and resource efficient sanitation and appliances made of plastics.



Affordable consumer goods in Plastics

Plastics – contribution to Transportation

Plastics are vital components in mankind's hugely increased mobility. The ability to travel and communicate has made the global village a reality and plastics. Plastics have now become on

Part of so many forms of transport from motor car to aeroplanes. In the latter part of the 20^{th} century, plastics have been at the forefront in extending our horizons still further – through space travel and exploration – bringing exciting possibilities for the future of mankind.

Why are plastics so important to the automotive industry ?

Plastic based materials are strong yet lightweight, versatile and flexible, allowing technological innovation and design freedom. Compared to 20 years ago, the use of plastics in care manufacturing has grown by more than one million tones, equivalent to an increase of 114 per cent. In terms of weight per car, 100 kilograms are now used on average rather than the 70 kilograms of the late 1970s. Many types of polymer are used in more than 100 different parts of all shapes and sizes. These vary from large applications such as all-plastics dashboards and fuel tanks to smaller items such as door handles and electrical components. Each polymer in turn can be adapted to meet the exact technical, safety, economic, environmental and aesthetic specifications required. The important plastics parts that are used in automobile are listed in the following table. The important factors that have promoted the use of plastics in automobiles are : Functionality, Light Weight, Safety, Resource Efficiency, Integrated Systems, Economics and Recyclability.



Plastics in Automobiles

Plastics make footwear affordable to millions

Use of Plastics especially PVC has made it possible for millions to afford footwear at affordable prices with exorbitant leather prices. PVC shoes and chappals offer a suitable alternative. Besides PVC footwear contributes to :

- Good flexibility and optimum hardness
- Light weight
- Abrasion resistance
- Aesthetic designs
- Low cost

Low cost PVC shoes and chappals for the masses

Sandals, chappals, shoes (micro cellular and compact), direct injection moulded footwear, sport shoes, unit soles sandwiched to leather and synthetic slippers (formal wear shoes) are being manufactured using various plastics and PVC in particular. Old PVC shoes can be recycled to make still cheaper shoes to be affordable by poorer sections of society.

Plastics shaping the future in building and construction industry

Balancing the building and construction needs of a booming global population with the protection of the natural environment is one of the greatest challenges facing city planners, architects and civil engineers today.

PVC profiles for doors and windows

Plastics have made enormous contribution to many different aspects of our urban environment and as we move into the 21st century, they will increasingly become the material of choice for achieving economic and environmental balance as well as meeting functional design and specification needs.

PVC home interiors

The building and construction sector is an important and growing market for plastics. It is the second largest plastics user after packaging. From the latest integrated service units to insulation systems for large-scale construction to interior furnishings, architects and civil engineers are increasingly turning to plastics to provide innovative solutions.

Providing shelter for millions worldwide

Plastics based insulation materials are being used to improve and build housing worldwide, and one manufacturer's partnership with Habitat for Humanity international is a good example of how the use of such products can address important economic, environmental and social needs.

A Full Plastics House

Plastic doors

Support for Habitat for Humanity was established in the early 1980s, donating insulating foams, sponsoring Habitat homes and contributing labour resource. This is helping Habitat reach its goal of Building millions of homes for and with people in need by the End of this century.

The insulation makes homes more comfortable; keeping them Warm in the winter and cool in the summer, and lowers utility Bills significantly for Habitat homeowners. It also makes sense for the environment, reducing Energy use and CO2 emissions. It is estimated that since the energy crisis of the 1970s, the use of

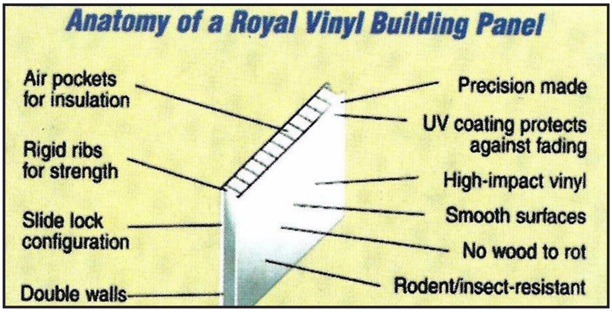
Such polystyrene –foam insulation in construction has saved the equivalent of more than five billion gallons of fuel oil, thus helping the conservation of resources, besides social benefits.

Disaster Management – Earthquake-Proof Plastic Housing Systems

Earthquakes are a major natural calamity bringing disaster and disarray to affected people across the world and India is not immune to such devastation in any manner. In fact, India experienced one of the worst earthquakes in January 2001 in the Kutch region of Gujarat where there were more than 30,000 fatalities in addition to incalculable loss of property.

During earthquakes, many buildings are damaged causing additional loss of life and property. Scientists have been working on models of making earthquake-proof housing, and here, again, plastics have risen to the needs of the people to offer effective solutions.

Royal Building Systems of Canada have developed technologies wherein formwork of rigid PVC components are filled with concrete, which, on curing remain in place. These concrete filled plastic components are interlocked to form a monolithic wall for a multiple of building applications: from single family dwellings to large scale multi-level building structures.



These structures have been proven to be earthquake resistant for seismic zones 0 – 4 and have also survived wind loads exceeding 160 kmph in the case of tornadoes, hurricanes and cyclones. These structures are tough and long lasting, being resistant to rusting & rotting and are attacked by neither insects nor mildew.

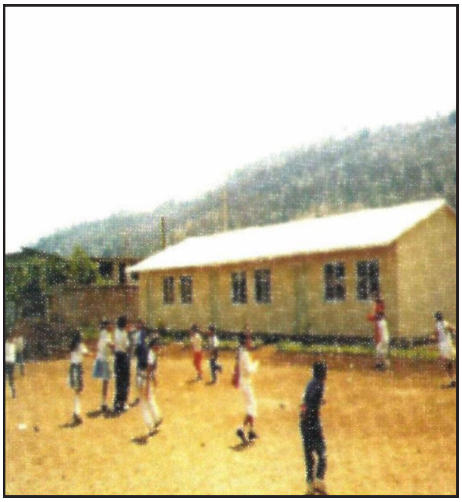
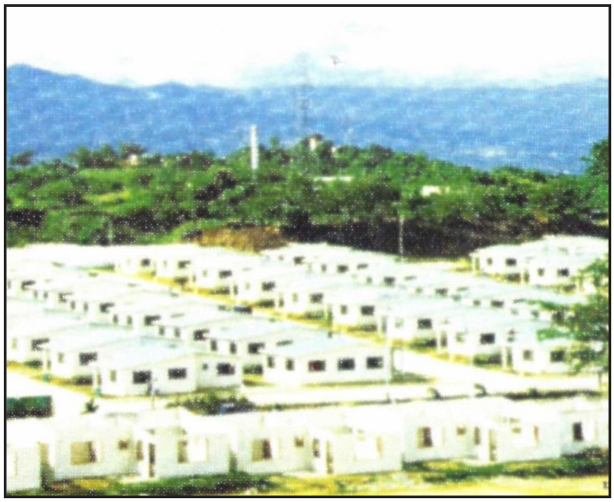
PVC structures have lower component costs and lower installation costs as compared to conventional building structures. Since the PVC panels used are self-coloured, these do not require painting nor do they require any replastering, thus, reducing maintenance costs to a significantly lower level.

The Royal Building Systems have been in use in many countries like Nigeria, Mexico, Antigua, Taiwan, Philippines, Russia, Argentina, USA, Canada,etc.

In India, after the Gujarat earthquake, the state government, with the help of leading industries, set-up residential and office blocks with residential areas ranging from 30 sq. mts to 5000 sq. mts.

Depending on the site infrastructure and preparedness, a plastic house can be set up within 3 to 5 days, with the help of locally available unskilled workers. The system has also been effectively used in regions that are not and arid to regions of sub-zero climates.



Plastic Houses built in earthquake affected areas in Gujarat (India)

Additionally, a plastic house is also much more cost-effective than a brick and mortar house. The construction cost is substantially lower than a conventional house. It is also completely maintenance free, since it is free of warpage, cracks and plastering, is rust, leakage and termite proof and requires no painting essentially, during its over 100-year lifetime, at the same construction cost, savings in maintenance, vis-à-vis a conventional house itself, pays for the cost of construction.

Plastics in Insulation and Energy Conservation

Thermal insulation is the second largest application of cellular polymers and largest application for rigid materials because of their thermal conductivity, ease of application, cost, moisture absorption and transmission permeance. Plastic forms contain captive blowing agent have much lower thermal conductivity than other insulating materials.

Refrigeration The lower thermal conductivities of polyurethanes, plus the ease of application and structural properties of foamed-in-place materials afford great freedom of design. As a result, rigid polyurethane foams have displaced traditional rock wool and glass wool in refrigerators.

Large institutional and commercial refrigerators, freezers and cold storage areas, including cryogenic equipment and gas tanks are insulated with polystyrene or polyurethane foams. Polystyrene foams are popular where cost and moisture are important; polyurethane are used for spray application. Polystyrene foams are also used load-bearing sandwich panels for low temperature applications.

Construction The use of plastics for wall and ceiling insulation of residential buildings has increased more than 200% over the past decade. Extruded polymeric foams are found in residential constructions as sheeting, perimeter and floor insulation under concrete and combined plaster based and insulation for walls. Both polystyrene and polyurethane foams are highly desirable for roof insulation.

Cellular polymers are also widely used for pipes and vessel insulation, especially polyurethane and epoxy foams; spray pour-in-place techniques are suitable. The use of cellular rubber and cellular PVC in insulation for small pipes is attributed to their ease of application, combustion properties and low thermal conductivity.

As energy cost continue to rise, energy conservations in buildings become increasingly important. The principal heat loses are through the ceilings, walls, window, doors, floors and foundations and through air infiltration. Following table shows the heat loses in an uninsulated and insulated house during heating and air-conditioning period.

Heat Loss Distribution for heating a Typical Residence

	Uninsulated				**Insulated**			
	Peak Hours		**Day**		**Peak Hours**		**Day**	
	kW.h	**%**	**kW.h**	**%**	**kW.h**	**%**	**kW.h**	**%**
Ceiling	5.4	42	99.3	43	0.8	12	15.8	14
Wall	2.1	16	51.9	22	0.8	12	22.1	17
Glass Conduction and Convection	2.7	22	38.1	16	2.7	40	38.1	33
Infiltration	2.5	20	42.4	19	2.5	36	32.4	36
Total load	12.6		231.6		6.8		116.4	

Heat Loss Distribution for heating a Typical Residence

	Uninsulated				Insulated			
	Peak Hours		Day		Peak Hours		Day	
	kW.h	%	kW.h	%	kW.h	%	kW.h	%
Ceiling	1.6	18	24.6	22	0.5	7	6.7	8
Wall	0.08	10	12.9	12	0.3	5	4.4	6
Glass Conduction and Convection	0.6	7	8.6	8	0.6	9	8.6	10
Radiation	4.4	49	34.5	31	4	60	34.5	41
Infiltration	1.5	16	29.7	27	1.5	19	29.7	35
Total load	8.9		110.2		7.2		83.7	

Insulated sheathing assemblies are widely used in residential construction. They consist of an interior finish, a stud cavity with or without insulation, exterior insulating sheathing, exterior siding. In addition some sheathing material have tongue-and-groove edges, which probably reduce air infiltration. Furthermore installation of sheathing material may reduce the temperature difference across the cavity and thus improve thermal performance by reducing convection. In residential insulation, roof insulation is most effective. The roof deck is usually flat, conventional over-deck assembly the insulation is located above the roof deck structure and covered by a built-up roof. Other techniques of insulation include membrane assemblies, underdeck assemblies and structural panel assemblies.

Plastic Window- Energy Efficient Solution

ऊर्जा दक्ष खिड़कियां

खिड़कियों से धूप आती है जो रोशनी और गर्मी देती है इसलिये ऊर्जा-दक्ष इमारतों में खिड़कियों का बड़ा महत्व है। एल्युमिनियम या स्टील के फ्रेम वाली खिड़कियों की तुलना में पी वी सी (पोली विनाइल क्लोराइड) का फ्रेम, दुहरी कांच की परत और जड़े हुये विण्डो फ्रेम, तथा खुली जगहों के बीच सही गास्केट लगाने से ऊर्जा की अच्छी बचत होती है।

नयी दिल्ली में इंडियन इन्स्टीट्यूट ऑफ टेक्नोलोजी द्वारा किये गये अध्ययन से पता चला है कि अगर बिजली का महसूल 5 रु. प्रति यूनिट की दर से लगायें तो खर्चा साल भर में ही वसूल हो जाता है। नीचे दी गयी सारणी में 735 वर्ग मीटर वाली इमारत में 30 प्रतिशत खिड़कियों पर बिजली की बचत का हिसाब दिया गया है।

शहर	पी.वी.सी. खिड़की से ऊर्जा की बचत (kWh/वर्ष)	अतिरिक्त लागत 800 रु./ वर्ग मीटर	प्रति यूनिट ऊर्जा की लागत
दिल्ली	34,545	1,76,400	1 वर्ष
चेन्नई	49,980	1,76,400	8 महीने

Plastic window and doors are very popular substitute of wood, metal, glass and other materials. These are not only light in weight but water resistance, rust proved and termite resistant. Mainly PVC windows and doors are used.

These Plastic products are not only environment friendly but also energy efficient solution to substitution of conventional materials. PVC windows with double glazing for air-conditioned or heated premises are very popular in USA, China and Germany.

Bureau of Energy Efficiency (BEE), Government Body of India has also recommended PVC windows as against Aluminium windows in air conditioned premises.

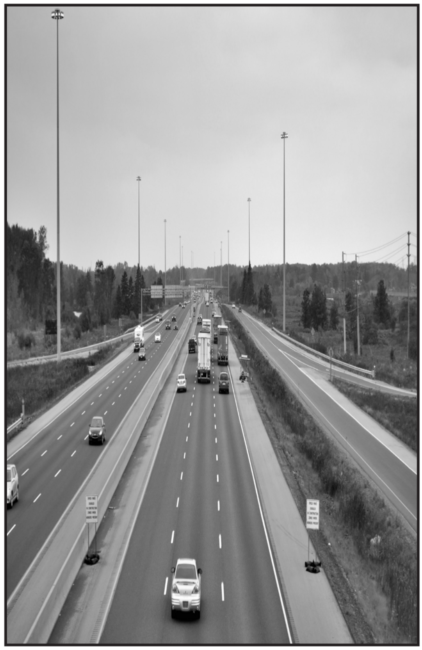
Exterior rolling shades and shutters can also provide summer shading. The simplest types are inexpensive bamboo shades, widely available at department and discount stores. They must be operated manually and usually need to be replaced every few years. More permanent and modern exterior rolling shutters combine shading, ventilation and security features. These shutters have horizontal slats guide rails, a housing unit to held the shutters when rolled up, and manual or automatic controls and are also made in PVC (Polyvinyl Chloride).

Use of Plastics in Infrastructure Development

One of the key challenges today is the development of sustainable civil infrastructure system. This has resulted in efficient transportation, safe water, reliable and affordable energy and a clean environment.

Geosynthetics and Geotextiles in Civil Engineering

Economical and effective maintenance and repair of concrete infrastructure and structural components such as bridge decks, girders, piers, abutments, and pavements present a substantial engineering challenge. Degradation of infrastructure is due to the combination of weather and environmental effects with the loading factors. Cracked concrete girders, columns, and bridge decks may be repaired by injection of grout or epoxy. However, the life expectancy of such repaired Infrastructure is usually low unless continued efforts are expanded to maintain the structure in good repair. To lower the maintenance cost it is necessary to substantially increase the time interval between repairs. Therefore, the durability of transportation structures need to be increased. The availability of new materials such as glass / epoxy and graphite / epoxy composites presents opportunities for better repair and protection of traditional concrete infrastructure. Alkaline resistant glass fibers must be used in g lass / epoxy composites to prevent fiber degradation that may be induced by moisture.



An Express Highway re-enforced with Geotextile

In recent past road / ground / drainage improvement using Geosynthetics has become very popular worldwide. The concept of reinforcement of roads using polymeric Geotextiles, has been accepted in India also. With the anvil of National Integrated Highway Project (NIHP) and Rural Road Project (RRP) in India, there is a huge demand and requirement of geotextiles for building cost effective highway structures with good performance. Similarly polymeric geogrids are effectively used in construction of bridges, flyovers, airport runways, railway track stabilization and ground improvement.

Use of fiber composites for the enhancement of concrete structural durability is discussed. Computer methods are utilized to evaluate the progressive damage and fracture tolerance characteristics of example fiber composite enhanced concrete structures. The methodology is based on an iterative reanalysis / reevaluation method to simulate progressive damage and fracture in structural concrete with various reinforcement systems. A continuous fiber composite mechanics module is used to evaluate the properties and stress limits of glass / epoxy reinforcement systems. The developed simulation method enhances structural concrete design by providing a tool for the rapid evaluation of fiber-composite reinforcement materials and configurations with regard to durability and damage tolerance. Because of cumulative benefit the geotextiles have been used for :

- Stabilizing sub-grade soil.
- Constructing reinforced soil wells / steep reinforced slopes for flyovers.
- Protecting backfill in a conventional retaining walls with filter layer.

Geosynthetic is a general classification for all synthetic materials used in geotechnical engineering application. It includes geotextiles, geogrids, geonets, geomembrances and geocomposites.

Geotextile : Any permeable textile natural of Synthetic, sued with foundation, soil, rock, earth or any other geotechnical engineering related material. In the present chapter, it is related to synthetic material only.

Reinforcement of road with Geotextile

Geotextile shall be made of polyethylene or polypropylene or polyester or similar fibres, either woven or non woven in variety, through machine made process of heatbonding or needle punching or weaving techniques. These fabrics are required to pass water through but retain the solid particles, which require specific cross-plane permeability or permittivity and apparent opening size or equivalent opening size or 095. The above two requirements alongwith the requirement of strength and durability denote general characteristics of geotextiles to be used.

The type of geotextile to be used in particular application shall be decided on the basis of design.

Geogrid : Geogrid shall be made from integrally jointed, mono or bio-directionally orientated or stretched meshes from polyethylene or polypropylene or polyester or similar polymer, with high modules : Geogrid, a deformed or non deformed grid of polymeric material used primarily for reinforcement purposes with foundation, soil, rock, earth or any other geotechnical engineering related material.

Geonets : These are net made of polymeric material used for drainage of foundation, soil, rock, earth or any other geotechnical engineering related material. These are made of Polyethylene or Polypropylene.

Geomemberane : An essentially impermeable membrane of polymeric material used with foundation, soil, rock, earth or any other geotechnical engineering related material,to control fluid migration. Made of Polyethylene sheets, U.V. stabilized.

Geocomposite : A manufactured material using geotextiles, geogrids, geonets and / or geomembrane in laminated or composite form.

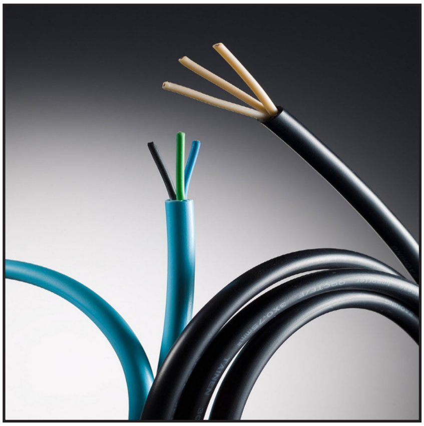
Reference :
Geosynthetices in Road and Bridge Construction. Specification for road and bridge works, published by Indian Road Congress on behalf of Govt. of India, Ministry of Road Transport & Highways, Phone 297 307.

Plastic Wire & Cables for Power Distribution

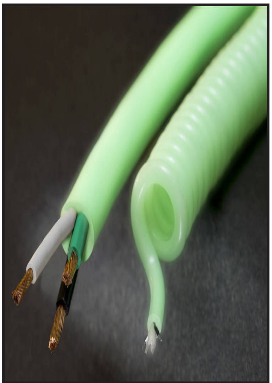
Since their introduction, the use of plastic materials for insulation and jacketing of power cables has been an ongoing development. Both Polyethylene and PVC cables have been effectively used. Modern cable production requires quality materials with outstanding characteristics. No material other than plastics, in general, and Polyethylene, in particular, has the insulation properties for power cables. Some of the advantages include :

- Super clean / Super smooth PE cables, for high electric stress.
- High speed of insulation material for production of medium voltage cables
- Cross linked XLPE cables for high voltage cables
- Flame retardant smoke-free PVC cables for high voltage

Cable performance under different installation condition require consistent performance and a long life. Polyethylene and PVC are the materials of choice. Being inert in nature with hydrophobic characteristics, they can be used for the underground cabling system. Further improvements in the plastic materials have been made to have better Environmental stress cracking resistance (ESCR) to find its use in different types of underground soils.



Plastic cables for power distribution



Plastic cables for Telecomunication

HDPE Ducting for optical fibre - Telecom Cable

Optical fibre cable have revolutionized the telecommunication sector globally. However this high-technology product requires a suitable ducting system to prevent its abuse. Silicon grafted HDPE ducting with extremely low coefficient of friction allowas a smooth passage of optical fiber cable for over hundreds of kms. No material other than HDPE can serve this function.

Gas Distribution through Plastics

Unlike Water, Gas is a compressible fluid. Hence the flow depends upon pressure. I. E. More pressure in the pipe – more Cu, mtr / hr flow.
Normally Gas pipe distribution network has the following network of pipes:

Transmission Lines – of very high pressures : Steel with PE coated

Distribution Mains -	of HDPE – PE100/Pe 80 depending upon the pressure: Yel low or even Black with Yellow longitudinal stripes can be used.
Sub-Mains	of MDPE – PE 80 also as service line for Industrial Consumer -depending upon requirement
Service Mains	into the Domestic consumers facilities

With the recent discovery of huge Gas reserves in Godavari basin (Reliance Industries) and ONGC there is going to be substantial increase in the production and transportation of gas. For effective transportation of gas, high Density Polyethylene pipes are required. Effective piping system will make domestic gas supply easier. The design and Installation of GAS pipes requires more skill, in view of the safety aspect involved. Hence world wide only Electro-fusion fittings are used for the joining of Polyethylene pipes.

Saddle tapping

Trenching with pipe

Corrosion Resistance with Plastics

The pipeline industry all over the world is confronted with a wide range of corrosion problems. External surfaces in contact with soil, water and atmospheric environment and also interior surfaces in contact with potentially corrosive materials carried through the pipelines are subject to the corrosion processes. Failures due to corrosion can be a major drain to any economy. The Federal Highway Administration of ISA (FHWA) of USA conducted a study in 19999 to assess the cost of corrosion in USA. **It was estimated that the total direct Cost of Corrosion to the U.S. Economy is USD 276 billion / year in 1998.**

The pipeline industry is a very high investment industry. Fully implemented corrosion control can effect millions of dollars worth of savings by reducing property losses, reducing the cost of repairs, by avoiding catastrophic failures and bys conserving natural resources.

Fibre Reinforced Plastics (FRP) and Polyethylene are very useful to provide a barrier against adverse environment.

Advantages of FRP, PE coated and PE pipes over conventional material :

1. Do not require painting
2. Relatively cheaper
3. Light in weight
4. Less maintenance cost
5. May be purchased with short lived time
6. Corrosion proof
7. Exceptional Chemical Resistance

Conclusions

If we take a comprehensive view of the present and potential benefits of plastics in its multitudnal forms, the implications of furthering the usage of plastics are phenomenal. The last century has seen plastics and its products emerging steadily to becoming a part and parcel of man's day to day life. Apparels, automobiles, consumer goods, defence & aircrafts and packaging applications, among others, have revolutionized our daily life style.

With further research, better technologies and more resources at our disposal, the plastic industry has greater promises for our future. It intends to change the way we grow our crops, the way we build our road, the way we manage our country's defence system and the way we save our natural resources. It has exponential growth opportunities on how we manage our economy – the way we create greater wealth, generate jobs and the way we live our life.

The concerns about the impact of waste and disposal are a small proportion of the larger picture. No doubt these concerns are important but the awareness is there and with a will to mitigate them, there can be no looking back. With this done, there is no disputing the fact that our future generations will inherit a healthier and happier earth by the use of plastics.

Chapter 2

Biodegradability : Myths and Realities

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BIODEGRADABILITY : MYTHS & REALITIES

Introduction

Plastics have almost replaced materials such as metal, glass, wood, paper, fiber, ceramics and etc. in packaging, automobiles, building construction, biomedical fields, electronics, electrical equipments, appliances, furniture, pipes and heavy industrial equipments. In a nutshell, from agriculture to transport and from aerospace to food packaging, the use of plastics has become an integral part of our modern day living.

Polymers can be classified as either natural or man-made 'macromolecules' which are composed of small repeating units. Polymers, which are bio-synthesized in plants, animals, and micro and macro organisms, are called Natural polymers. Examples are polysaccharides, proteins, fats, nucleic acid and natural rubbers. The most easily recognized natural polymer is Cellulose, the most abundant organic polymer on earth.

Polymers/Plastics,which are man-made, are called synthetic polymers. Polyolefins are the most important group of synthetic polymers. Synthetic polymers are ubiquitous in our world finding diverse applications in many fields because of their useful properties and contribute to enhancement of comfort and quality of life in our modern industrial society. The properties of synthetic plastics like durability, resistance to weathering and photodegradation as well as substance to biological attack and hydrophobicity, have contributed to their utility in different applications.

The same properties that made the synthetic polymers to be so useful have contributed to their disposal problem. They receive the brunt of media attention on this issue because of their visibility in the environment as litter and garbage. Recycling of plastic waste contributes a viable option, provided appropriate collection and separation mechanisms are operative but ineffective system reduces our cities to garbage dumps. However, for materials that come in contact with food or biomedical waste, recycling is not a viable option. Indiscriminate littering of plastics and its unhygienic recycling causes great concern and pose a serious health and environmental menace. Incineration and biodegradation (landfills or composting environment) offer a solution to the disposal of such wastes.

Biodegradable polymers are polymers in which the degradation results from the action of naturally occurring microorganism such as bacteria, fungi and algae. However, biodegradable and compostable plastics are not a panacea for all issues on wastes generated by the plastics in the environment **nor they are universal substitutes for the common resins of commerce.**

This report highlights the myths and realities associated with the plastics and traditional materials used for various applications. Different issues concerning plastics in the environment are discussed. The merits and myths of plastic's ecofriendly nature is explained in detail with a discussion of emerging technologies. Different testing standards discribed. A systematic and comparative study is made on the biodegradability of synthetic and natural polymers. Guidelines and possible solutions are discussed with the recommendations from the Indian point of view for the future.

Aspects of Biodegradability

The changes from the Stone age to the Bronze age and Bronze age to Iron age took hundreds and thousand of years. At the same time, Plastic age came in just through a single lifetime after the steel age. Over the past century, synthetic plastics have become the most efficient materials ranging in applications from replacement of human body parts to the construction of super-sonic aircraft and spacecraft. This growth has occurred at the expense of traditional materials like steel, aluminium, wood, paper and glass. Examples are wood, whose consumption leads to loss of forest cover, glass and paper, which consumes enormous fossil fuel for their conversion apart from generating toxic pollutants. One of the common myths about plastic is that their production depletes oil or natural gas which are nonrenewable resources. Traditional materials such as paper, wood, jute, etc. are believed to be biodegradable. Metals are non-biodegradable and can be recycled easily without much effect on desirable properties. The popular view is epitomized in the following statement from GREEN PEACE.

'Materials made from naturally occurring or biologically produced polymers are the only truly 'biodegradable plastics' available. Since living things construct these materials, living things cart metabolize them.' However, this statement is not completely true as proved by many research investigators.

Degradability and its Mechanism

Photo Degradability

Photodegradation begins with the production of macro-radical (P') in the amorphous regions of polymer substrate. This radical rapidly reacts with oxygen to give a macroperoxy radical (P00') which abstracts a hydrogen atom from the polymer backbone to produce a hydroperoxide group (POOH). The hydroperoxide group is photolytically cleaved to produce the highly reactive radicals which continue the cycle of chain degradation in the polymer'.

Chain initiation

$$\underset{\text{(polymer)}}{\mathbf{PH}} \xrightarrow{hv\ /\ \Delta} \mathbf{P^{\cdot} + H^{\cdot}}$$

Chain propagation

$$\mathbf{P^{\cdot} + O_2} \longrightarrow \mathbf{POO^{\cdot}}$$

$$\mathbf{POO^{\cdot} + PH} \longrightarrow \mathbf{P^{\cdot} + POOH}$$

$$\mathbf{POOH} \xrightarrow{hv\ /\ \Delta} \mathbf{RO^{\cdot} + {}^{\cdot}OH}$$

The cycle is terminated when two radical combine or recombine to form a non-radical product.

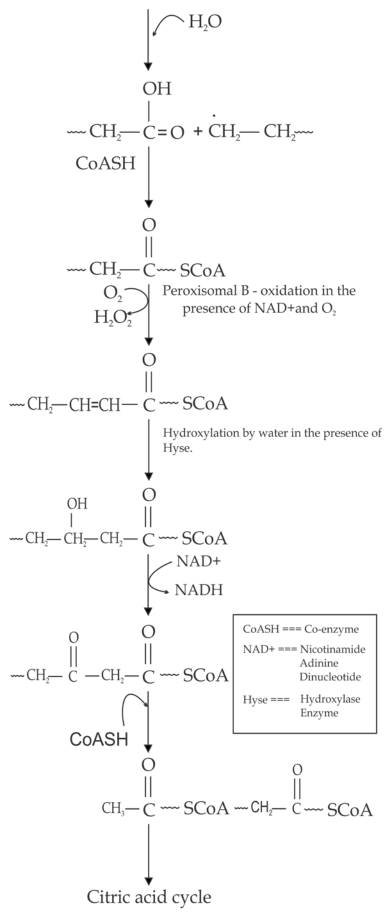
Thermal Degradability and Mechanisms

The fundamental degradation mechanisms of polymers are based on the same principles for both the thermal and photodegradation. The only exception in that photodegradation proceeds at a faster rate than thermal degradation and hydroperoxides are thermally cleaved to reactive radicals in thermal degradation.

Biodegradability

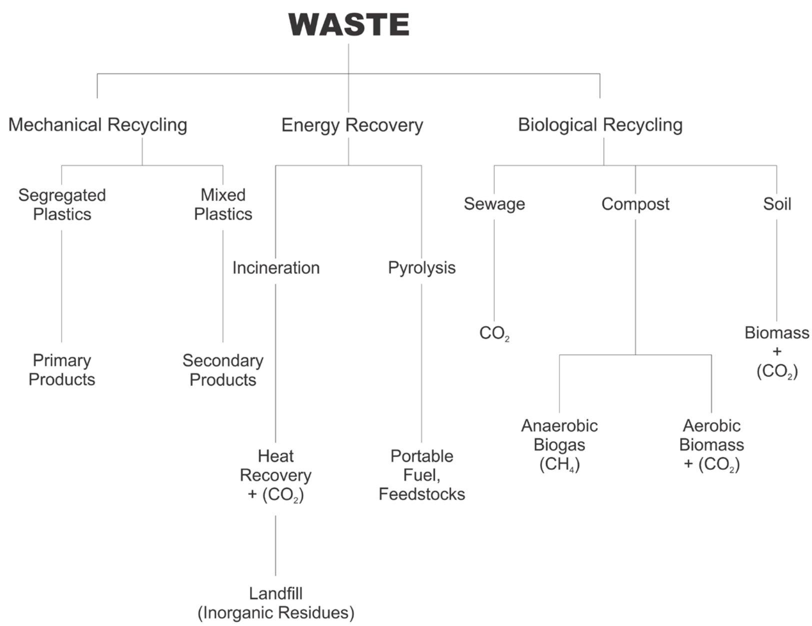
Biodegradability is the ability to be utilized as a carbon source by microorganisms and converted safely into carbon dioxide, biomass and water. Microbial attack is started where the carbonyl group is found. These functional groups are introduced in polyolefins during photodegradation and / or thermal degradation.

<u>Proposed mechanism of biodegradation:</u>
ESTER GENERATED DURING ABIOTIC DEGRADATION



Traditional Pathways of Plastic Waste Management

The purpose of solid waste management is to remove wastes from living areas in a way that protects human health and the environment. By sealing wastes in well-designed and managed landfills, one tends to preserve waste rather than degrade it. Uncontrolled biodegradation could result in production of leachate that, if leaked, would endanger near groundwater supplies, lakes and streams. Many landfills include heavy-gauge plastic liners which are required by the EPA to help protect the groundwater from contamination. While the total number of landfills is decreasing, total landfill capacity is actually increasing[7]. In 1991, 28 states in USA reported that they had less than 10 years of disposal capacity remaining. In 1996, however, only 13 reported having less than a decade. Conversely, while less than half of the states reported having more than 10 years of remaining capacity in 1991,35 states now claim to have more than a decade of disposal capacity. To manage the wastes generated by plastics in the environment, several options are available, namely mechanical recycling, energy recovery and biological recovery.



Definitions of Some Key Words, Standards and Testing Methods

a. Definitions

The definition of biodegradation is not always clear and is open to a large diversity of interpretations. Here are the definitions of some key words according to the **ASTM D20-96:**

Degradable Plastic: A plastic designed to undergo a significant change in its chemical structure under specific environmental conditions resulting in a loss of some properties that may vary as measured by standard test methods appropriate to the plastic and its applications in a period of time.

Biodegradable Plastic: A degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae.

Photodegradable Plastic: A degradable plastic in which the degradation results from the action of natural daylight.

Thermal Degradable Plastic: A degradable plastic in which the degradation results from the action of heat.

Composting and Plastics: A plastic that undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds and biomass, compostable materials and leaves visually no disintegrable or toxic residue.

Although a number of standard committees have sought to produce definitions of biodegradable plastics, each gives its own definition of biodegradable polymer. In conclusion it can be said that the intrinsic capacity of a material to be degraded by the action of microorganism called biodegradability. More specifically there are two definitions depending on the final fate of the polymer in the environment.

i. Compost

Compost is an organic soil conditioner obtained by biodegradation of a mixture consisting principally of various vegetable residues, occasionally with other organic material and having a limited mineral content. Compost quality has to be defined by the relevant national standards.

ii. Compostable Plastics

Compostable plastic is a plastic that undergoes degradation by biological processes during composting to yield CO_2, water, inorganic compounds and biomass at a rate consistent with other compostable materials and leaves no visible, distinguishable or toxic residue. (ASTM D 6400-99)

iii Compostability

Compostability is a property of a packaging to be biodegraded in a composting process. To claim compostability it must have been demonstrated that a packaging can be degraded in a composting system as can be shown by the standard methods. The end product must meet the relevant compost quality criteria.

- **Primary Biodegradability** (Partial Biodegradability) is the alteration in the chemical structure of the material and loss of specific properties.

- **Ultimate Biodegradability** (Total Biodegradability): The material is totally degraded by the action of microorganisms with the production of carbon dioxide (under aerobic conditions) and methane (under anaerobic conditions), water, few mineral salts and biomass.

Disintegration is the falling apart into very small fragments of packaging or packaging material caused by environmental degradation mechanisms. Very often disintegration is misunderstood and is claimed as biodegradation, especially in the case of polyolefins. Many blend compositions of polyolefins (especially with starch) disintegrate and do not biodegrade.

b. Test Methods to Evaluate the Degradability

In order to fully characterize the long-term properties of polymers, a variety of techniques must be used. Several of them may give similar results but often they complement each other. The most important thing is to relate the observations obtained by the analysis with postulated degradation mechanisms, whereby it should be possible to describe the possible degradation of material.

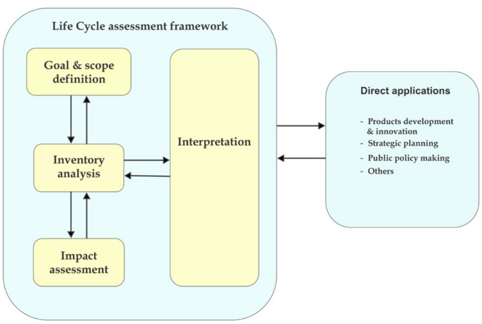
Life cycle evaluation, is therefore, a three-part process :

(i) An inventory of the raw materials, energy and wastes associated with the manufacture, use and disposal of a product.
(ii) An estimation of the impact of raw material extraction and emissions.
(iii) An improvement of analysis.

c. Life Cycle Assessment (LCA)

Life cycle assessment is now a preferred technique to describe the design of ecologically acceptable material. LCA of the materials provides a useful comparison of the ecological impact of comparable products. LCA can be used to compare the ecological acceptability of different raw materials, processes and end products. In general, there is a correlation between ecological acceptability and cost which is of primary concern to the manufacturer of polymer products. This is a 'cradle-to-grave' assessment of alternative strategies for a given application. Since the procedure generally involves a comparison of alternative manufacturing and disposal techniques, it is essentially an assessment of the overall energetic and environmental impact of a product.

Steps of an LCA



d. International Standards for Biodegradation

The American Society for Testing and Materials (ASTM) and other organizations have developed the standards for testing the biodegradability in different specified conditions. The degradation of the material must be measured by the following methods.

1.	ASTM D 5247	Determining the Aerobic Biodegradability of Degradable Plastics by Specific Microorganisms
2.	ASTM D 6002-96	Guide for Assessing the Compostability of Environmentally De gradable Plastics
3.	ASTM D 5338-98	Test Method for Determining Aerobic Biodegradation of Plastic mate rials under controlled composting conditions.
4.	ASTM D 6340-98	Test Methods for Determining Aerobic Biodegradation of Radio-labeled Plastic Materials in an Aqueous or Compost Environment.
5.	ASTM D 5209	Test Methods for Determining the Aerobic Biodegradation of Plastic Materials in the presence of Municipal Sewage Sludge
6.	ASTM D 5210	Test Methods for Determining the Anaerobic Biodegradation of Plastic Materials in the presence of Municipal Sewage Sludge
7.	ASTM D 5152	Water Extraction of Residual Solids from Degraded Plastics for Toxicity Testing.

The international Organization for Standardization (ISO) is a worldwide federation of national standards bodies (ISO member bodies). Since the working group on biodegradability of plastics was created in 1993, rapid advances have been made in this area. The following three aerobic biodegradation test methods have recently advanced to Draft of International Standard (DIS) stage.

Standard	Description
ISO/DIS 14851	Evaluation of the ultimate aerobic biodegradability in an aqueous medium-method by determining the oxygen demand in a closed respirometer
ISO/DIS 14852	Evaluation of the ultimate aerobic biodegradability in an aqueous medium-method by analysis of released carbon dioxide
ISO/DIS 14855	Evaluation of the ultimate aerobic biodegradability and disintegration of plastics under controlled composting conditions- method by analysis of re leased carbon dioxide

These three ISO/ DIS 14851, 14852 and 14855 are recognized as useful screening tests for establishing the aerobic biodegradability or compostability of plastics.

DIN (German) standards:

DIN 54900-Draft Evaluation of the compostability	

CEN (European) Standards:

CEN TC 261/ SC4/ WG2	Evaluation of the compostability, biodegradability and disintegration

Significance of Non-biodegradability and Biodegradability of Materials

a Non-biodegradability : Merits

Non-biodegradability of the polymers enables them to be applicable to diverse applications. Perhaps the most remarkable aspect of polymers derived from natural products is that such environmentally unstable materials should be the basis of environmentally durable industrial products. Rubber tyres before fabrication are among the least environmentally stable of all polymers and yet automotive tyres survive for many years in the outdoor environment long after use. The key applications of so called non biodegradable thermoplastics are as follows:

1. In Packaging

The major use of synthetic polymers has been as replacements for more traditional materials, particularly in packaging. Polymers are light in weight and yet have very good barrier properties against water and water-borne organisms. Compared with glass they have much superior impact resistance and resilience, resulting in reduced product loss during transport. They protect not only perishable commodities from the environment and also the environment from corrosive or toxic chemicals. The production processes for plastics from crude oil are much less labor and energy intensive than traditional materials[9-11] (ref. table below).

Energy requirements for the production of materials used in packaging

Material	Energy requirement $kWhkg^{-1}$
Aluminium	74.1
Steel	13.9
Glass	7.9
Paper	7.1
Plastic	3.1

The fabrication of plastics by injection molding is also less energy intensive than the fabrication of traditional materials. The polymer is converted into useful product in a single rapid and repetitive process that does away with intermediate forming and joining procedure. When these factors are combined with lower density of polymers, the energy requirements for similar containers are found to be lower than for traditional materials.

To compete with plastics, even if no energy were involved in the transport and cleansing of returnable bottles, these returnable bottles would have to be recycled about twenty times. Further Energy requirements for similar beverage containers in comparison of plastics are shown in the subsequent table.

Energy requirements for similar beverage containers

Container	Energy usage per container (kWh)	Weight (pounds)
Aluminium can	3.00	1.41
Returnable soft drink bottle	2.40	10.60
Returnable glass beer bottle	2.00	8.83
Steel can	0.70	1.76
Paper milk carton (1 pint)	0.18	0.92
Plastic beverage container	0.11	1.23

2. In Transportation

Polymers are light in weight compared with metals and ceramics. The modern plastic milk container is only a fraction of the weight of a similar bottle made from glass and this has a significant influence in transport costs. It is a popular belief that milk delivery in returnable glass bottles is ecologically preferable to single-trip plastic containers. Non-biodegradability makes the synthetic polymers suitable to this purpose. Due to their long-term stability, plastics are also increasingly replacing traditional materials in automotive components, for example in motor vehicles, aircraft and boats. In addition, since much more energy is used in the production of metals and glass than manufacture of the common plastics, it follows that the more plastics can be used to replace metals and glass in vehicles, the less fuel will be used in transport.

3. In Agriculture

Plastics have changed the face of rural environment by their wide range of uses in agriculture, waste management and irrigation. Plastics have largely replaced glass in greenhouses and tunnels. They are much cheaper than glass in greenhouses but they have to be replaced more frequently. Biodegradable polymers would be of not much use as longevity of usage is a major criteria in these application.

4. At Home and Office

It is now taken for granted that for equipment operating at ambient temperatures, plastics are the modern materials of choice for items such as food mixers, vacuum cleaners, hair driers, television consoles, computers, word processors and other office equipments. Who would want appliances which biodegrade & disintegrate in a span of few weeks or months.

5. As Paintings and Surface Coatings

Naturally occurring 'drying oils' based on polyunsaturated fatty acid esters have been used for centuries to protect metals from corrosion and wood from biological action. By far, the most important of the 'environmentally compliant' technologies to emerge were crosslinked coatings and printing based on oligomeric acrylate monomers. These could be crosslinked rapidly by UV light in the presence of photosensitizers. Water resistance and nonbiodegradability make plastics the natural choice for such application_

6. In Building and Civil Engineering

A very visible and valuable contribution of polymers in the building industry is the replacement of wood in window frames and outdoor cladding. The advantage of plastics is their resistance to biodegradation and this characteristic, coupled with reduced decoration costs, making them the materials of choice as replacements for wood and iron.

Pigmented rigid PVC (unplasticized) is the most widely used polymeric material for outdoor use where they have to be stabilized against the effects of weather. It is achieved by the use of synergistic stabilizers. It is also used in. windows and roof-lights which need a long life of a few decades in extreme weather condition neccesiating non- biodegradability.

7. In Public Utilities

Polymers have, in recent years, assumed an increasingly important role in underground applications. These include piping, ducting and underground chambers where previously steel or concrete were used. New uses include impermeable membranes the contaminant of water in reservoirs and of effluents in sanitary landfill, in grids and nets in soil stabilization and in underground electricity cables. These sub-soil uses cc polymeric materials make use of their resistance to biodegradation. The underground transport of oil, water and gas by pipeline is an ever-increasing aspect of utility supply to industrial and domestic destinations. Iron. and steel were the main materials for construction 50 years ago and as they fail due to corrosion, they are now replaced by plastics that do not corrode. Particularly favoured are HDPE, LLDPE, PP and to a lesser extent rigid PVC.

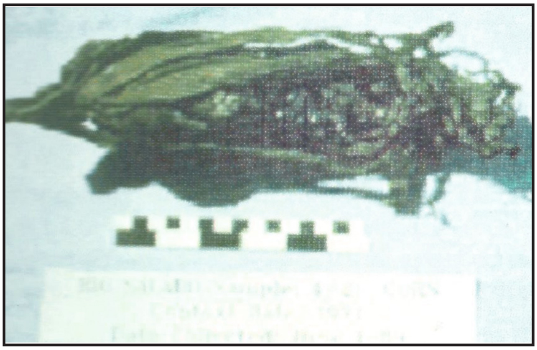
8. In Biology and Medicine

The biological inertness and lightness of polymers make them very attractive in potential biomedical applications. Typical examples of this are dental applications. Replacement plastic prostheses are now state of the art. However, in this application the durability and biocompatibility of the polymer under the aggressive conditions to which they are subjected subjected in use is a basic design parameter.

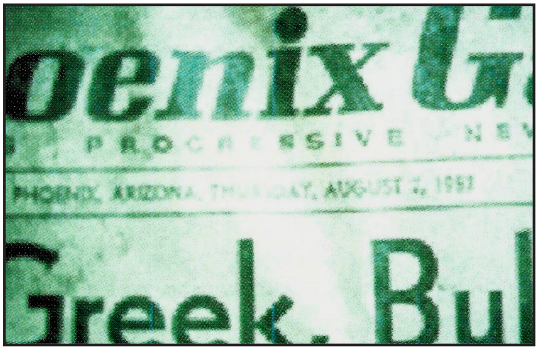
b. Biodegradability of Traditional Materials: Realities and Myths

This is a misunderstanding that there is intrinsic difference between the biodegradability of natural polymers and synthetic ones. In fact, it is not so for example, natural rubber cis-poly(isoprene], as produced by the rubber tree, is bio-assimilated into the environment initially by peroxidation followed subsequently by bio-degradation of low molar mass oxidation products (laevulinic acid, acetic acid, formic acid). Synthetic cis-poly(isoprene), manufactured from petrochemical feedstock, behaves in exactly the same way under the same conditions. However, both natural and synthetic cis-poly(isoprene) become highly resistant to biodegradation when made into industrial products (e.g. tyres). This has nothing to do with the inherent bio-degradability of *cis*poly (isoprene). It is a direct consequence of the presence of highly effective antioxidants added during manufacture. [4,12]

It is generally believed that paper and cellulosic materials are biodegradable and do not pollute the environment like plastics. However, several studies on biodegradability of cellulose material including newspapers has shown that these materials can persist in the environment even after land filling for more than 30 years.



A corn ear after 18 years of land filling



A news paper after 37 years of land filing

Wood, a natural material, which is normally considered biodegradable, may be highly resistance to biodegradation. Sequoia trees are well known to remain stable under normal climatic conditions for 500 years. Trees contains hydroxy phenols which not only protect the wood from bacterial and fungal attack but are also very powerful antioxidants with activity similar to the most effective synthetic chain breaking antioxidants[5,6]. In fact such antioxidants present in polyolefins protect them from environmental degradation. In the absence of such protective additives polyolefins will easily disintegrate in the environment.

A comparison of overall environmental burden in the process of polyethylene and paper is shown in the table below.

Comparison of air and water pollution associated with plastic and Kraft papers

Environmental burden	Polyethylene	Unbleached kraft paper	Paper combinations
Energy (GJ) for production process	29	67	69
Air pollution (kg.)			
$S0_2$9.9	19.4	28.1	
NO_x	6.8	10.2	11
CH3.8	1.2	1.5	
C0 6	3.0	2	
Dust	1	3.2	3.8
Waste water burden (kg.)			
COD	0.5	16.4	107.8
BOD_5	0.02	9.2	43.3

It is obvious that the energy cost of plastic per pound is substantially less then that of all its major competitors. The conclusion is ***"The replacement of polyethylene by paper carry bags makes no sense ecologically. The production of polyethylene carry bags requires less energy, and in the process result in less burden to the environment. There is no significant difference in the disposal of polyethylene and paper bags"***

Thus the degradability or Eco-friendliness of materials is decided by the conditions of its use and disposal.

This can be further endorsed by the fact that there are infinite number of applications where long life time is essentially required and usually this can not be achieved by the so called ecofriendly traditional like material wood, paper and cellulosic materials. The table below depicts the average durability required for various application where plastics are being used extensively and successfully.

Expected durability of some materials

Material	**Expected Durability (years)**
Cable	50-60
Underground pipes	30-50
Automotive compotes	15-30
Aircrafts & Boats	10-20
Office equipments	20-30
Televisions & computers	10-20
Paintings & coatings	1-10
Window frames & Door cladding	20-50

Further, without plastics, 400 percent more material by weight and 200 percent more material; by volume would be needed to make packaging, while the volume of packaging would more than double.

a. For every seven trucks needed to deliver paper grocery bags to the store-only one truck in needed to carry the same number of plastics grocery.

b. Plastic members, made with recycled plastic, holds nails and screws better than wood, is virtually maintenance free and lasts for 50 years.

c. Foam polystyrene containers take 30 percent less total energy to make than paperboard containers.

d. By using plastic in packaging, American product manufactures save enough energy each year to provide energy to a city of 1 million homes for three and half years.

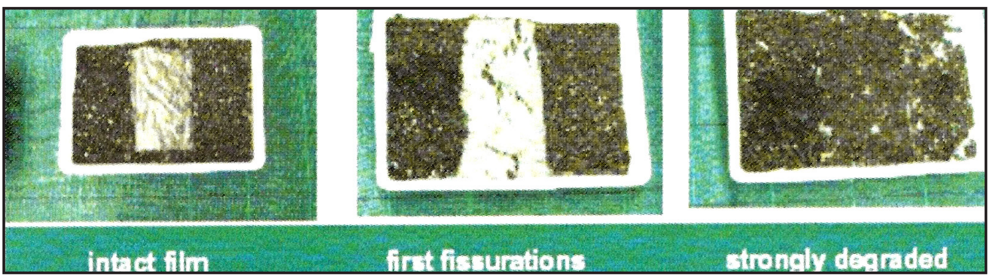
Requirement of Biodegradability

All advantages and benefits mentioned above become an issue from the point of view of environmental pollution generated by one time use disposable packaging materials. Certainly, we need to make much more efforts to make thermoplastics stable for certain applications but at the same time the biodegradability is essentially required for short lifecycle plastic materials as shown in the table below.

Expected durability of common commodity plastic materials

Materials	Generally Expected Durability (Days)
Carry Bags	30-100
Milk Pouches	30-100
Mulching Films	40-125
Disposable Food container (Food Packaging)	30-100

One biodegradable plastic film must degrade in a prescribed fashion resulting in the generation of carbon di oxide and water leaving behind some residual biomass as is shown in figures below some examples of biodegradable films from Enviro case are also shown alongside.



ideal trend of biodegradation

With Envirocare ™ Ag 1000: Mulch film becomes brittle after the desire lifetime

Without Envirocare™: Mulch film remains intact after use

Examples of biodegradation of products from Envirocare TM

International Status of Biodegradable Polymers and their Functional Advantages

Polyhydroxy alkanoates (PHA), are hydro-biodegradable polymers and can be made by fermentation of sugar. Since this process is expensive and inefficient, work is currently in progress to genetically modify oilseed rape (Brassica napus) to produce seeds containing PFIAs. Polylactic acid is another hydro-biodegradable polymer and can also be produced from sugar or corn¬starch. However, it is doubtful whether such materials could satisfy the world packaging requirements without the raw material coming into competition with food application. It seems inevitable that, even if acceptable yields of polyesters could be obtained from food crops, plastics production would be in competition with food production. In the long-term, a more acceptable ecological strategy would be to utilize the agro wastes themselves (e.g. molasses) to produce biopolymers. Since the time of the first forays into the market, biodegradable plastics have matured greatly. New polymers offering improved properties, one of which is true susceptibility to microbial attack, have entered the marketplace. In addition, standards have been developed which assess the propensity of a material to degrade biologically. Biodegradable products are no longer pitched at eliminating landfill issues but rather are targeted to specific applications such as the collection of leaf and yard waste destined to composting operations and food contact applications. In this end use, a truly compostable bag, compatible with the operation may afford economic benefit and / or improved quality of finished compost.

The use of such type of polymers in the body as temporary inclusions such as sutures and supporting meshes which require to dissolve and biodegrade over a relative short period of time requires the design of new material which, unlike the present range of bio-inert polymers, can be bioassimilated into the body after they have served their purpose. Biodegradable polymers have made possible the introduction, of mulching films where non-biodegradable polymers cannot be used. Biodegradable mulch from natural sources has been used since time immemorial to provide an insulating layer round the roots of vegetables and soft fruits.

Biodegradable and compostable plastics are available in the market from many sources. A few of them are as follows.

- Bayer - Germany has introduced a novel biodegradable polyester amide. The resin is semi-crystalline and can be injection moulded or extruded on conventional machinery. The resin is made of hexamethylene diamine, butane diol, and adipic acid. The film is translucent to transparent. Biodegradation begins when material comes in contact with humus. Target markets are trash bags, plant pots, food packaging and disposable utensils.

- Eastman Chemical Co. - TN began making copolyester 14766, sold as Eastar BioCOPE, a year ago. Expected end uses include lawn and garden bags, food packaging, and horticultural applications. When composted, the material breaks down to carbon dioxide, water and biomass at a rate comparable to newspaper. It is semi crystalline, translucent to transparent as film, with a modulus lower than PE, and oxygen-barrier properties slightly better than PE.

- BASF, Ludwigshafen, Germany has a biodegradable COPE, Ecoflex, said to have properties comparable to low density PE. Ecoflex films are tear resistant and water resistant. Unlike LDPE, they allow water vapour permeation. DuPont, Geneva, Switzerland announced last year the commercial release of its Biomax hydro / biodegradable polyester. As a modified PET, it is only marginally more expensive to produce than conventional PET. Biomax has a melting point of about 200°C. Elongation is from 50 to 500%. Strength may also be adjusted from that of LDPE to 50% of the strength of DuPont's Mylar polyester film. The company is marketing the product in the U.S. and Europe.

- Symphony Environmental Ltd, Hertfordshire, England, launched sales of a polyethylene based degradable plastic in which degradation is controlled by an additive which can be preset to ensure degradation is complete in as little as 60 days or as long as five years. Novamont SpA, Novara, Italy says the firm has four formulations of Mater N., a nontoxic, starch-based polyester and wants to increase this to fit the resin to a broader realm of niche products. Current applications include golf tees and animal toys.

- Environmental Polymers Group (EPG), a license of BTG, London., intends to further develop special grades of polyvinyl alcohol which are biodegradable in hot or cold water. These will be used in extruded blown film applications. EPG technology has two components : proprietary low shear extrusion technology and formulating technology for PVOH-based biodegradables. Firm officials say films produced will have equivalent or better physical properties than films made from PVC or PE.

- Idroplast SPA, Montecatini Terme, Italy, produces Hydrolene based on PVOH. Solubility in water occurs based on water temperature, so the material must be stored in paper and then in PE or PP sheets,. It is bubble extruded using modified extruders. Printing can be done by silk printing, offset, and lithography without pretreatment. Targets are packaging for agricultural products, seeds and disinfectants.

Some commercial examples of starch based biodegradable polymers are shown below.

Company	Brand Name
Biotech GmbH	Bioplast
VTT Chemical Technology	COHPOL
Groen Granulaat	Ecoplast
Japan Corn Starch Limited & Grand River Technology	Evercorn
Novamont SpA	Mater Bi
Starch Tech Re NEW	
Supol GmbH	Supol
Novon International	Novon

Water Soluble – Biodegradable Polymers

Water soluble polymers are used as detergent builders, scale inhibitors, flocculants, thickeners, emulsifiers and paper sizing agent. Conventional water soluble polymers persist in oceans, lakes and other water depositories. To avoid accumulation of recalcitrant substances in waterways, the commercial development of water-soluble biodegradable polymers are urgently needed. Water-soluble biodegradable polymers are synthesized by modifying starch and cellulose. Carboxy methule cellulose (CMC) is a family of water-soluble polymer. Water soluble polysaccharides, manufactured by microbial fermentation are also used as biodegradable polymers. Xanthan is the most widely used microbial polysaccharides. Poly (amino acid) with free carboxylic groups, such as poly (aspartic acid) and poly (glutamic acid) are also common among water soluble biodegradable polymers.

Additives for Plastics to promote Degradation

Some additives manufacturing companies are also working towards developing additives which will make conventional plastics degradable or disintegratable. Such additives offer a scope for modifying the properties of conventional resins like polyethylene, polypropylene, polyvinylchloride etc. Ciba Speiality chemicals has developed additives for degradable, controlled-lifetime agricultural polyolefin products, They claim that after harvesting the degradable mulch film which will left in the ground while a nondegradable film must be collected, transported to a collection centre and disposed of by burial, landfilling or incineration. So collection and disposal cost can be saved.

Challenges in Biodegradable Polymers

a Market Trends of Biodegradable Polymers

The European market for biodegradable plastics is small, about 7,000 tonnes/year, according to Greg Bohlmann of SRI Consulting. This includes about 3,800 tonnes of compost bags, 1500 tonnes of loose-fill packaging, 700 of paper coatings and 500 of food packaging.

b Costs and Commercial Availability

Price economics of currently available biodegradable polymers (Nov. 2002)

•	Lactic acid based biopolymers	: 1.5 to 3.0 US $ per pound
•	PHB based polymers	: 4 US $ per pound
•	Starch based biopolymers	: 2.25 – 2.90 US $ per pound
•	Price of conventional thermoplastics	
-	Polyethylene	: 700 – 800 USD/MT
-	Starch filled polyolefins	: 550-825 USD/MT
-	Polypropylene	: 520 – 540 USD/MT
-	Poly (vinyl chloride)	: 440 – 460 USD/MT
-	Polystyrene	: 550 – 590 USD/MT

c Being higher priced materials, widespread applications of biodegradable polymers as substitute for petrochemicals derived polymers is beset with limitations in commodity application.

NIMITLI programme on biodegradable polymers

In order to derive the fullest benefit from the indigenous Science and Technology system, the Government of India has mounted the New Millennium Indian Technology Leadership Initiative (NMITLI). This is a farsighted programme and seeks to capture for the country a global leadership position, in few selected niche areas. The onerous task of managing the NMITLI programme has been entrusted to Council of Scientific and Industrial Research (CSIR).

Agricultural byproducts constitute one of the most important classes of renewable and sustainable feedstock for the production of polymeric materials. Natural polymers such as modified starch and cellulose have been examined as biodegradable materials. India possess several agricultural products and byproducts having a large agricultural based economy. One of the NMITLI programme also aims to examine such low cost raw materials such as bagasse, Molasses and Waste grain as a precursor for producing value added biodegradable polymeric materials such as cellulose acetate, poly (latic acid), etc.

Recommendations and Conclusions

Many packaging manufacturers have exploited the 'green conscious' consumer with exaggerated claims to 'Environmentally Friendly' biodegradable packaging materials without a proper understanding of the absolute principle of 'biodegradable' materials. The replacement of traditional packaging plastics (LLDPE, LDPE, HDPE, PS & PP) by synthetic biodegradable polymers groups (polyesters viz. PLA, PCL etc.) is currently expensive proposition. Although scientific literature are replete with several publications and patents of different kind of formulations, to achieve the biodegradability either thought blending with natural biodegradable material or by the sue of only additives or biodegradable fillers, *real biodegradation* (absolute conversion of material to water and carbon dioxide leaving some biomass residues) is achieved or demonstrated only in a few selected cases. There are several factors which determine the degradability of material in the environment e.g. temperature, humidity, pH, soil enrichment, availability of sunlight, mechanical factors etc. Sellers of biodegradable plastics should be capable of supporting their claims through appropriate certification, labeling programme and must be willing to provide information indicating that their products meet recognized standards or be willing to demonstrate through field of testing that their products will meet the buyer's expectations. Buyers of biodegradable, compostable plastics should seek evidence that the product being offered has been certified or meets recognized standards or degrades in his specific conditions in a manner that meets his needs.

The following are the major recommendations

1. To set up a Centre for study of Polymer Degradation and Life Cycle analysis (PDLCA) in a well reputed institution to systematically explore all facets of polymer usage and its impact on the environment.

2. Setup in one or two locations, basic test facilities for certifying the bio or environmental degradability of materials for defined end applications. Here NCL is willing to play a lead / catalytic role in helping set up such facilities

3. Develop and establish Indian Standards for testing and evaluation of degradability of polymers (bio and environmental) and provide hands on training to representatives of industry for the same.

4. BIS should constitute a committee on biodegradability and bio-polymers and adopt such standards.

5. Conduct training and awareness programs on all aspects of bio and environmental degradation of polymers and life cycle analysis

References

1. R. P. Singh, P. N. Thanki, S. S.Solanky and s.M. Desai in Advanced Functional Molecules and Polymers (ed. H. S. Nalwa), Ch.1., Vol.4(2001).
2. Working party of the National Association of Attorneys General of the USA (1990) The Green Report.
3. A. G. Sadun T.G. Webster and B.Commmener Breaking down the degradable plastics scam. Washington : GREEN PEACE, 1990.
4. G. Scott., *Atmospheric Oxidation and Antioxidants*, Elsevier Science Publishers, 2nd edn., Vol. II(ed.G.Scott), 1993
5. G. Scott., *Atmospheric Oxidation and Antioxidants*, Elsevier Science Publishers, 1st edn., p387 (1965)
6. G. Scott., *Atmospheric Oxidation and Antioxidants*, Elsevier Science Publishers, 1st edn., p276 (1965)
7. S. J. Huang., *Polym.Mater.Sci.Eng.*, **63**,633(1990)
8. R. Narayan., *Proceedings of the 'UNIDO-ICS International Workshop on environmentally degradable polymers,* nov. 1997.
9. J. E. Guillet., *Plast.Eng.*, **Aug** (1974), 47-56

10. A.B. Makhijini and A.J. Litchenberg., 'An Assessment of energy and materials utilization in the USA,' Memorandum no. ERL-M310 (revised), (1971), Electronics Research Laboratory, College of Engineering. University of California, Berkley.,
11. I. Boustead and G.F.Hancock., *Energy and Packaging* (1981). Ellis Horwood Publishers. Chichester.
12. G. Scott. *Antioxidants in Science, technology, medicine and nutrition*., 1997., Albion Publishing, Chichester.
13. Materials Matter: Toward a sustainable Policy, K. Gieser, MIT Press, 2001.
14. D.L. Kaplan, *Biopolymers from Renewable Sources*, Springer Verlag, 1998.
15. E. Chellini and R. Solaro. *Adv. Mater.*, **8(4)**, 305 (1996)

Chapter 3

Plastics in Healthcare and Safety

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PLASTICS IN HEALTHCARE AND SAFETY

Plastics offer a range of benefits to society at large – helping in its advancement and standard of living. Since their discovery many years ago and subsequent commercialization and public acceptance, plastics now play a major role, although often unnoticed part, in the lives of virtually everyone who lives in a country. Longer life expectancy derives not only from the remarkable pharmaceutical development of the twentieth century, but also from the plastics based technology which make the life-saving and life-enhancing surgery possible – for example heart valves and hip joint replacement. Even fundamental medical care involves plastics namely blood bags, disposables, hygienic medical instruments, safer spectacles contact lenses and gradual delivery of medicines via capsules and patches. All of these maker better and longer lives a reality for both richer and poorer in society, in both developed and developing nations.

This chapter looks in detail at several aspects of plastics used in healthcare and safety. Not only are many products packaged in plastic, but many durable goods are also either produced from plastics or are encased in them. Plastics continue to this day to be used for more applications because of their low cost, noncorrosiveness and nontoxicity, nonbreakability, ease of color, resistance to corrosion, and other beneficial attributes. The packaging of healthcare products includes, pharmaceutical products which are usually packaged in bottles, blister packs, etc. Another use is in medical products, i.e., those used by medical practitioners themselves, in hospitals, clinics, home healthcare and in other applications.

A detailed account has been provided of use of plastics as medical devices, implants and disposables. Role of each polymeric material for specific health care system has been highlighted. The analysis has been segmented by use of specific plastic material like thermoplastic polyesters (primarily PET), polyethylenes (HDPE, LDPE, LLDPE), polypropylene (PP), polystyrene (PS) and styrene copolymers, and polyvinyl chloride (PVC).

An overview of the aspect of enhanced safety associated with use of plastic products in home, automobiles, toys and childcare has been given. Discussions in this section are focused on how the dynamics and major changes that are continually occurring in plastic industry and shape up the safety of public in the modern life-style.

Issue of disposal and waste management associated with the use of plastics in healthcare have become quite a vital issue. Some implementation on the waste disposal and the efforts therein has been given.

Lastly the standards and specifications used by the plastic industries in order to meet the quality and demands of specific properties in healthcare including food and pharmaceutical products have been provided.

PLASTICS - FRONT RUNNER IN HEALTH AND HEALTHCARE

Plastics Packaging - Extends drug life - improves hygiene

Plastics have made very significant contribution in the areas of health and healthcare. For more than 40 years, plastic medical products from disposable syringes to IV blood bags to heart valves have helped doctors and nurses save lives. Many of the medical practices that are common today - and weren't even dreamed of twenty years ago - are made possibly by plastic. Plastics have found uses in simple applications like packaging of drugs and syringes as well as body implants. There are clearly two types of uses of plastics in healthcare. One end of the spectrum includes applications where these are used inside the human body or in contact with tissue, blood and/or biological fluids. The other end of spectrum is that in which plastics are used in medical related applications such as packaging, devices, hearing aids, low vision aids, artificial limbs, etc. and medical equipments.

Plastics offer a very wide variety of materials ranging from soft rubbers to hard tough plastics as well as bio-stable and biodegradable materials. Plastics are an ideal class of materials to cover large application areas in health and healthcare due to their lightweight, bio-compatibility, non-corrosive nature, chemical inertness, low cost and comparable densities with that of human organs. In some cases, they may contain additives or reinforcing agents to modify and / or enhance properties.

Market for Plastics in Healthcare

The global market for medical devices in 1996 was US $ 130 billion and in year 2000 it had reached $ 260 billion, thus representing a tremendous growth potential. Global demand for plastics in medical devices is approximately 5 million tons in 2002 with an annual growth rate of about 5% (world wide demand for majority commodity plastics in healthcare as listed in the table below). The Indian market will see a similar growth rate, which will increase as more players in the country get involved in the development and manufacture of medical devices. This will of course lead to the development of new polymeric materials and given the large Indian population this would represent a significant amount of business opportunities.

World wide Demand for Major Commodity Plastics as Medical Products

Material	Demand for major plastics (KTA) Year: 1994	Year: 2000
PVC	715	835
PP	405	474
PE	600	702
PS	364	400

Plastics used in medical applications must adhere to very rigid standards, and must be non-toxic, noncarcinogenic, biocompatible, and in no way injurious in the biological environment.

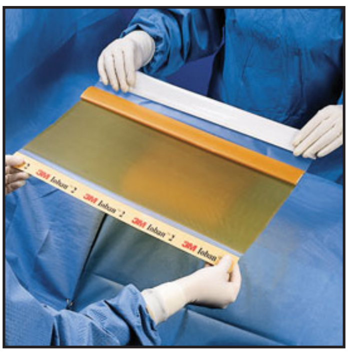
Traditional materials like glass and metal have various disadvantages which include :

- Packaging problems
- Fragility and weight
- Non flexibility
- High co-efficient of friction to withstand fluid flow
- High cost.

The benefits of plastics as medical products are as follows:

- Flexible, ductile, tough and light weight
- Low co-efficient of friction to withstand fluid flow pressures and facilitates flow
- Inert in contact with blood, tissue and other body fluids / matters
- Transparent – vital to monitor visually / electronically flow through the tube
- Less cost and recyclable.

Applications of Plastics in Healthcare



Incise Drape film

The medical applications of plastics are again to be classified in two categories, one in which they are used as devices in healthcare where the plastics are not in direct contact with the human body. The other is as biomaterials where the plastics are in contact with the human body tissues and fluids. The application areas include a wide spectrum including dentistry, contact lenses, blood bags, artificial organs, sutures, catheters, syringes, surgical drapes, equipment housing and several others. The biggest potential for growth in the future is in the development of new plastic systems for implantation in the human body. Some examples of implants include orthopedic implants, cardiac valves, pacemaker, trachemetry tubes, intraocular lenses, sheet implants and breast implants.

Plastics Used in Medical Applications

The plastics used in medical application may be either biodegradable or bio-stable depending on the requirements. The plastics that generally find applications in healthcare include high density polyethylene (HDPE), ultra high Molecular weight polyethylene (UHMWPE), polypropylene (PP), polyvinyl chloride (PVC), polymethylmethacrylate (EMMA), silicone rubbers, polyethyleneterephthalate (PET), polytetra¬fluoroethylene (PTEE.), polycarbonate (PC), styrene —butadiene — styrene copolymer (SBS), elastomeric polyurethanes, polyacrylonitrile, polyacetals, polyamide, polylactide polyactal, and polyglycolate. Each plastic offers unique properties suitable for specific applications. Various polymers and their medical applications are listed in the table below.

Urine collection bag

Plastics and their Medical Applications

Plastics	Applications
HDPE/	Blood filters, catheter, reconstruction of
MDPE	joints Syringes, Splints, Bone fracture treatment, IV Fluid bottles, etc
LDPE	Packaging films, Wound covering films, Urine bags, Examination gloves, Catheter tracheal prostheses
PP	Membrane support suture, Packaging foils, Syringes
UHMWPE	Joint replacement prosthesis
PTFE	Catheters & drainage tubes, coating for suture membrane for artificial lungs, cannulae, artificial bone/joints
PVC	Blood bags, Blood tubing, Surgical gloves, Suction pipe, Infusion drip chamber, blister packagin etc
Polyamides	Surgical instruments, Suture material, Artificial skin, Splints etc

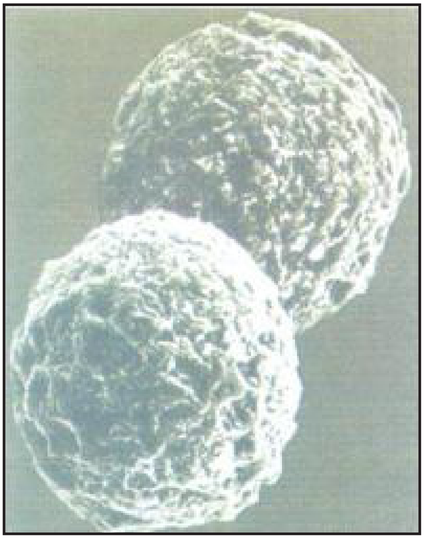
Healthcare with Plastics

Delivery of Drugs

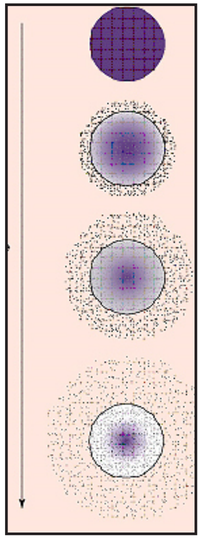
Plastics play a very important role in ensuring the delivery of the drug in appropriate concentration to the target side. Many of the tablets are coated with thin plastic to increase its palatability and to prevent deactivation in the stomach for drugs intended to be released in the intestine for absorption. In addition to this modality there are various other formulations including sustained release formulation wherein the active drug is bound to various plastics to increase the period of disintegration and release of the active drug at regular intervals thereby ensuring a constant release and absorption into the blood stream. There are also newer delivery models of the drugs where a thin plastic film impregnated with the drug is implanted into the body or into the target issue and the drug is released at a constant rate through the film to exert a sustained action at the target issue. These drug deliveries are commonly used for cancerous tissues as well as in implantable contraceptive devices (Norplant). Some long acting injectable preparations are also available which are oil or plastics bound. Delivery of drugs is also done through devices like pumps that sense the blood, levels and accordingly injects the required amount of drug like insulin pumps used for control of diabetes.

In recent years, there has been a rapid growth in the area of drug delivery, facilitated by novel technologies such as combinatorial chemistry and high-throughput screening. These novel approaches have led to drugs which are generally more potent and have poorer solubility than drugs developed from traditional approaches of medicinal chemistry The development of these complex drugs has resulted in a more urgent focus on developing novel techniques, to deliver these drugs more effectively and efficiently.

The "ideal" Plastic for Drug Delivery



Micrograph of particles used to carry drugs to the lung



Drug delivery from a typical matrix drug delivery system

Various synthetic as well as natural plastics have been examined in drug delivery applications. If the plastic matrix does not degrade inside the body, then it has to be surgically removed after it is depleted of the drug. Hence to avoid the costs as well as risks associated with multiple surgeries, the plastics used should be biologically degradable. Thus for a plastics to be used as a drug delivery matrix, it has to satisfy the following criteria.

1. It has to be biocompatible and. degradable (i.e. it should degrade in vivo to smaller fragments which can then be excreted from the body).
2. The degradation products should be nontoxic and should not create an inflammatory response.
3. Degradation should occur within a reasonable period of time as required by the application.

The most commonly used plastics for this application are polylactide (PLA) and Poly (lactidecoglycolide) (PLGA). These plastics have been used in biomedical applications for more than 20 years and known to be biodegradable, biocompatible and non-toxic.

Biologically Degradable Plastics in healthcare

Biologically degradable plastics can be loosely defined as that class of plastics, which degrade to smaller fragments due to chemicals present inside the body Thus two types of degradable plastics can be included under this definition, viz. Biodegradable plastics and bioabsorbable plastics. Biodegradable plastics are the ones which degrade to smaller fragments by enzymes present in the body Bioabsorbable plastics on the other hand are those which degrade in the presence of other chemicals in the body (generally this class refers to hydrolytically less stable plastics).

Polyesters like polylactide (PLA), polyglycolide (PGA), poly (lactide-co-glycolide) (PLGA), poly (e-caprolactone), poly (orthoesters) are bio-degradable and used in the drug delivery systems. Lupron-Depot, the first FDA-cleared PLGA product is administered monthly for prostrate cancer thus replacing the daily injections. Poly (e-caprolactone) has a slow degradation rate and is suitable for long-term drug delivery systems. It is useful for the controlled release of steroids. Hence, it has been used to deliver contraceptives for a period upto one year. It functions as a surface degrading system and a constant degradation and drug release rate can be achieved.

Polyanhydrides are highly reactive and hydrolytically unstable with degradation time ranging from days (aliphatic) to years (aromatic). They are used in Gliadel system for the delivery of bisthloroethylnitrosourea (BCNU) to the brain for the treatment of glioblastoma.

The simplest method of drug delivery is the entrapment of the medicament into the hydrogel network. Hydrogels are cross-linked polymeric structures with the ability to swell in water_ They can be homopolymers, copolymers or multipolymers. They are frequently used for reservoir and matrix type delivery systems. The polymer formulation, water contact and the cross-linking density affect the drug release rate of hydrogels. The monomers used for biomedical hydrogels include methyl methacrylate(MMA), hydroxyethyl metahcylate(HEMA),anhydride, etc. Some of these can also be used as injectable liquid polymeric hydrogels when injected becomes solid implants in the body upon contact with water in the body fluids or at elevated body temperatures. These can also be used to deliver small molecules, peptides, recombinant proteins, antigens, genetic materials, etc.

Biodegradable polymers can also be used as scaffolds for tissue engineering. These materlaii¬elicit a specific functional response and can be used to engineer tissues/organs like skin, cartilage, bones, fat, etc. Composites of polyhydroxybutyrate (PHB) have been successfully manufactured and are being investigated for use as bioactive, biodegradable matrices to guide and support tissue in growth.

Use of Plastics for Healthcare in Medical Devices

There are various devices that are being used in various medical specialties. These devices are usually made of plastics to ensure that they are light weight while at the same time have the

GROWING HUMAN ORGANS

Polymers are already being used in tissue engineering to make materials for skin grafts. Advanced Tissue Sciences in La Jolla,California, manufactures Dermagraft - a living skin product used to treat burns patients and problems such as diabetic ulcers. The graft acts as a protective barrier and promotes the regrowth of the patient's own skin cells

Such skin products are developed using a polymer scaffold to guide tissue growth. The scaffold needs to be the right size and biodegradable. The tissue is grown by impregnating a polymer scaffold with cells, which are encouraged to grow using growth hormones. The scaffold and cells are then placed in the body, where the scaffold eventually breaks down leaving behind the new tissue.

Neil Cameron, Professor in polymer synthesis at the University of Durham, UK, is experimenting with a poly (e-caprolactone) based from scaffold, in an attempt to produce a frame able to facilitate the growth of organs such as the liver and heart.

The major drawback of Cameron's scaffolds is that they are not fully biodegradable, a problem that Cameron expects to have solved very soon. Part of this process will involve replacing styrene, with a more biocompatible material such as methyl methacrylate. " We could have a viable scaffold within the year", he says.

Close wound suction unit

strength to bear weight in devices used for weight bearing applications. The most commonly used devices are splints and calipers, used as orthopedic devices for providing artificial limbs or providing support to the damaged skeletal systems. Other devices like spectacles and low vision aids are a common sight in the visually disabled persons. There are many other devices which are commonly used by the population to help them overcome their various disabilities and limitations while pursuing a normal life. The second category of devices includes medical devices which are used to help in diagnosis or treatment. One of these devices are the endoscope which are used for a wide range of activities from diagnosing gastrointestinal disturbances to laparoscopic surgeries. The diagnostic devices include various kits used for estimating the levels of various hormones etc. Developments in medical devices are as under.

Artificial Heart Devices

Since the early experimental cardiac replacement using a totally artificial heart in a dog in 1957, there have been many breakthroughs in artificial heart design. Most recently, there have been several clinically significant applications of a totally artificial heart in humans. The success of these applications has been debated, but their importance as biomaterial development is widely accepted. The first patient survived 112 days, and others longer. The most widely tested design and the one used most in these early procedures was the Jarvik-7-type artificial heart pump with a pump body composed of polyurethane.

The plastic materials that have been used in the artificial heart studies include **polyvinly chloride (PVC), silicone rubber** (Silastic), **polyurethane**, Biomer and polyolefin rubber (Hexsyn).

Mechanical Circulatory Assist Devices

In 1971, the successful use of paracorporeal left ventricular bypass pump to separate a patient from a cardiopulmonary bypass was reported. In the United States, Europe, and Japan, temporary mechanical circulatory support devices are used with patients who might otherwise die from cardiac failure. Left or right ventricular bypass, or a combination of both, has -been applied. These devices used diaphragms, air-driven pumps with valves, or cardiac chamber cannulae systems with an external roller pump. The plastic materials are similar to those used in the artificial heart devices.

Extracorporeal Heart-Lung Machines (Oxygenators)

In open-heart operations, the heart is temporarily replaced with an extracorporeal heart-lung machine. In the bubble-type oxygenator, blood is directly exposed to oxygen. The oxygenating section can be made of soft **PVC (plasticized)** film or rigid polycarbonate (PC). In the membrane type oxygenator, the blood is oxygenated through a plastic membrane, eg, polypropylene, silicone rubber, PTFE, or polysulfone. The bubble-type oxygenator causes more damage to blood cells. Extracorporeal membrane oxygenation (ECMO) can also be used as an artificial lung in the treatment of acute respiratory insufficiency (ARC). A safe and effective microporous **polypropylene (PP**) hollow-fiber oxygenator has become commercially available. The fibers have an internal diameter of 20 mm, with pore size of about 70 nm.

Oxygenators made from PVC

Artificial Kidneys

Artificial kidneys often referred to as hemodialysis units, remove waste products from the blood with a plastic semipermeable membrane. Hernodialysis and hemofiltration depend on membrane techniques. Permeability limits the clinical utility of plastic membranes for these applications. Commercial dialysis membranes are made of cellulose acetate, regenerated cellulose polvcarbonate, poly- methyl methacrylate (PMMA), polyacrylonitrile, ethylene-vinyl acetate copolymer (EVA), and polysulfone. They are used in disposable forms, eg, as hollow fibers or integrated plates.

Jaipur Foot

Due to rise in road accidents, disasters and other hazards in India 25,000 new cases add to the population of amputees every year. The fitment of artificial limbs, therefore has to be further augmented on a large scale. The concept of extraordinary prosthesis -Jaipur Foot founded by Internationally respected Dr. P K Sethi, Jaipur foot has become a household name and has brought smiles to thousands of those who suffer from amputation of limbs.

Jaipur Foot is a below knee prosthesis which is indigenously designed and is manufactured from locally available and durable **High density polyethylene (HDPE)** pipes. It looks like a normal foot and provides good range of movement required for normal human locomotion.

Plastics in Jaipur Foot

Plastics Caliper for Polio Patients

Poliomyelitis is one of the most dreaded diseases that leads to locomotor disability amongst children. For children afflicted with polio a mobility device commonly known as CALIPER is provided. Calipers need to be lighter and durable. They also have to be tough to support the weight of the individual.

The Plastic calipers have following characteristics:

- Plastic calipers are lighter and more durable than the conventional metal calipers.
- Plastic calipers are provided with a good quality sports shoes to achieve maximum comfort and cosmesis, which makes it highly acceptable and popular amongst children.
- Soft Padding is provided for support and comfort.
- Ankle joints are provided in calipers to achieve normal gait (walk), the desired ankle motion can also be provided like posterior stop, anterior stop, etc. This caliper is washable, velcro fasteners allows easy operation.

Hydrocephalus Shunts (Ventricular Shunts)

These devices correct congenital hydrocephalus in children or infants. The prosthesis uses a valve connected to silicone-rubber tubes, which allow the cerebrospinal fluid to drain from the brain ventricle to the vena cava, atrium, or peritoneal cavity.

Use of Plastics in Healthcare for Implants

A lot of plastic products are in use in the medical field which are implanted into the body and are usually surrounded by a body fluids. These biomaterials come in various shapes and sizes depending on the needs of a particular situation. The biomaterials are used in various implants, which are used to replace the functioning organ of the body or some part of a functioning organ. These include orthopedic implants for knee replacements and total hip replacements. For cardiac surgeries various heart valves have been devised for replacement of the damaged valves as well as in artificial heart has been developed as an alternative two-organ transplant. The most common, product, which is used in all surgical fields, is the use of sutures for superficial as well as deep tissues. Depending on the need the suture materials varies from insoluble material (which needs to be removed later) to soluble materials that degrade at a constant rate and dissolve completely in a given period of time.

Intraaortic Balloon Pump (IABP)

This is a simpler mechanical circulatory device used to provide temporary cardiac assistance. It is much less complicated than a total heart replacement. The balloon, material of choice is polyurethane, known by the brand names of Avcothane, now Cardiothane, and Estane. Biomer has been investigated for use in balloons but is not used commercially.

A team of heart specialists and space engineers from NASA have devised a radically new plastics- based solution for assisting the heartbeat and extending a patient's life until a donor organ becomes available for transplant, or until their own heart is sufficiently recovered for successful surgery.

While others have tried to design devices that mimic the heart, the team discovered that, as long as it could pump ten litres of blood a minute without damaging blood vessels, a machine needn't use the same pulsating action as the human heart. Armed with this knowledge, they developed a propeller the size of a fountain pen, based on the same principal as pumps used in the space shuttle to move large amounts of fuel at low pressure. The device made of plastics is sewn onto the heart so that blood can bypass the heart's main pumping chamber.

Use of Plastics in Cardio-Vascular Surgery

Vascular Grafts

Vascular grafts based on plastic biomaterials were among the first successful prostheses, and are still among those most frequently used. The clinical use of vascular grafts is, in the main, restricted to internal diameters larger than 6 mm. Problems of thrombus formation limit the use of smaller grafts. The plastics most often used are in knitted or woven form. The highly porous PTFE Gore-Tex allows ready formation of new lining; vascular prostheses of 6-mm diameter are used in artificial kidney patients.

Patients undergoing coronary revascularization may not have suitable autologous vessels for artery grafting and may need vascular prostheses. Gore-Tex vascular grafts 4 mm in diameter have been used in coronary-artery bypass surgery. An expanded PTFE material called Impra Graft gives similar results. Biomer yields vascular grafts resembling a natural artery.

Heart Valves and Pacemakers

Diseased aortic and mitral valves were first replaced with mechanical ball-and-cage prostheses in 1960. These devices have since been widely used. Some of the plastics employed are a Dacron cloth cuff and a silicone rubber ball. Silicone balls absorb lipids and are no longer used. The housings of pacemakers contain epoxy resins. Silicone rubber has been used in the electrical conduits of pacemakers. Seamless trileaflet valves have been made of polyurethane, i.e, Avcothane-51. With a heartbeat of 60/min, such a device would be subjected to 12 billion flexes during 40 years of operation.

Continuous Ambulatory Peritoneal Dialysis (CAPD)

In peritoneal dialysis, the patient's peritoneum is used as a dialysis membrane. CAPD keeps the dialysate a longer time in the peritoneum. This procedure was initiated in 1975 using a silicone rubber Tenckhoff indwelling tube and PVC plastic bag for the dialysate. Four exchanges of dialysate are usually required daily; this yields a drainage volume of ca 9.5 L/d (6.6mL/min).

Artificial Joints

Ultrahigh Molecular Weight High Density Polyethylene (UHMW HDPE) is the appropriate material used for knee replacement surgery which is physically inert and compatible with human metabolic system. It is also used for other artificial joints like acetabulum cups in total artificial hips (TAH) and as the gliding parts in shoulder, ankle, and elbow joints. PP or silicone rubber is used in finger joints.

Plastics in Knee Replacement Surgery

Use of Plastics has been successfully made in specialized orthopedic application like artificial knee replacement. World renowned Indian doctor Chittarranjan Ranawat who specializes in knee joint operation has been using plastics for this sophisticated medical wonder. He has performed thousands of operations including the one on Sh. Atal Bihari Vajpayee — Honourable Prime Minister of India.

Breach Candy Hospital, Mumbai
Where Prime Minister Sri. Atal Bihari Vajpayee was operated

Plastics in knee replacement surgery

Use of Plastics in Medicine

Dr. Harish Bhende
Center for Joint Replacement Surgery
Laud Clinic, Dadar, Mumbai

"Surgical advances have seen that we are able to treat the patients with deformed joints with artificial joint. The well-publicized Knee replacement surgery of Prime Minister Atal Bihari Vajpayee has brought this fact to the forefront. These joints are made up of a specially prepared plastic — Ultra High Density Polyethylene (UDHP). This is a Bio-Inert material — a material having no biological effect in the living tissue of a human being. It is also very durable and can be molded in various shapes and sizes. When it articulates with a metal component, it has a very low coefficient of friction. It means that it can create a joint having similar characteristics as a normal joint!
We can create a hip, knee, shoulder or elbow joints for the patients. Currently the medical field in India has advanced enough to use these artificial joints to treat the patients with arthritis and joint deformities.

Plastics and other plastic materials are also used for making sutures — the threads that are used to stitch the patient's various tissues like muscles, fasciae and skin. We use Polyglycolic acid for stitches which gets absorbed and Nylon or Polyamide for stitches that are not absorbable and need to stitch the skin after surgery.

The stents — the tubes which keeps the internal structures like blood vessels and gall bladder ducts open — are also made up of plastics. This has resulted in avoiding many of the open operations on the patients by allowing close surgeries. These surgeries are usually done with flexible cameras (called Flexible scopes - like Laproscope for surgery in abdomen or stomach, Arthroscope for joint surgery, etc) These scopes are made up of various plastics and plastic materials with metal reinforcement to strengthen them.

A mesh of Polypropylene is used in surgical fields to augment body tissues in the repair of Hernias, a common problem, which many of us are aware about."

Bone Cements

These are used for anchoring artificial joints such as total hip prostheses in the medullar cavity. The most commonly used cement is an acrylic resin self-curing at room temperature.

Tendons and Ligaments

Growth of tissue around silicone rods forms a new tendon sheath; the rod is subsequently removed. Artificial tendons made of polyethylene (PE) have been investigated, as well as a substitute collateral ligament.

Plastics in Ophthalmological Applications

Soft contact lenses are among the most widely used applications of biomedical plastics. Hard contact lenses made of PMMA, less comfortable, are now used less frequently; there have been about 10 million users of hard contact lenses. Soft contact lenses are polyHEMA hydrogels, sometimes coplasticsized with vinylpyrrolidinone. Soft contact lenses are used for the controlled release of drugs such as pilocarpine and tetracycline into the eye.

Intraocular lenses, made of PMMA, are used in eye surgery, mostly for cataract extraction. A new UV absorber was developed for these lenses. Contact between acrylic intraocular-lens surfaces and the corneal endothelium was the main cause for cornea endothelial damage during intraocular-lens implantation; damage was minimized by the use of soft contact lenses or solutions of hydrophilic plastics such as poly(N-vinyl-2-pyrrolidinone) (PVP) or dextran to coat the PMMA.

Oral and Maxillofacial Applications

Acrylic plastics in many modifications are used as a base for restorative dentistry, including denture base, artificial teeth, crown and bridge materials, dental cements, and impression materials. Acrylic resins were introduced in 1937 and were rapidly accepted because of their ease of use and aesthetic characteristic. Acrylic resins are still the principal plastics used in dentistry A new application is for capped metal pins in tooth implants.

Silicone rubber is the preferred plastic for restoring facial tissue. Acrylic implants have used in the glenoid fossa to push the chin forward. Silicone rubber has been used to correct the chin profile.

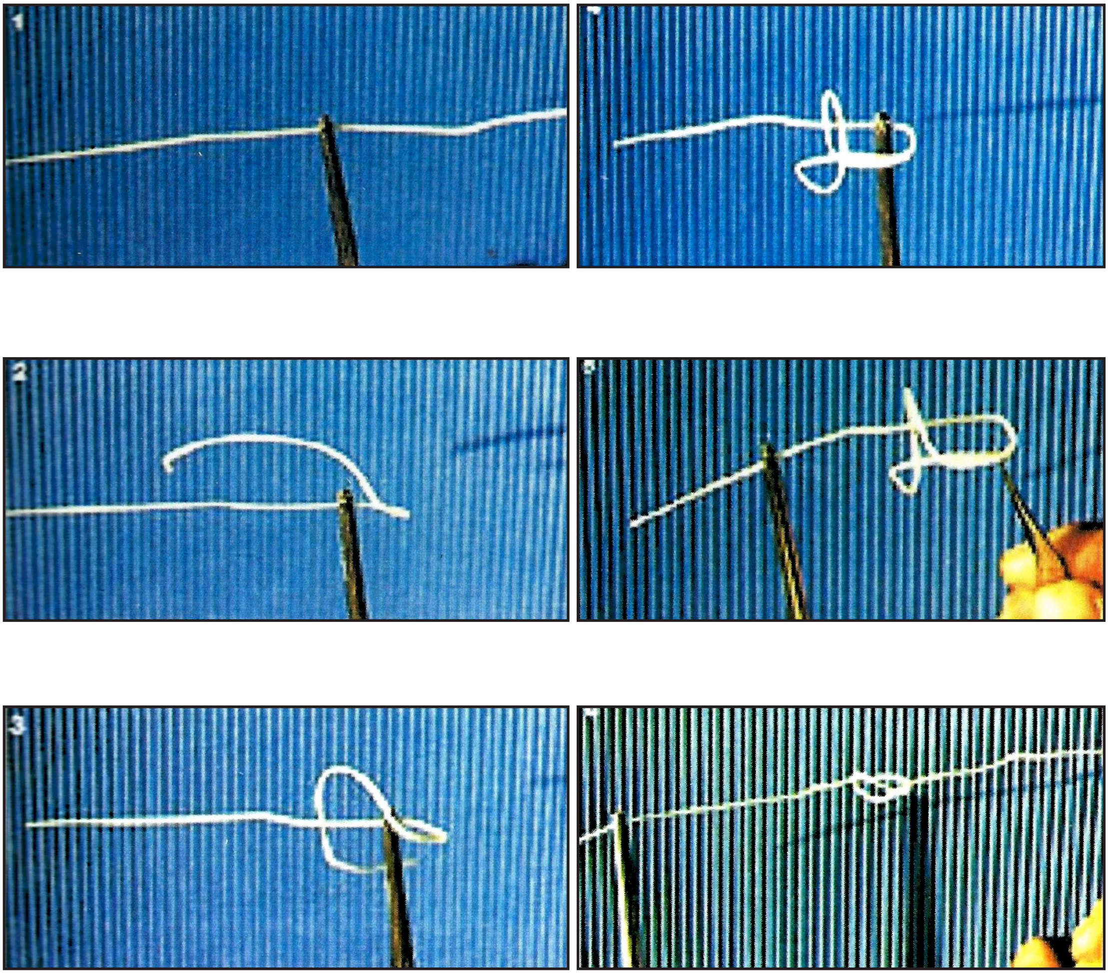
Otolaryngological Applications

In rhinoplasty and reconstruction of the external ear, silicone rubber is probably the most widely used plastics, although fluoroplastics stapes and ossicles are also used. More than 10,000 nose, chin, and prostheses are implanted yearly in the United States. Microelectronics has greatly helped the deaf. Artificial devices (bionic hearing) utilize an external compute, where eight tiny plastics-coated wires are implanted in the inner ear, connected to a nickel-sized plastic plug behind the ear.

Silicone rubber can be used as an artificial eardrum membrane (in myringoplasty); Polyethylene and Teflon have been used for stapes prosthesis (in tympanoplasty).

Plastics for Sutures

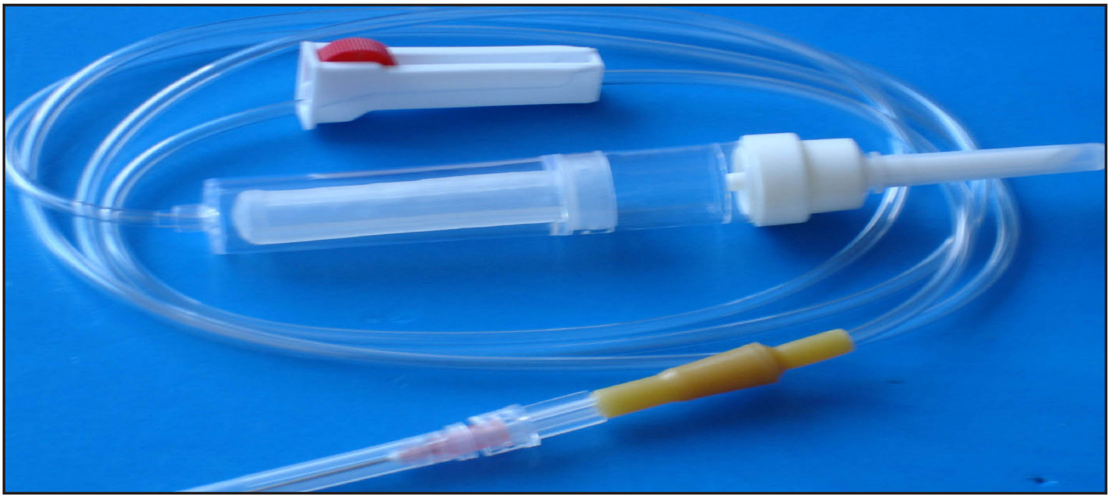
Various polymeric materials like polyester and Polypropylene have been used extensively in medical surgery. Biodegradable sutures made from Polyglycolic acid (PGA) have also been successfully used. Hence both non-biodegradable and biodegradable find use in this specialized medical applications.



Plastic Sutures used in Surgery

Use of Plastics in Disposable Products

The use of plastics has reduced the cost of various devices to an extent that they can now be discarded after a single use. These devices include syringes, catheters, blood bags, cannulae and surgical drapes. The disposable nature of these devices by preventing their reuse helps in preventing various diseases like hepatitis, AIDS, and other infections, which are transmitted by directed contact with body fluids.



Blood transfusion set with filter

Under water seal pleural drainage system

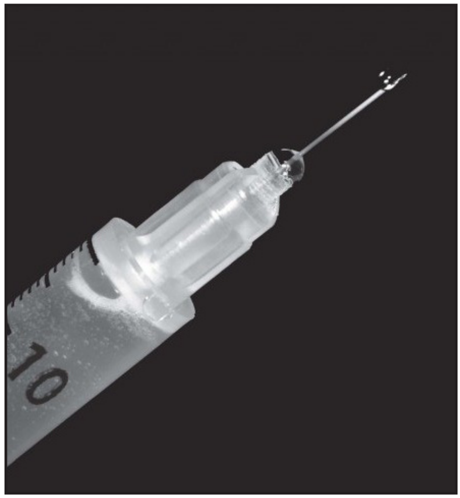
Percutarteous Transluminal Coronary Angioplasty (PTCA).

Coronary-artery bypass surgery is an effective means of myocardial revascularization. PTCA, a newer, less invasive technique for the treatment of obstructive coronary-artery disease, is also a safe and effective method of myocardial revascularization.

It was first used in 1977 and utilizes a special balloon dilation catheter introduced through a peripheral artery and directed across the obstructing plaque in the coronary artery to relieve the obstruction. Dilating catheters, such as Gruntzig Dilaca, have a fixed guide wire at the tip with straight or J configuration and are made of **PVC**. Another type, made of **polyethylene**, has a central lumen through which a movable guide wire is used.

Polypropylene Disposable Syringe - Prevention to AIDS spread.

One of the main reasons of spread of dreadful diseases like AIDS is through blood transfusion and multiple use of syringe. Polypropylene disposable syringes are light, sterilisable and cheap. Being affordable; they can be use to one —time use and thus decreasing the spread of AIDS in the intervenous drug uses.



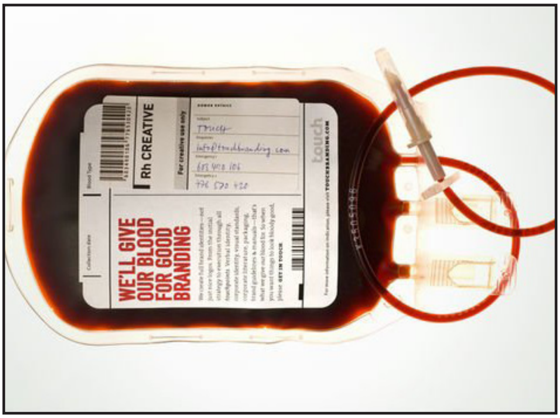
Polypropylene Disposable syringes

Connection Components

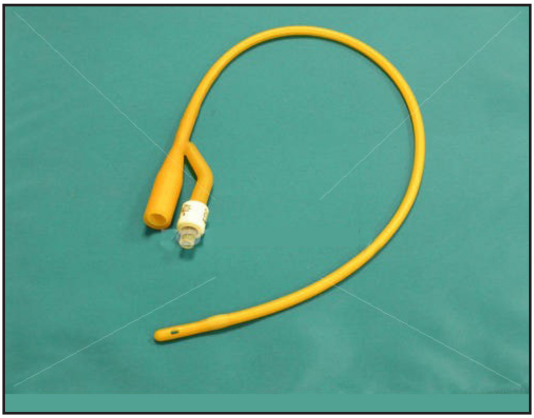
Connectors used in intravenous (IV) fluid lines and other fluid-transfer systems are ubiquitous in the medical device industry, comprising components such as stopcocks, y-injection sites, cannulae, check valves, filter housings, and male and female luer fittings. These products are typically bonded to flexible PVC tubing to create preassembled sets that are stripped sterile for clinical use. For such components, polycarbonate gives the device manufacturer valuable flexibility in choosing the sterilization mode. For example, preassembled kits are most often sterilized with radiation or EtO; however, if a prepackaged pharmaceutical is included in the kit, it can be steam autoclaved to avoid potential interactions of these methods with the drug. Once again, clarity and toughness are the important characteristics for polycarbonate connectors. Transparent components permit the user to monitor fluid flow or see obstructions in an IV line, while toughness and dimensional stability allow for tight connections with minimal risk of leaking.

Blood Bags

No other material than flexible **poly vinylchloride (PVC)** has found universal application for blood bags. Plasticized PVC blood bag has ease of handling, transparency, bio-compatibility and low cost. It can be stored effectively at refrigerator temperatures.



PVC Blood Bags



Catherers

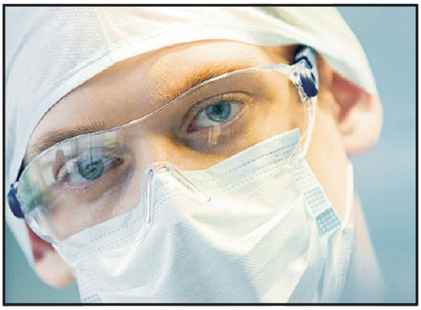
Plastics for Safest Body Contact – Baby Diapers/Adult Diapers

Plastics like PE, PP and PVC are inert materials and hence can be used safely in direct contact with the skin of even an infant. Baby diapers have become popular worldwide and effective hygienic conditions are possible by the use of plastics. Use of plastic in adult diapers is becoming common especially with the people having urinary problems.

Baby diapers - Made from softest plastics film

Disposable Apparels for medical application

Plastic apparels have formal immense the in medical specially during surgery. During gown, surgeon caps, Isolation gown, Patient gowns, Body bags, pillow covers, surgical gowns.




Packaging of Healthcare Products

The primary requirements for packaging of disposable are protection of the product, sterility maintenance, and ease of use. Sterilization methods, process conditions, shelf-life requirements, product resistance, and protection from environmental conditions are some of the factors to be considered in the selection or development of medical packaging materials. Thermoformable plastics such as polystyrene (PS), poly vinylchloride (PVC), acrylics, polyesters, polypropylene (PP), and polyethylene (PE) are used extensively in tray or blister-type packaging. Film extrusions or laminations, alone or in combination with papers or foil, meet the needs of flexible packages.

The earliest forms of disposable device packaging consisted of paper bags or pouches, used for dressings, bandages, gloves, drapes, and several other low cost single-use supplies. As more devices were made from plastics, such as syringes, tubing, ostomy products and clamps, they too were converted to single-use supplies and put into individual packages.

Several factors have prompted the changes in traditional products used for packaging. These are the need for storable, sterile, ready-to-use supplies and for better infection control in hospitals; the need to reduce labor-intensive hospital functions and to produce larger quantities of medical devices for a growing market; development of lower-cost plastics to replace glass and metals and of mass sterilization methods by manufacturers; development of single-use packaging; and impending legislation for control of medical supplies.

The introduction of plastics in disposable device packaging began with films for use in bags and pouches. A novel package developed consisted of extrude PE with a built-in linear tear feature, achieved with specially designed extrusion dies and film orientation. This film made into bags was sufficiently permeable to permit slow sterilization with ethylene oxide (EtO) and provided easy opening with the linear tear feature.

Other films were designed to be heat-sealed to paper to form pouches, which could be filled, sealed, EtO-sterilized, and maintain sterile contents for the intended shelf life of the device.

In order to form a sterile package, heat-seal coated papers were used as lidding for trays. Plastics commonly used for medical device trays in the 1960s were cellulosic plastics, i.e., cellulose acetate (CA), cellulose acetate propionate (CAP), cellulose acetate butyrate (CAB), PS, and PVC. Paper coatings were typically vinyl- or nitrocellulose formulated to heat-seal to these plastics.

To enable the package to be EtO-sterilized, coatings were usually applied in a pattern to allow uncoated areas for gas transmission. The pattern coating and use of prime coats for release were also intended to minimize excessive fiber tear when lids were removed.

In 1967 a new nonwoven material was introduced that has significantly influenced sterile medical device packaging. This material, a spunbonded polyolefin made from HDPE was developed by DuPont and is marketed under the registered trade name of Tyvek. By 1969 Tyvek was being used in a limited number of device packages and within a few years was recognized as the premium packaging material in this industry. Tyvek has several characteristics that distinguish if from other synthetic or natural fiber-based flexible materials used. Among these are superior strength, wet and dry; water resistance; chemical inertness; and excellent dimensional stability In its early commercial use Tyvek's excellent puncture and tear resistant qualities suggested use in protective packaging, particularly for irregularly shaped bulky parts. - Tyvek has a unique fiber structure that allows rapid transmission of gas vapors. But at the same time provides an effective barrier to microorganisms.

Material Characteristics

Three categories of materials are commonly used to satisfy the basic requirements of the primary package forms, i.e., pouches, bags, and trays.

Flexible materials, i.e., papers, Tyvek, films, composite materials laminations, may be used in pouches or bags, or as lidding materials on trays. Polyolefin coextrusions are used as the thermoformed bottom part of a tray or three-dimensional package. These materials are commonly used in form-fill-seal packaging system.

Semirigid materials, such as various plastic sheet products, typically over 0.127-mm (5 mils) thick, are used in performed trays or may be run on form-fill-seal equipment. Semirigid tray materials may consist of PVC, PS, acrylics (XT plastics), polyesters, high impact polystyrene (HIPS), HDPE, PP, polyacrylonitrile (PAN) (Barex), polybuty-lene (PB) (K Resin), cellulose plastics (CA, CAP, CAB), polycarbonate (PC), or may be coextrusion of different plastics.

Sealants or adhesives are generally applied to the surface of a flexible material and enable the sealing of different packaging structures together, usually with heat and pressure. Sealants (qv) are often highly formulated adhesive coatings or may be extrusion of very adhesive plastics such as ethylene-vinyl acetate (EVA).

Films, Laminations, and Coextrusion

Most flexible packages for medical devices contain at least one part that is a plastic film. The most common material used in device packaging is a lamination of polyester and PE. This film provides a number of functions in a pouch: product visibility, puncture resistance, sealability, and peelability.

The materials typically used are 0.0127-mm oriented polyester films, adhesively laminated to low-to-medium density PE (0.038-0.051 mm), usually modified with EVA for better sealability. These films may be sealed to plain or coated Tyvek, plain or coated papers, or other films. Peelability depends on the type of film used or the sealant on the opposite web. These films may also be heat-seal-coated for adhesion to a wider variety of materials or to provide peelable all-film packages for barrier purposes or for radiation sterilization.

Through laminations, coextrusion, or coatings, film constructions may be tailored to perform a wide variety of specialized functions in medical packaging (Ref table below).

Laminated and Coextruded Film and Their Applications

Film Layers	Properties and applications
Nylon-PE	Thermoformable packing
Polyester-PE-EVA	Peelable, heat-seals to plain Tyvek
Polyester-Surln[a]	Wide seal range, high not tacks, strong seals
Polyester-nylon-PE	High flexibility and puncture resistance
Polyester-PP	Steam sterilization packing
Polyester-nylon-PP	High temperature resistance and flexibility
Polyester-PVDC[b]-PE	Oxygen or moisture barrier
Metalized polyester-PE	Light resistance and improved barrier
Polyester-foil-E	High barrier and puncture resistance
PWT-foil-PT-Surlyne	High barrier and chemical resistance
PC-PE-EVA	High clarity, strength, flexibility

[a]PE coplastics ionomer resin; [b]Poly vinylidene chloride.

Pharmaceutical and Medical Applications

Among the pharmaceutical uses, gelatin capsules are probably best known. Hard capsules are made by a dipping process that uses high gel-strength gelatins. Soft capsules are made by a continuous rotary die method from plasticized (water-glycerol) gelatin of low-to-medium gel strength. The soft capsules are formed, filled with pasted or liquids, and sealed in one operation. If intestinal (enteric) absorption is requires, coatings or cross-linking agents may be used to delay release of contents.

Packaging of drugs

Other pharmaceutical and medical uses include glycerinated gelatin for suppositories, pastilles, and torches; as a binder in tablets; as a vehicle for topological application of medications; as a stabilizer in oil emulsions; as a plasma expander; and in wound-dressing adhesives. Gelatin is used, frequently with gum acacia, to microencapsulate drugs. For surgical use, a sterile sponge known as gelfoam is made by cross-linking a gelatin solution and forming a porous, absorbent pad. This sponge aids in hemostasis; it is insoluble in water but may be left in place during healing since it eventually is dissolved by tissue enzymes. A sterile, absorbable gel film is also produced.

Packaging of drugs in plastics

Tropical climates like India can have a. serious effect on the life of pharmaceutical products, which deteriorate quickly in the hot and humid conditions. Plastics — coated blister packaging (**PVC** coated with PVDC) protects drugs in these countries as the barrier properties of the material prolong the shelf life and provide tamper-proof security.

The use of plastics in medical, applications requires good manufacturing process, which is most important and critical. This would require a clean working environment, filtered air, positive air pressure, sterilization of working area, cleaning disinfecting procedures & schedules and excellent characterization procedures to ensure purity of the materials made. Clearly plastics materials have provided a very significant input in the area of health and healthcare with a tremendous growth potential.

Packaging Material Selection

In theory, a choice can always be made from any one of the following groups of packaging materials used in packaging of medicines as well as bulk packaging applications.

- Glass
- Paper
- Plastics
- Metal

A detail comparison of different packaging materials in term or their strength and weakness are given in the table.

Heat-Stable and ethylene oxide-permeable films are important for sterile disposable medical packages. Paper and plastic are the most popular medical packaging materials.

PVC, PE, PP, PS, and polyester are commonly used. Single layers may not provide all the characteristics necessary, ie, strength, clarity, barrier property, stability during sterilization, impermeability to bacteria, heat-sealability, etc, and multilayer plastics have been developed, using lamination, extrusion coating, and coextrusion; the last requires the lowest manufacturing costs. The barrier properties of PC are enhanced by coextrusion with other films providing an extrudable adhesive tie layer. This technique provides an ideal medical packaging material of high strength, high temperature resistance, clarity, and good barrier properties. PV-EVA and PV-PP coextrusions appear to be economical alternatives to oriented polyester-ethylene-vinyl acetate (OPET-EVA) and OPET-PP laminations.

HDPE wide mouth

PET Boston rounds

HDPE & PET wide mouth rounds

Comparison of Different Packaging Material in Terms of Their Strengths and Weaknesses

Packaging Material	Strengths	Weaknesses
Glass	• Abundance of raw materials Hygienic • Established capability to be returnable/ Refillable • Established bottle bank recovery system in most developed countries • High public esteem and participation in recovery and recycling	• Very high energy consumption in production • High pollution associated with production-furnaces • Relatively high pack weights compared to other materials • Safety hazards from breakage splintering • Reliance on voluntary action for recovery / Recycling system
Plastics	• Efficient and economic use of material for individual packs • Hygienic packaging for foods and beverages • Excellent protection from physical damage provided • High energy recovery from incineration • Non-degradable, suitable for medical application • Moisture resistant, suitable for packing hygroscopic commodities • Fully reusable and amenable to recycling	• Raw material derived from non-sustainable resources of fossil fuels, though only 4% of the world's oil consumption used in total plastic products.
Paper	• Sustainable raw materials • Long-established recovery and recycling systems • Energy recovery through incineration	• High energy consumption in production • Pollution risks in manufacture effluents from bleaching and other chemical treatment • Low residual value of much of the recovered material • Frequent use as a laminated and /or coated material • Strong association with litter • Degradable, unsuitable for medical application
Metal	• Efficient and economic use of materials for individual packs • High pack safety and minimal secondary packaging requirements. • Easiest materials to recover from the waste stream due to its magnetic properties • High reuse capacity.	• Significant energy consumption in raw materials • Pollution risks in materials production-Furnaces. • Low residual value of recovered material. • Less public awareness of environmental merits than for some other materials.

LIFE CYCLE ANALYSIS

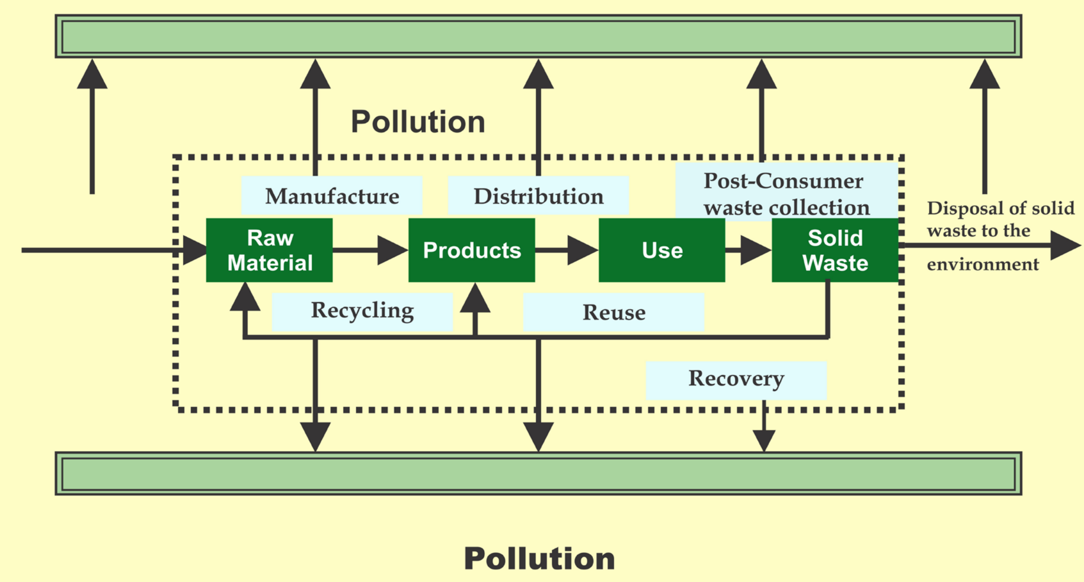
Life cycle analysis (LCA) is an effective tool to qualify/quantify the impact of a product/process on the environment. LCA covers the environmental and resource impact and keeping the positive aspect of plastics in general. Life cycle analysis aims at assessing the environmental impact or consequences of the inputs and outputs from birth to death, (cradle to grave approach) i.e. during the raw material extraction, production, use, and disposal of a product, or the entire physical life cycle of a product. The analysis includes all the inputs (materials, energy, capital, equipments, man-hours, etc.) and the outputs (products, by-products, waste materials, emissions, etc.) at every stage.

Life cycle assessment involves two stages:

- The first stage, consists of an accounting process that produces an inventory of all inputs and outputs in terms of energy, materials, and emissions in the life cycle of a product or package; and

- The second stage involves evaluation of the effects of this inventory on the environment, producing an environmental burden.

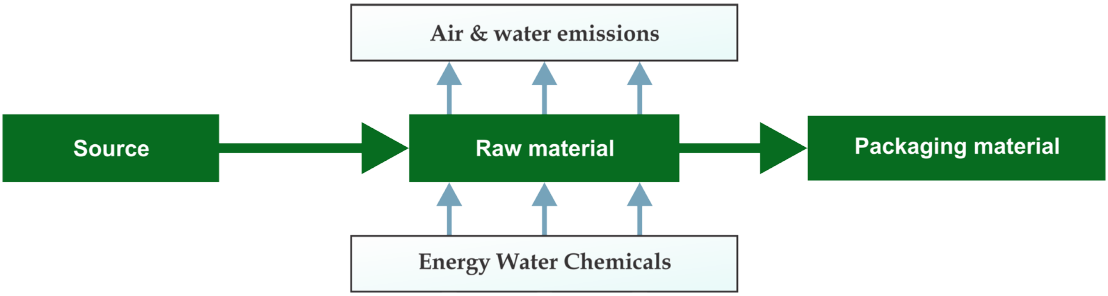
Different phases of life cycle analysis are diagrammatically shown in the figure below. For the complete life cycle of a packaged product, a model of resource and pollution flows is presented below:



A model of resource and pollution flows, to and from the environment, for the complete lifestyle of a packaged product

For each of the processes within the product system defined during goal and scope definition, information has been now collected on the input and output (environmental exchanges) and possibly on the internal interactions with an operator if working environment is to be included in the impact assessment.

The compilation of inventory data relates the inputs and outputs of the different processes to the life cycle of the product. This quest for product specificity is a very important point. It is a fundamental characteristic of the life cycle inventory and the ensuing impact assessment, the purpose of which is to evaluate the environmental impacts of the life cycle of the product.



In practice, life cycle assessment is a tool to aid decision making on environmental criteria. It provides the data needed to permit objective comparison of the environmental burdens caused by different products or packaging systems. In the present era of increasing environmental awareness, this prospect has attracted much interest from consumers seeking reliable environmental information, manufacturers wishing to improve the environmental performance of their products and packaging, and legislators or voluntary bodies involved in environmental labeling schemes.

SAFETY WITH PLASTICS

Each year, at least five million people die from injuries around the world. Globally, about half the deaths are in the age group 10-24 years are due to injuries, intentional and unintentional. For all ages, injuries are projected to account for about 25% of years of life lost in 2020. The comparative advantage of plastics lies in the following properties, which give a comparative advantage over many other materials. Ease in designing special and complex shapes, flexibility in changing shapes and properties, possibilities of designing for variable and complex structural and mechanical properties, and electrical as well as heat insulation purposes.

Plastics play very important role as new materials, designs and structures in areas of transportation, home and domestic products, work place and leisure activities. Comparative advantage of plastics are i) Design special and complex shapes, ii) Flexibility in changing shapes and properties, iii) Designing for variable and complex structural and mechanical properties, and iv) Electrical as well as heat insulation properties.

Plastics help in establishing domestic safety by avoiding toys hazards arising out of sharp edges, pointed objects and splinters from wooden toys and injuries from impact. Many of these hazards have been. reduced in plastic toys because they are lightweight, and it is much easier to manufacture them with rounded edges and without sharp joints. This is particularly true for toys made with softer plastics. Since plastics do not need to be painted, they can be provided in attractive colours without the hazard of children biting and ingesting poisonous chemicals.

Plastic play food set

Baby hand held Toys

Plastic feeding bottles made of polycarbonate or polypropylene have almost completely replaced glass bottles, later being useful being unsafe because of the risk of high breakage resulting in injury to the infants and babies. Plastic feeding bottles are made from food/pharmaceutical grade **PP/PC** and are lightweight, unbreakable, hygienic and easy to sterilize (in boiling water). Feeding nipples attached to these bottles are made from silicone rubber, again a plastics material.

Plastics are the best insulating materials and thus promote electrical and thermal safety. Plastic electrical insulation materials have made it possible to provide thin covering on electrical with specially tough properties which prevent children's teeth from penetrating the insulation when they bie such cables attached to electric irons, heaters and vacuum cleaners

Electric irons and cooking utensils, etc. made using plastics contribute significantly to thermal safety. Examples of such applications can be cited as handles which do not get hot as much as coated insulation on metals.

Tamper and Break Proof

The introduction of blister packs and child resistant container have made medicines tamper¬proof. Plastic bottles because of their high impact strength are break-proof unline glass bottles. These can be moulded in diverse shapes, are lightweight and possess excellent chemical resistance.

Transportation Safety

Plastic Helmet

The advantages of using plastics are because of their ability to be designed into specially engineered structures with differential properties and shapes. They also respond to impacts at different velocities in maintaining constant forces, in providing high energy absorbing capabilities, or in stretching/deflecting according to pre-designed criteria. Plastic helmets have been extensively used both in transportation and industrial and construction worker. Other such important products are laminated windshields, air-bags, seat-belts, bumpers, dashboards, steering wheel assembly padding, etc.

Plastic Currency notes - Safe and hygienic

Paper currency notes attract dust, get soiled easily and may spread deadly contagious diseases, a study has warned. Karachi University's microbiology Department determined, that banknote carry pathogens of E-coli, the blood and kidney infection which can lead to death and other bacteria which cause diarrhea, skin infections and septicemia. It is said that almost all of the 450 notes or coins collected from public places including meat shops, restaurants, bus drivers and even hospitals, pharmacies showed alarming presence of bacterial and fungal species.

Contaminated notes may act as potential source of infections ", said the study The bacterial load in notes collected from bus drivers and meat sellers was particularly high. Coins were Found to contain far fewer undesirable microorganisms, however, due to germ-killing effect of metal.

More than sixteen countries have already shifted to plastic currency notes made of PP oriented aim, which is inert, does not soil, absorbs no moisture and cannot be duplicated.

MEDICAL PLASTICS WASTE MANAGEMENT

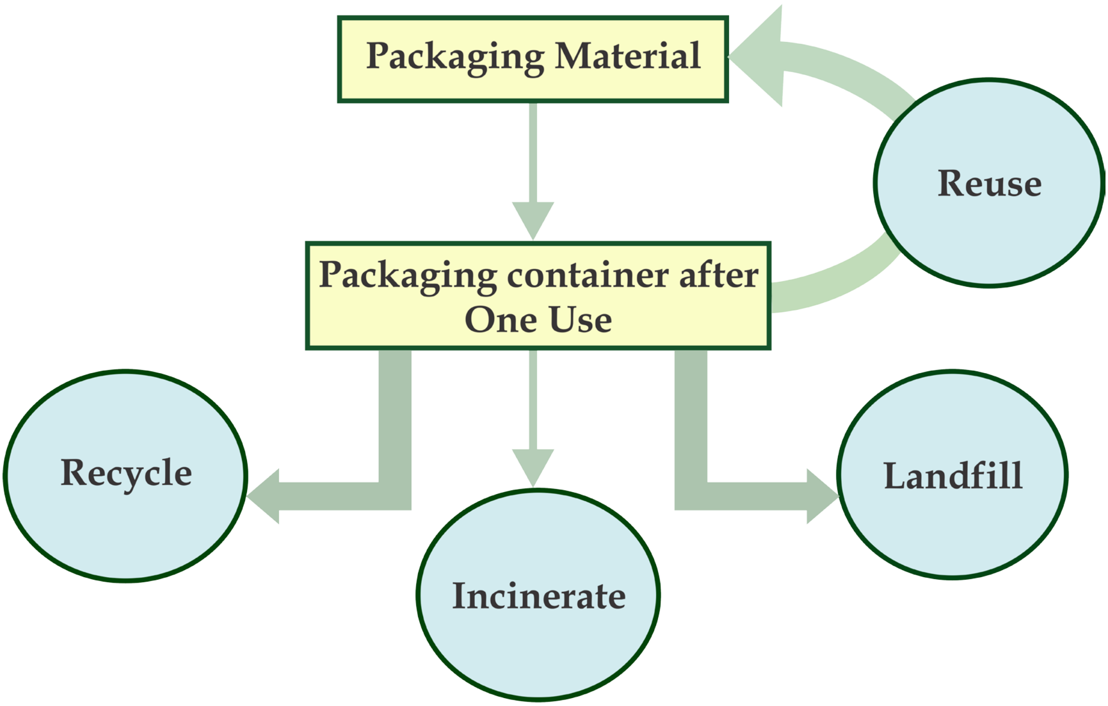
Waste is an inevitable product of society. Solid waste management practices were initially developed to avoid the adverse affects on public health that were being caused by the increasing amount of solid waste being discarded without appropriate collection, or disposal. Managing this waste more effectively is now a need that society has to address. In dealing with the waste, there are two fundamental requirements: less waste and an effective system for managing the waste produced.

The Organization for Economic Cooperation and Development (OECD) defines waste in general terms as: 'Unavoidable material for which there is currently or no near future economic demand

and for which treatment and / or disposal may be required'. The United Nation Environment Program (UNEP) defines waste as: 'objects which the owner does not want, need or use any longer, which required treatment and/or disposal.' The European Community broadly defines waste as : 'any substance or object which the holder disposes of or is required to dispose of pursuant to be provisions of the national law in force.'

Waste management in case of bulk commodity packaging materials involves four different techniques :

- Reuse
- Recycle
- Landfill
- Incineration



Different Techniques of Managing Waste

The life cycle inventory of different materials is given in the table below.

Life Cycle Inventory Table for Waste Management

	Reuse	Recycling	Incineration	Land filling
Metal	×	√	×	√
Plastic	×	√	√	√
Paper	×	√	√	√
Glass	√	√	×	√

As the Plastics have assumed a major role in a variety of medical applications, the medical market has become the fourth largest area of plastic applications and the medical use of plastics is growing 6% annually. Besides these, availability of easy to use kits at lower price is expected to assume a major role in rural health care and delivery. So all these indicate that, a substantial amount of used plastics is being generated at present and the amount will increase steadily in the future.

Plastics used in patient care are associated with blood, sputum, urine and many other components of the living systems. These components contain disease-causing microorganisms and sometimes they also serve as a good medium for the growth of microorganisms. Usually, at the site of collection, the numbers of organisms are generally small. Later, due to cross¬-contamination during storage, the entire load potentially becomes harmful. Bacterial multiplication may occur in the days following the disposal due to moisture content and availability of other favorable conditions. So the clinical wastes become dangerous. The risk of infection or injury can be minimized by proper handling and careful disposal of these wastes.

The daily production of solid waste by rural hospitals in India range between 0.5 kg. to 1.5 kg. per bed and that of All India Institute of Medical Sciences is around 5 Kg. per bed. Presently, 30 to 50% of these wastes are plastics. Around 10% of these wastes estimated to be hazardous.

Infectious waste can be disposed by 1) chemical inactivation, ii) autoclaving, m) exposing to microwave, iv) incinerating and v) dumping in the waste pit. A practical disposal method should be one, which is economical and involves minimum risk during the process. Besides this, the method should be sustainable for a long time without causing long term ecological hazards.

Following steps are critical for the safe disposal of infectious wastes: i) initial storage (waste ii) segregation iii) transport and iv) final disposal treatment each of these steps requires proper inventory and strict supervision.

No doubt, the safest method of final disposal is to incinerate every bit of waste. But, economically and ecologically, incineration becomes unrealistic, even for rich countries. Next best way of disposal is to make a waste pit. This will be a good solution for rural health care facilities of India. WHO has suggested the following design and management for the cost affective and easy to make a waste pit.

1. The pit must be located where no ground water or surface water can come into contact with the deposit and, no leaching of liquids from the waste into ground water can occur. The waste pit must never be close to water sources such as wells or springs.
2. The site must not be located where ground is likely to be used for agriculture or where land development could take place.
3. The ground must be soft enough for manual digging but of low permeability.
4. The pit must be provided at least 1 m3 per bed to have service life of approximately 5 years.
5. The pit must be protected from scavenger (animal, birds, humans)

Finally, the most desirable long-term solution is to develop biodegradable plastics that are capable of degrading in nature after their use without producing any toxic by-products. Several groups around the world are in pursuit for such plastics.

Incineration of Waste

The techniques for burning refuse have been improved immeasurably over recent years from the crude fixed cell incinerators of the 1930s. Incineration without energy recovery is not an environmentally acceptable solution since the material resources are simply destroyed without any effective recovery.

Incineration with heat and power generation overcomes this weakness and may be the effective method of disposal for our major conurbations in the future. However, such a plant is not economic below an annual input of 0.25 million tonnes. This quantity of waste represent the arising from a population of nearly one million people and only in our major centers of population does this concentration of development exist within an effective transportation distance of the chosen site.

As already mentioned, emission standards for flue gases are going to be very stringent in European Community countries, and these will only be met by a high capital investment in the flue gas scrubbing equipment. Incineration will continue to be the most expensive of all the techniques.

Dioxins

Much attention now a days is given to dioxins because of their apparent toxicity. Dioxins are not produced intentionally and have no known use, but they occur in the environment in air, soil and water. Dioxins occur as a result of natural processes (forest fires, volcanoes). It is commonly accepted today dominant source formation of dioxin emission are — steel mills, combustion of coal, iron & steel plant, paper mills, non ferrous metal operations and hospital waste. If you really mean ZERO, then stop all heating with fossil fuels, all traffic and all factories. Dioxin is present in nature without human intervention in barks of redwoods, natural fires, wood rotting fungi, million year old clay layers, mushrooms, cow's milk and also from unexpected sources like, cotton garments (upto 100ppb), domestic sludge, dry cleaning residues, household dust, recycling emissions — cu (2280)/AI (35)/ Paper (14)/Steel (6), Production emissions — Glass (8.7)/Steel (8.4), any material incinerated/ burned (wood)/paper etc. will emit dioxins.

Dioxins is the general collective term for chlorinated aromatic compounds, consisting of a group called Polychloro-dibenzo-p-dioxins (PCDDs) polychloro-dibenzofurans (PCDFs). These compounds have high melting points, low vapour pressure and a low water stability. They are highly toxic materials causing severe health hazards to human beings. However, out of 210 dioxin congeners, only 17 congeners with chlorine have potential health hazard. Dioxins are generally present at very low concentration in all foods, but are specially found in fatty foods such as cow's milk. WHO permits/recommends Tolerable Daily Intake (TDI) of 10 pg/ kg body wt/day TCDD.

Dioxins can be formed in chemical process where chlorine is involved. The following processes in particular have been identified as source of dioxin formation given in tables below:

i. Pentachlorophenol (PCP) — Product used as a wood preservative.
ii. Poly Chlorinatedbiphemyls, 2,4,5 — trichlorophenol an intermediate chemical compound, Ethylene Dichloride (EDC), Chlorinated aliphatic compound, Chlorination, Chllroibenzene,

etc. None of the plastics (except PVC) contains chlorine is in any way closer to the above mentioned chemicals. Bulk of the commodity plastics like, Polyethylene, Polypropylene, Polystyrene, Polyesters do not contain chlorine, hence chances of dioxin phenomenon at any stage of their existence is ruled out.

Sources of Dioxin – Rank Order

Process	Dioxin (gram TEQ)
Backyard trash burning	1125
Municipal waste incineration	1100
Landfill fires	1050
Hospital waste incineration	461
Metal smelting	293
Forest fires	208
Wood, coal, vehicles	198
Cement kilns	171
Iron ore sintering	25
Sewage sludge incineration	15

Sources of Dioxin - Rank Order (Contd)

Process	PCDD Emission (kg/yr)
Waste incineration	1130
Cement Kilns	680
Biomass combustion	350
Ferrous metal production	350
Medical waste incineration	84
Sec. Copper smelling	78
Leaded fuel combustion	11
Unleaded fuel combustion	1

Dioxin and PVC

There is a general myth being propagated that chlorinated plastics, principally PVC (Poly Vinyl Chloride) are a major source of dioxin generation in production, processing, recycling and even in incineration. However, the truth is that studies in UK, Germany and USA point out that dioxin emissions have declined by 50% since 1970, a period in which PVC production in these countries has more than trebled. These long term trends are demonstrated in the scientific publications of Allcock & Jones, Environ, Sci Tch (1996).

Every analysis of dioxin shows that major activities like municipal incinerators are the biggest generator of dioxins. General manufacturing, including PVC manufacturing generates insignificant amount of dioxin. For example emissions in the Netherlands show municipal waste incinerators emitting 790 gm per year compared with 51 gms from metal industries, 16 from wood burning and just 5 from chemical processes of all kinds.

In the Dioxin 96 meeting in Amsterdam, Hans Wagenaar et al presented a paper entitled "Analysis of PCDDs & PCDFs " in Virgin suspension PVC "resin". They concluded that the results demonstrated that virgin suspension PVC resin from 11 production sites in Europe does not contain PCDDs & PCDFs at concentrations above the limit of quantification, which is less than 2 parts per million (PPT). In the same meeting W.F. Carol et al presented results obtained in a similar study in USA. For PVC pipe resins, results ranged not from detected to 1.4 ppt TEQ for 12 samples. For bottles & packaging resin on 8 sample results varied from 0 to 0.7 ppt TEQ No. 2,3,7,8 — TCDD, which is believed to be the most toxic dioxin congener, was detected in any sample.

Measured emissions to air of different materials during lifetime: (All figures expressed in microgram 1-TEQ per ton material.)

Product	Production		Recycling		Fire		Incineration		Incineration
	Min	Max	Min	Max	Min	Max	Min	Max	1997
PVC		0.1		0.0		4.0	7.0	277	< 1
PE		7		0.0		7	7.0	277	< 1
Glass	0.3	8.7		?		0.0		0	
Steel	1.3	8.4	4.4	6.0		0.0		0	
Aluminium	1.3	8.4	4.4	6.0		0.0		0	
Copper		?	5.0	2280		0.0		0	
Wood	1.0	4.1	-	-	13	135	7.0	277	< 1
Paper		0	0.2	14(*)		?	7.0	277	< 1

Sources : RIVM/TNO inventory of dioxin sources in The Netherlands, 1991
(*) Ubiquitous Nature of Dioxins

Recent investigations in US and Europe have reverted that dry cleansing solvents contain much more 'dioxins' after us than many other sources. The German PVC producer Vinnolit has made a comparison, based on real dioxin measurements of the emissions from the whole life time of window frames as given in table below.

Dioxin emission from the whole lifetime of window frame

Material	Dioxin Emission(TEQ per window frame)		
	Production	Incineration	Total
PVC 15 kg	18	4	22
Steel	30	-	30
PVC+steel	48	-	52
Woods (17 kg)	47	20	67
Aluminium	285	-	285

All alternatives to PVC, give also dioxin during production, transport, recycling and/or incineration. In many cases, they give more dioxin releases than the production, transport use, recycling, incineration and accidental fires of PVC.

There is no reason to blame PVC as the Dioxin source because it contains chlorine. And there is no reason at all to exchange PVC for alternatives to reduce Dioxin emissions.

It can fairly be concluded that PVC is hardly a source of Dioxin at any stage of its usage. Self-regulating charter adopted by PVC Industry against Dioxin emissions is an example. The dioxin content of PVC is below detectable limit.

Dioxin & Polyolefins: One of the myths is regarding the emission of dioxin/incineration of polyolefins. Since Dioxins esentially contain chlorine as a constituent; these is absolutely no reason that Polyethytene or Polypropylene which only contain carbon & hydrogen (no chlorine all) should emit dioxins on combustion.

Standards and Specifications For Materials Used In Healthcare and Safety

Primary properties of plastics used for diverse end applications do not pose any health hazard because of their chemical inertness vis-a-vis metabolic processes. A representative list of different

types of that are generally used in medical & health applications include HDPE & PP for various

bone joints, syringes, packaging of medicines, dairy products, etc.; PVC for blood bags, UV sets, plasma bags; PMMA for optical lenses; PET for packaging of water; polylactide and polyester for medical sutures. Almost all plastics meet the requirements of BIS and International Standards for safe use in food, pharmaceuticals, and drinking water.

- PP meets the requirement stipulated in BIS standard IS 10910 on "Specification of Polypropylene and its coplastics for safe use in contact with foodstuff, pharmaceuticals and drinking water".
- Additives incorporated in polypropylene conform to the positive list of constituents as prescribed in BIS standard IS:10909
- The grade of additives incorporated in PP also comply with the FDA: CFR Title 21, 177, 1520 Olefin Plastics.

HDPE used for the Manufacture of Food & Pharmaceutical Packaging Products

- Meets the requirement stipulated in BIS standard IS: 10146 on "Specification of Polyethylene and its coplastics for safe use in contact with foodstuff, pharmaceuticals and drinking water ".
- Additives incorporated in HDPE confirm to the positive list of constituents as prescribed in BIS standard IS 10141.
- The grade of additives incorporated. in HDPE also comply with the FDA: CFR Title 21, 177, 1520 Olefin Plastics.

All plastic packaging materials intended for food contact applications need to be first evaluated by migration tests before being subjected to shelf life studies etc. Similarly the safety of additives is apprised in terms of:

- Extent of its proposed use

- The amount that would be consumed under all likely dietary patterns
- The nature of biologic response it may provoke
- Its nutritional contribution to food
- The possibility of additives undergoing change after its contact with food

It is interesting to note that stringent norms exist for plastic for food contact applications; these are not possible in case of traditional materials of packaging, say jute, paper or metal. Health problems related to these products are discussed further.

Most of the plastics coming in food contact application are food grade and even the additives present confirm to the norms of basic regulations of food packaging. Specifications (both Indian and International) exist for plastics raw materials, residual monomer contents, coplastics composition and additives. Every plastic material intended for food and pharmaceutical application must be certified as "food/pharmaceutical" grade as per the specification laid down by different countries. The regulations are regularly revised to incorporate necessary changes from time to time.

For food packaging application, the **"safe for food"** certification and tests carried out are certified by Central Food & Technological Research Institute (CFTRI) Mysore,. To quote a few examples:

CFTRI has developed a suitable method for estimation of RVCM in PVC material and foods packed in them upto 0.01 ppm levels. CFTRI has further after detailed analysis certified PVC bottles within the safe limit of food use. Similarly, CFTRI has set the global migration limit of 100 mg/dm2 or 60 mg/ht (ppm) for all the plastics as given in table.
References : P. Ravi, Baldev Raj, N.S. Vijaylakshmi, Food Packaging Tech. Deptt, CFTRI, Mysore, Packging,December 99 — January 2000.

There are hardly any standards available for any other materials used for packaging of food and drugs.

A list of standards related to plastics for food and pharmaceutical application are given in the tables below.

Some BIS on Plastic for food and Pharmaceutical Contact Application

Plastic	Global Migration limit	Plastic list of constituents
Polyethylene	10146-1982	10141-1982
Polypropylene	10910-1984	10909-1984
Polyester (PET)	12252-1981	12229-1987
PVC	10151-1962	10148-1982
Polystyrene	10142-1982	10149-1982
Nylon – 6	12247-1980	12248-1900

Conclusions

Plastics have played a major role in the human health care and safety Their inherent properties like flexibility, toughness, chemical resistance and body compatibility have made their use vital in medical devices, implants, disposables, carriers for drug delivery and packaging. Advances in surgery owe a great deal to the use of plastics. All the plastics used for Food, Medicare and Pharmaceuticals conform to National and International standards.

Plastics are the ideal packaging material for medical devices, drugs and pharmaceuticals and other health related items. They play an important role in the areas of safety viz. domestic, industrial and transportation.

Incineration of plastics does not produce any dioxins. Moreover plastics like PE and PP do not contain any chlorine hence there are absolutely no chances of release of any dioxins.

References

1. Dinesh Mohan, Ashok Misra, "Safety With Plastics", plastics 2000 indian millennium proceedings, p387.
2. Encyclopedia Of Polymer Science And Engineering, Vol 9, Ed. Anna Klingsberg, Rosemarie, Piccininni.
3. Ahbe, S., Braunschweig, A. and Muller-Wenk, R. (1990). Methodik fur oekobilanzen auf der Basis okologicher Optimierung. Bundersamy fur Umwelt, Wald und Landschaft (BUWAL), report No. 133. Bern, Switzerland.
4. Beck, LW., Maki, A.W., Artman, N.R. and Wilson, E.R. (1981). Outline and Criteria for evaluating the safety of new chemicals. Regulatory Toxicology and Pharmacology 1:19-58
5. Boustead, I. (1990). Summary in: Life Cycle Analysis for Packaging Environmental Assessment. Proceedings of the specialized workshop, Leuven, Belgium, Sept. 24-25,1990. IMSA and IPRE.
6. Boustead, 1. (1991). A practical Guide to choosing the methodologies. Proceedings of IIR Conference: The Practical Application of Product Life Cycle Analysis. IIR, London, UK.
7. Boustead, I. And Hancock, G.F. (1989). E.E.C. Directive 85/339. U.K. Data 1986. A report for INCPEN (Industry Council for Packaging and the Environment). The Open University, UK.
8. ENDS (1990). Life-cycle Analysis: an environmental management tool for the 1990s. Environmental Data Services Report 188: 19-21.
9. John Katz, Medical- Productivity Through Innovation, NPE 2000, Society Of Plastics Engineers.
10. CBI (1991). Towards a recycling culture. Confederation of British Industry, London, UK
11. Chemistry And Industry(2002)
12. Vasudeo Y.B. & Rangaprasad, R. Green Plastics — Plastics from Renewable Resources — Concept paper on Biodegradable Plastics, RIL

13. British Polythene Industries PLC – Biodegradable Plastic Friend or Foe ? 1997
14. Antonin SLEJSKA Biodegradability Plastics (1997) – (www.vurv.cz)
15. Richard A. Gross & Bhanu Kalra Report on Biodegradable Polymers for the Environment"
16. Mike Baker and Bill Haille A Novel Biodegradable Copolyster for Films and Fibres Eastman Chemical Co.- Sept 2002
17. Plastics & The Environment – Widespread Myths and Tactual Position- Indian Centre for Plastics in the Environment, Mumbai
18. Life Cycle Analysis of PP-HDPE Woven sales vis-à-vis jute/paper sales in terms of environmental studies, Anup K. Ghosh. Ed., Indian Institute of Technology, New Delhi, 2002

Chapter 4

Plastics as Safe & Hygienic Medium for Packaging Food & Food Products

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PLASTICS AS SAFE & HYGIENIC MEDIUM FOR PACKAGING FOOD & FOOD PRODUCTS

In modern India, we are living with many paradoxes. While we are most modern and advanced in some areas, we are also considered backward in many. To every concept, there is always a segment ready to oppose. Yet, we are progressing and adopting technologies and materials, which provide us convenience and economics. Plastic, happens to be one such group of materials, which is the most recent entrant in the area of Food packaging and finds a growing use as in the other parts of the World. Let us see why and how plastics are used beneficially for food packaging applications.

GLIMPSES OF MODERN INDIA

Views & changing practices

You can still hear our senior citizens talking about; buying freshly crushed cooking oil from the crushing units, benefits of consuming fresh seasonal vegetables and fruits hand picked from the vegetable markets, "chakki ki atta" best if ground in front of you, not to reheat and eat cooked items stored in refrigerator and many other similar consumption opinions. But, they may appreciate tasting noodles cooked in three minutes by their grandchildren, chocolates and candies that are attractively packed, the peas pulao, which is prepared from the packed peas and available through the year, the milk & curds which is available in attractive packs and many more products of similar nature.

Scarcity among plenty

India is the third largest producer of raw food, but it is the lowest in processing and preserving these items. Declared National priority of encouraging food-processing sector, programme for reducing staggering 30% losses of fresh produce, implementation of health & other statutory requirements and to remove the poverty and malnutrition of our masses has become a mission for us all.

Consumer market

Although 35% of the population lives below the poverty line, the spending power of a growing middle class has increased. During the last decade in particular, there has been a large growth in the working population, women work force, changing eating habits, improved personal disposable incomes, consumer realization and consciousness towards better health and hygiene conditions, exposure to international brands, lack of skills or time required for meals preparation-thus, creating the demand for convenient and packaged food.

Need to defeat the motives of ever existing unscrupulous elements in pilfering, tampering or adulterating the food we consume even at added cost is realized.

Food packaging - a need

Distinct need of packaging of our food is established and is witnessed by 18 to 20% growth in this sector. Factors mentioned above have given ample marketing opportunities and we see the Industry ready o take the challenges like appeasement of local tastes, handling the increased demand for segmented and fragmented consumption, extended shell life, and anti-counterfeiting measures, ready packed dishes packed in handy sized portions, convenient supermarkets operating at very low margins, micro-oven able food which can be heated in, and even eaten from, the tray, durable and the Eco friendly packs.

To contain the ill effects of this rapid growth and contribute to a sustainable society with Eco efficiency and economy following areas are to be addressed:

a Packed food safety
b Appropriate packaging Design
c Kind of packaging materials consumers really need. Be it local consumption or for exports.
d Effect of packaging waste on environment
e Emerging solutions.

FOOD SAFETY-THE ULTIMATA

Unhygienic food processing and improper packaging can create hazards like salmonella, microbes, endotoxins, migration of toxins from packing material, adhesive & inks etc. and can render the food unfit for human consumption. Even after following proper processing practices by means like HACCP, one has to ensure that packaging is designed properly for a particular food with the specified shelf life. Scientists have concluded that different packaging materials can influence the biochemical and microbiological deterioration of foods. Other degrading factors due to packaging could be physical and chemical changes, migration of chemicals, off flavors, color and texture change, moisture and oxygen transfer, and the effects of light and temperature changes.

Suitability of a given package system and its compatibility with a given food product must includes the following considerations:

a Is the packaging material in contact with the product presently regulated by any National / International law for food packaging usage.
b Does the material contain only those additives, which are regulated at or below the permitted concentrations?
c To what extent do these trace amounts of various constituents of the packaging migrate from the materials into the product ?
d Is the correct package design methodology followed?
e Under what conditions will the packaged product be processed and stored ?
f Finally, is the packaging cost effective?

Risk assessment & food packaging regulations

Regulation of food packaging is done on a generic basis. The primary concern with approval of plastic resin for food packaging is that package does not adulterate the food in some way that could potentially be harmful to the consumer. Thus the main concern is migration of constituents from the Plastic packaging material to food in contact. For undertaking any risk assessment, it is necessary to lay down the threshold limit; this threshold limit could vary with the country, region and possibly the race. U.S. Food & Drug Administration (FDA) has established a threshold of 1.5 micro gm/person/day as a level "low enough to ensure that public health is protected" even in the event that a substance exempted from regulation as a food additive is later found to be carcinogen" This threshold approach has been found to be an excellent model by which majority of packaging materials is evaluated.

Compatibility studies

With the choice of Packing material made, compatibility studies form an essential requirement for any Packaging design for the food product. Apart from the specialized equipments, testers and the dedicated staff it also requires the long practical experience of the designer. Tests for compatibility may vary with type of Packaging material chosen. However, for Plastics, the following need to be ascertained.

Appearance factor: Some packaging taboos are self-evident. Everyone knows not to place a wet product in a paper bag. However, many a time the effect of product on packaging material is learnt often the hard way, e.g. mustard packed in PE shows distinct yellowing as mustard migrates through white PE.

Chemical compatibility: Many plastics are sensitive to high acidity or high alkalinity or both. EVA, EAA and ionomer are examples of plastics that would be severely altered by products exhibiting pH extremes.

Physical endurance. The selection of the packaging material must also take into consideration the physical stress exerted by the product. Ground coffee, for example, is highly abrasive. Placing this product into a plastic pouch creates unusually tough demands on the endurance of the package. Bone in meat, frozen products with sharp edges also can have tearing effect on the pack.

Testing – Shelf Life studies. Ideally shelf life studies up to two years should be conducted. But many a times packaging technologist utilizing his past knowledge and data for forecasting the results with the accelerated ageing analysis can predict the behavior. But this requires the utmost care where single handed consultants with inadequate test facilities may fail miserably e.g The experience gained with the prior printed materials is not applicable to the new inks, or the new print designs on laminates. There have been cases in which ink change caused residual solvents in very minute trace quantities to migrate into the food product and impart an off flavor. Even delamination may occur with increase in print with other design conditions remaining same. Factors considered in shelf life studies are indicated in the following table.

To Guarantee the Shelf Life of a Product, a Packaging Material is Required that Offers

Good seal integrity
- √ Avoid easy exchanges between external and internal atmospheres through channels in the seal areas

Moisture barrier
- √ Moisture loss of semi humid products like fresh bakery makes them dry
- √ Moisture gain of a product makes it soft and subject of hydrolytic reactions if it contains fats
- √ Both loss or gain of humidity causes staleness of the product

Oxygen barrier
- √ Oxygen can cause oxidation of sensitive foods containing oils and fats
- √ It helps mould and micro-organism to grow when water activity of the product is favorable
- √ Oxygen also contributes to product's colour change

Light barrier
- √ Light acts like a catalyst of oxidation reactions causing rancidity
- √ Visible and UV wavelengths are both harmful
- √ Oils and fat acids are broken down into aldehydes, ketones and acid which cause the off-odours

Aroma/off odour protection
- √ Protect the original flavour and taste of the product
- √ Prevent absorption of off odours
- √ Avoid insect infestation

Accelerated ageing. In accelerated testing product is packed in the specified pack and subjected to the specified accelerated storage temperature and humidity conditions. Packages kept under these conditions are examined at periodic intervals.

Migration modeling

This is one word, which is invariably used by the anti Plastic lobby. Migration, essentially a diffusion process, is considered to be an undesirable package / product interaction, and takes place as a result of mass transfer from the package into the contained product. Such mass transfer phenomena is not unique to Plastics and can take place in any other package material used.

The use of low molecular weight additives and their usage levels, as well as the presence of residual solvents, reaction and degradation, by-products, monomers and oligomers in plastic packaging materials is subject to strict regulations on the basis of which alone food grade application certificates are issued.

In the recent years, migration modeling as a tool for quality assurance of food packaging has advanced significantly. Through the efforts of International Standards, Measurements and

Testing (SMT) project (SMT4-CT98-7513), **a single validated model has now been identified and is available as a commercial software package. There is no uncertainty on the characteristic of a particular Plastic use for food packaging. Food grades Plastics are thus considered safe from the criteria of migration danger.**

PACKAGE DESIGN

I have come across many excellent international package designs, specifications and materials that have just not worked in our country. It is necessary to understand that Packaging is a socioscientific discipline, which operates in a society to ensure delivery of goods to the ultimate consumer in the best condition intended for their use. It operates as a system of product, packaging and distribution within three environments: physical, atmospheric and human. In each of these environments, packaging performs three functions: protection, utility and communication. The functions interact with the environments in a way that can be considered as a matrix, with each function reacting with each environment in some way. The designer addresses the problem and opportunities, which exist at each juncture of interaction between function and environment. He or she has to analyze socio, scientific, environmental and business problems and create solutions, which contribute to the success of marketing a product. Thus it should be understood that Package design is an elaborate scientific process needing the back up of an Institution. Indian Institute of Packaging is one such body in India, which is engaged in the activities of designing the food Packaging specifications.

Packaging development process

The process of food packaging development starts by assessing the demands of the product and its internal market and drawing up a list of critical values, which must be met with for success. If a product is reactive/acidic, the degree needs to be understood, if it is moisture sensitive, the extent of this sensitivity needs to be determined. If the target market for the product is a school-age child, the requirements of this sector are defined as closely as possible and not simply stated in vague terms. The hazards to which the packaged product is likely to be exposed through its entire life cycle needs to be defined: if the product is being shipped to tropical countries, the climatic conditions prevailing therein are specified. Other demands are imposed by packaging machinery, legislation, competitor's activities and time constraints, as well as economics as already mentioned.

All of this information in the form of packaging brief, a portfolio of requirements, is used as a checklist when searching for a suitable material and assessing candidate design.

Plastics as a choice

On the basis of the above, "Which Material" to select becomes a decision process. Almost all types of materials are used in food packaging, be it Glass, Steel, Aluminum, Paper, Wood, Jute, Bamboo etc. Some may have more acceptance than others. Polymer films interact with their environments differently than do glass or metal containers. Molecules can dissolve or diffuse in a polymer film and designers gainfully employ this property. Different Plastics offer different qualities, giving the designer the freedom to choose the type of plastic that best suits the application. Plastics can be rigid when protection is needed, or flexible for convenience's sake. They can be clear or opaque. And they can be moulded into a wide variety of shapes and sizes. Thus, it will not be out of context to state that Plastic as packaging material can have tailor made properties that are optimally desired by the designer.

"Plastics are an essential and enduring form of packaging". It is no coincidence, for example, that around 50% of food in Europe is packed in Plastics whereas in India it may be around 15-30%. Plastic packaging is versatile, durable, and hygienic and cost effective as well as being environmentally sound. Present and future consumption trends are indicated in the table and have a definite bearing on its selection for food packaging.

Plastic use for Packaging in India
(Quantities in million tons)

Type of packaging	**Year 2000**	**Year 2010**	**Growth**
Rigid packaging	0.4	1.8	16%
Films	0.6	3.0	17%
Woven sacks/multifilament	0.5	1.4	12%
Total	1.5	6.2	16%

Source: Presentation "Polymer Industry a new Decade" Mr. K.P. Nanavaty, RIL, Mumbai

Lowest cost packaging?

With our kind of economy where a large consumer base can afford to buy only smaller quantities at a time, changes in the distribution system, and the cost conscious market forced the package designers to study the utilization of disposable packaging. They desired to substitute the traditional package at least in small sizes with a lightweight, less expensive material with the basic objective **"To provide consumers with a highly economical pack which is only marginally costlier than buying the product in loose form".**

Flexible friends. India is among the first few countries to adopt the Plastic pouches for the mass consumption items like milk and cooking oil. Its use has expanded quickly in recent years by eating away at the market share of more established materials. The biggest advantage of Plastic laminates is its ability to have tailor made properties of the composite film by utilizing food grade resins in various combinations.

With the above mentioned design process if a Plastic material has been selected as a Packaging medium, I think it should pose no danger as raised by the anti Plastic groups.

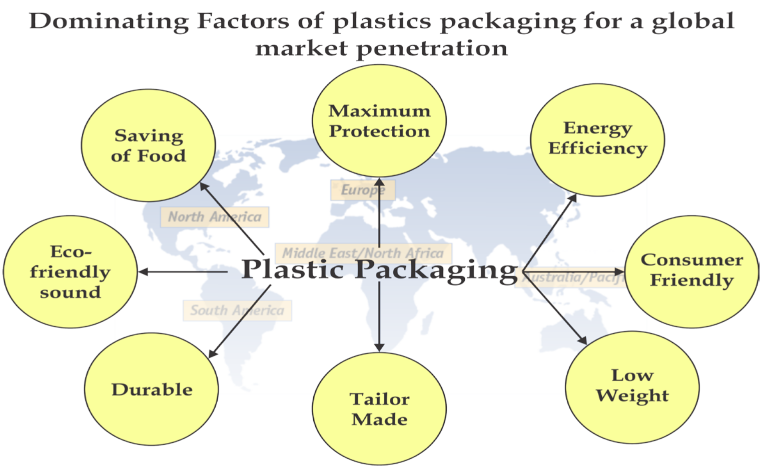
PLASTICS - PACKAGING SOLUTION FOR FOOD PRODUCTS

Packaging is constantly evolving to meet the changing demands of the society. A major change has been our ability to protect and preserve products with Packaging. It has been a revolution and some societies have enhanced it quicker than others. Plastics with their unique combination of properties are the keys to meeting these demands in a sustainable manner, in both the developed and developing world. Today Plastic packaging is 38 % of market valued at US $ 434 billion and growing rapidly. In India also an impressive growth is recorded vis-a-vis other Packaging mediums (ref. table below). Share of various packaging materials in the following table shows not much of a deviation from the past, except that the share of plastics is increasing from 4 % in 1983 to 12 % in 1997 and over 32 % by 2000. Plastics are beginning to play an important role in the Indian packaging Industry.

Growing use of Plastics in Packaging

Material	1983	1997	2000
Paper & paper board	32%	31%	22%
Glass Containers	15%	23%	15%
Tin Plate & Steel	16%	13%	9%
Plastics	4%	12%	32%
Composites	1 %	4%	10%
Aluminum	1%	1%	2%
Jute	30%	18%	10%
Total	**100%**	**100%**	**100%**

Dominating Factors of plastics packaging for market penetration



Plastics and their present usage

Plastics are a large, comprehensive family of materials with very wide range of properties to meet almost every requirement of the packaging industry. Plastics being the synthetic materials can be tailor made to cater to a specific need or combination of performance requirements. Plastics are light in weight, non-toxic, and hence absolutely safe to use even in direct contact with food products. They have excellent barrier properties towards oxygen, moisture and gases to achieve the anticipated shelf life. Level of usage of various Plastics in food packaging is indicated in the table below.

Indian Polymer Demand in KTPA

Polymer	1998-99	2000-01
PVC	724	927
PS	172	229
LDPE/LLDPE	525	690
HDPE	710	939
PP	600	869
Total	2731	3654

Source: Working Group Report-Govt. of India

For Food application, predominantly polyolefin's i.e. HDPE, MDPE, LL & LDPE, PP and its copolymers are used extensively as indicated below. Their resins are safe for food contact applications. However, to get "Safe for Food" certificate, each manufactured lot has to undergo specified tests that are provided by the manufacturers. Testing facilities are available with Institutions like CIPET, CFTRI and IIP. Sample certificates are shown below in the subsequent table.

APPLICATIONS	PLASTIC MATERIAL FOR PACKING
• **Milk Products**	
Milk Plain, Pasteurised and UHT	LDPE/LLDPE
- Flavored Milk	LDPE/LLDPE
- Channa, Khoa, Cheese, Chakka and Shrikhand	Nylon, EVA, lonomer, BOPP
- Buri	BOPP/LDPE/LLDPE
- Canned Rasogolla	PET/LDPE, BONF/LLDPE
• **Fruits and vegetables**	
- Synthetic and Fruit squashes	PET/PE Laminate
- Tomato ketchup	PET/PE
- Mango chutney	PET-PET/lonomer, PVC
• **Meat, Fish and Poultry**	
- Meat (Fresh chilled)	LDPE/LLDPE
- Meat products	BONF/LDPE or PET/LDPE/LLDPE
- Canned Meal products	LLDPE
• **Poultry and Poultry Products**	PET/LDPE/LLDPE
• **Fish and fisheries products**	
- Frozen products	LLDPE/LDPE
- Frog legs and lobster tails	Nylon/LLDPE
• **Bakery and confectionery products**	
- Bread	LDPE/LLDPE
- Biscuits	Cello/LDPE, BOPP/LDPE, PET/LDPE
- Bombay Halwa	Glassine/LDPE
- Baking Powder	PET/LDPE, BONF/LLDPE
- Cakes	Glassine/LLDPE

• **Protein Rich Foods**	
- Protein rich flours and concentrates	LLDPE
- Ready-to-eat, Protein rich Extruded foods	BOPP/LDPE, Glassine/LDPE
- Protein chewy candy	BOPP/LDPE, Glassine/LDPE
- Protein fortified Bread	LLDPE/LDPE
• **Protein rich concentrated Nutrient Supplementary Food & Food supplements for Infants**	
- Protein based beverages	LLDPE/LDPE
- Protein rich biscuits	Cello/LDPE, PET/LLDPE
• **Edible Starches and Starch Products**	
- Flours and starches (Maize, Tapioca, Arrawroot)	LLDPELDPE
- Custard Powder	PET/LDPE, BOPP/LDPE
- Edible spray dried potato flour	BOPP/LDPE, HDPE
• **Oils and Fats**	
- Edible Oil	PET/LLDPE/LDPE/HDPE/lonomer
• **Food Grains and Foodgrain Products**	
- Cereal grains	LLDPE/LDPE/HDPE/PP
- Cereal flours	LLDPE/LDPE
- Corn flakes	LLDPE /HDPE
- Papad	PET/LDPE, BOPP/LDPE
• **Sugar and Honey**	
- Cube sugar	LLDP/HDPE/PP
- Bulk sugar	PP/HDPE
• **Stimulant Foods**	
- Tea	LDPE/PET, LDPE, BOPP/LDPE
- Roasted and Ground Coffee	LDPE, PET/LDPE, BOPP/LDPE
- Soluble coffee chicory and soluble	LDPE, PET/LDPE
- Coffee powder	
- Cocoa, Roasted Chicory, Roasted Coffee	LDPE, PET/LDPE,
- Chocolate	LDPE, BOPP/LDPE
• **Atta**	PET/LLDPE/HDPE/LDPE
• **Salt**	LDPE/LLDPE
• **Alcoholic Drinks and carbonated Beverages**	
- Carbonated Beverages	PET
- Vodka, Gin, Country spirit, Brandies	PET
- Beer	PET
- Toddy	PET
• **Spices and Condiments**	
- Whole spices	LLDPE
- Black pepper, whole	LLDPE
- Ginger, Ground	LLDPE
- Curry Powder	PET/EVA, BOPP/EVA
- Chilies	PET/EVA, BOPP/EVA
- Saffron	BOPP/LDPE
- Tamarind Concentrate	BOPP/lonomer
- Cloves	PET/LDPE

Food grade conformence tests of plastics

- **Global Migration Test (IS : 10146-1982,10141-1982,10171-1986, 9845-1986)**

This is a compulsory test for food grade
The Global migration values must be below specified limits.
Polyolefin LLDPE films used for milk pouch, edible oil pouch, snack foods pass this test.
ITDPE used for making Woven sacks for packing of sugar, food grains, cattle food passes this test.
(Ref: CFTR1 Test Report No. FT/FPTD/MR-5/98) (1998)

- **Extraction Tests (as per US-FDA, 177,1520 olefin polymer)**

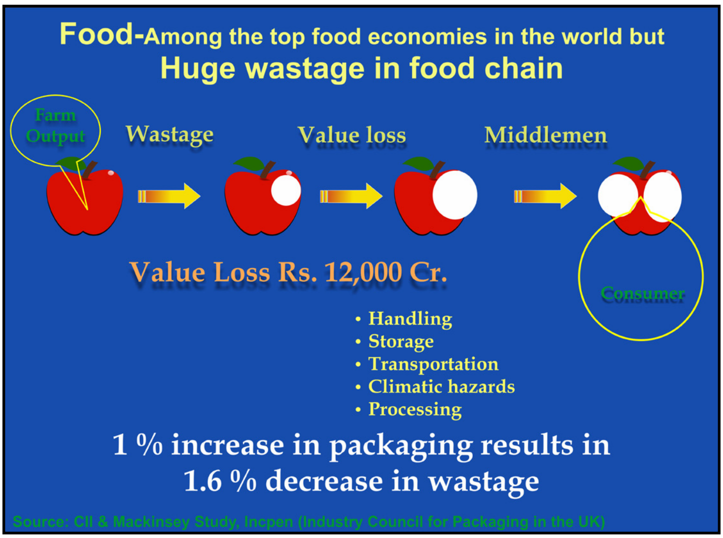
Polyolefin fimls (LLDPE) and HDPE for Plastics woven sacks for food grains and sugar also pass this test.
(Ref: CFTRI Test Report No. FT/FPTD/ER-5A/98) (1998)

- **Extraction Tests (IS: 9845) for Pharmaceutical Products Packaging**

Polyolefin films (PP etc.) used for food and pharmaceutical packaging application pass this test.
(Ref: IIP Test Report No. 1/759B/2001/LAB/M-7)

Plastics reduce Post -Harvest Wastage

In India, it is estimated that about 50% of the vegetables and fruits grown do not reach the consumer because of poor harvesting and packaging. Value destruction in this food chain from field to consumer is estimated at 5 billion dollars annually.



Source: Mckinsey Report

Avoidable losses in the Indian economy due to various food products are indicated in the table and to a great extent these losses can be reduced with proper packaging.

Wastage of food products in India

Product	Spoilage(%)
Fruits & Vegetables	30
Foodgrains	11
Sugar	5
Comment	4
Flour	3
Tea	3

Plastics packaging can help reduce this wastage to a very large extent. For example, foodgrains are stored in bags at various procurement sites across the country. Storage period can range from 1 to 3 years. Plastics being mostly inert and resistant to any bacterial/fungal attack, the chances of deterioration of the packaged foodgrains are virtually eliminated. Use of plastic bags also eliminates growth of moulds and caking of stored grains which takes place in the presently used bags.

Plastic Leno bags hold a good promise for packaging of vegetable like potatoes which are stored in cold storage for longer duration and need regular fumigation where plastics are the ideal packaging media.

Bananas ripened with ethephon in suitable plastic film package had longer shelf life and better organoleptic quality than the bananas ripened in air. Similarly dipping lemons in 2500 oom ethnel and packing in Polyethylene film have also been reported to improve the quality and marketability. As an interesting feature of plastics in post harvest, healing in mechanically harvested citrus fruits was observed way back in 1984 and reported in J. American Society. Similarly the use of High Mol. Wt HDPE as fruit wraps during transportation was found to arrest ripening of mangoes.

Plastic Crates for post harvest Packing

Plastic crates of various sizes and shapes, both collapsible and non-collapsible are manufactured and available in plenty in our country. These can be gainfully used for packing and collecting horticultural produce from the field. The use of plastic crate would avoid bruising damage of the produce generally caused by the sharp edges of conventionally used large baskets made of bamboo or any other plant material. Most of the large scale handlers of horticultural crops, viz. Fruit and vegetable marketing unit of "Mother Dairy", H,P .M.C. etc have started using plastic crates primarily because of their durability.

Polypropylene boxes for horticulture Packaging

Polypropylene corrugated board, which was introduced to the trade in 1980, has now been recognized for its added performance. It has very good properties and can be used easily for horticultural produce. It has been reported that the dimensional stability of the corrugated polypropylene board boxes could be increased by using corrugated compartments for long distance transportation of apples.

Plastics crates for milk, fruits and vegetables

PP cartons for fruit packaging

Onions in leno bags

Onions in torn jute bags

Polypropylene Leno Bags for Fruit and Vegetable Packing

Plastics in bulk packaging

Traditionally, Jute has been the packaging material for bulk commodities like foodgrains, sugar, cement, fertilizers, chemicals etc. With the increasing growth of these commodities over the last few decades, there has been a quest to look at alternate packaging materials due to the stagnant jute production (ref. table below). Plastic woven sacks (PWS) have the potential to fulfill this need in a cost-effective manner thereby offering a tough competition to Jute bags.

Bulk Packaging : Jute v/s PWS

Commodity Production -Increased by 70%
Jute Production -Stagnant

Production	Units	87/88	97/98	98/99	99/2000
Commodities	Min tons	212	343	346	369
Raw Jute	Min bales	8	11	10	9
Jute & Jute Prod. Imp	000 tons	20	54	111	121*
Changed since 87-88					
Commodities	Min tons		121	134	157
Raw Jute	Min bales		3	2	1
Jute & Jute Prod. Imp	000 tons		34	91	101

*Estimated
Net Import of Jute (111,000 mt imported in 98/99) to fulfill domestic demand under JPMA.

Suitability Of PP / PE Bags for Food Grains & Sugar Storage

Packaging and storage of foodgrain and sugar is a challenging job. Both are hygroscopic and thermally active. An ideal packaging system should have sufficient tensile strength, weather resistance, resistance to handling abuse and conducive to grain metabolism.

Large quantities of food-grains are produced in India every year. About 30% of the produce are procured by the Government and Semi Govt. agencies from the farmers in accordance with Govt. policy. Such food-grains are stored in jute bags in the conventional godowns. Since production of jute has been stagnant, cost of importing these bags is prohibitive. The procurement/ storage of food-grains is becoming a costly affair for the Govt. As an alternative, Polypropylene (PP bags) and High Density Polyethylene (HOPE) bags of BIS specifications being manufactured can be used for our foodgrains WITH PROPER SHELF LIFE STUDIES. These bags are already used for procurement and storage Of cement, sugar, salt and fertilizers, etc. in the country. Compatibility/shelf-life study of storing grains in PP/HDPE bags is being carried out by various bodies. Comment by Indian Grain Storage & Management Institute (IGMR1) for the two options of grain storing as shown in table below is quite interesting.

Study suggests that PP/HDPE bags can be used for storage of food grains.

Board Comparison between 50 kg. Packing jute bags and HDPE/PP bags for food grain packaging

S. No.	Description	Jute Bags	HDPE/PP bags etc
1.	Mass or bag	665 gms	135 gms
2.	Moisture regain	22%	Nil
3.	Max oil content on deoiled material basis	3 per cent max by wt.	Nil
4.	Basic price per bag (excluding sales tax)	Rs. 17.05 (Average of last 5 months & incl of excise duty)	Rs. 10.44 (incl. of 16% excise duty & freight)
5.	Cost of packing 1 mil. mt of wheat/rice	Rs. 37.50 crs @Rs. 18.75 per bag (i.e. Rs. 17.05+Rs. 1.70)	Rs. 20.88 crs @ Rs. 10.44 per bag
6.	Packing cost of 20 mil, mts of wheat by FCI	Rs. 750.00 cr	
7.	Packing cost of 20 mil. mts of rice by FCI	Rs. 750.00 cr	
8.	Aeration	Good	
9.	Problems/Quality complaints	Supplies are generally not strictly as per delivery schedule and have been carried over to next months in he past inspite of pre-inspections by Quality Assurance Wing of DGS&D complaints about poor texture of bags leading to spillage of grain and variations in length/width of bags are there. Besides complaints bout damage by water/rains	Good, - no moulds, cake formation, condensation or musty smell on rice, wheat Raw material available in plenty. No disturbance in supply schedule. The quality checks may be easier to enforce on HDPE/PP bags and the possibilities of bags getting damaged by water/ rains during transit will be lesser.
10.	Other advantages/ disadvantages	1. Not resistant to water, seepage and contamination 2. Contamination of food grains by jute batching oils (a hydrocarbon and suspected (carcinogen) present in the jute bag cannot be ruled out 3. Cost of transportation is higher than of HDPE/PP bags which are almost 1/5th in weight of the jute bags 4. Rough handling may result in burst/ tear of bags rough handling of bags	1. Resistant to water, seepage and contamination is very high. 2. No. J.B.O. Present and therefore no such possibility of contamination of grains with JBO 3. Cost of transportation will be much lesser than the jute bags 4. During trials no burst/tear of bags so far noticed on

Wheat Packed in PP woven sacks
(Clean and hygienic packaging)

Wheat Packed in Jute bags
(huge grain loss)

Sugar packaging in PP woven sacks
(Clean and hygienic packaging)

50 Kg PP bag for sugar packaging

Bulk Packaging of Food grains and Sugar in Plastic Woven Sacks (PWS)

Plastic Laminates for packing processed food

Speciality Plastics packaging for processed food

PET containers for packing food item

The aseptic packaging process has been named “the most significant food science innovation of the last 50 years, “by the Institute of Food Technologies (IFT), a non-profit scientific society working in food science and technology.

Environment-friendly aseptic packages, also known as drink boxes, most often contain single-*serve* beverages.

The drink box combines thin layers of paper, plastic, and aluminum to form a unique, high-performance beverage and liquid-food container that is both compact and lightweight, yet tough enough for children and active adults. Each material used in the drink box plays an important role in protecting food quality.

- Paper (70 percent) provides stiffness, strength and the efficient brick shape to the package
- Polyethylene (24 per cent) on the innermost layer forms the seals that make the package liquid-tight. A protective coating on the exterior keeps the package dry and provides a unique printing surface for nutritional information and graphic design.
- Aluminum (6 per cent) forms a barrier against light and oxygen. The ultra-thin layer of foil eliminates the need for refrigeration and prevents spoilage without using preservatives.

The aseptic packaging system is unique in that. It fills a sterilized package with a sterile food product within the confines of a hygienic environment. Filled aseptic packages are sealed tight, rendering a packaged product capable of being stored over long periods of time -at normal room temperatures and without preservatives. This is in contrast to many other package types and delivery systems, which must include the use of both preservatives and refrigeration for many products. Thus, aseptic processing and packages can preserve even delicate foods such as milk and orange juice for months without refrigeration or artificial preservatives.

The aseptic packaging process is a major advancement over traditional canning techniques. The liquid food or beverage is sterilized outside the package using an ultra-high temperature (UHT) process that rapidly heats and then cools the product before filling. The processing equipment allows the time and temperature to be tailored to place the least amount of thermal stress on the product while ensuing safety.

Compared with traditional canning, where products are heated in the container for 20 to 50 minutes, aseptic packaging' flash heating and cooling substantially reduce the energy use and nutrients loss associated with conventional sterilization. As a result, aseptically packaged products can retain more nutritional value and exhibit more natural texture, color and taste, all while using less energy.

The aseptic process is revolutionary, ahead of even the microwave! The IFT stated that, "Compared with traditional canning techniques, the aseptic process allows a substantial reduction in the time and tempera hire necessary for sterilization. That, in turn, increases nutrient retention and flavor for ensuing safety".

Specialized Food Packaging

In addition to regular plastic packaging for milk, oil, different food items new concepts are also coming for making most economic and suitable packaging applications based on enhancing shelf life of food products by using different polymeric structures and different packaging technology.

Modified Atmosphere Packaging (MAP): Modified atmosphere packaging is a term applied to a range of food packaging technologies that relies on mixtures of the atmospheric gases like O_2, CO_2, N_2, in concentrations different than those in air, to retard deterioration processes in foods. Such atmosphere sometimes with the addition of small amounts of other gases such as CO, Eton, S02 or Argon, maintain foods in a "fresh" state for periods of time necessary to move them through extended distribution and marketing chains. The majority of these technologies rely on combination of MAP and rigorous refrigeration to forestall microbial and chemical deterioration. The key to the technologies lies in the different concentrations of the common gases and the beneficial effects conferred by specific concentrations of various gases. The proper marriage of food, gas mixture and package type has been the subject of most of the developmental efforts in the area. Gas barrier properties of some common polymers are indicated below.

Barrier Properties of some common Polymers

Polymer	Oxygen	Nitrogen	Carbon dioxide	Moisture
PVDC	0.02-0.03	0.005-0.07	0.1-1.5	0.005-0.05
EVOH	0.014-0.095			0.95
LDPE	500-700	200-400	2000-4000	0.35
HEPE	200-400	80-120	1200-1400	0.095
PP	300-500	60-100	1000-1400	0.16
PVC	10-40	60-100	40-100	0.55
PS	500-800	80-120	1400-3000	1.8
PET	6-8	1.4-1.9	30-50	0.45

Vacuum packaging (VP) is a form of MAP that establishes an atmosphere by drawing a partial vacuum to remove the ambient gases inside a gas barrier package and then sealing the package. MAPNP are employed to delay deterioration of foods that are not sterile and whose enzymatic systems may still be operative. Thus these methods differ from traditional methods of food preservations, such as cooking, canning etc. but rather are methods to maintain foods in a "Natural condition".

Most MAPs rely on flexible monolayer or multilayer plastic films and / or plastic and composite trays. Plastics probably comprise 90% of the MAP whereas remaining 10% covered by paper, aluminum foil, glass etc. The most commonly used plastics are PE, PP, polyester, PC, PS, Nylon, EVOH, PVDC, butadiene etc. In addition sealant layers of ionomers or other plastic materials are sometimes used. Gas permeability in mol/m.s. Moisture permeability in mol/m.s at 38deg and 90% **RH**

MAP are used mainly for Red Meat, Poultry, Bakery, Prepared foods, and Fresh Fruits and Vegetables packaging.

Controlled Atmosphere Packaging (CAP): CAP packaging requires the package to be selectively permeable to gases when used to extend the shelf life of fresh produce that must respire, unlike MAP which requires a barrier film that will prevent atmospheric gases mainly O^2 re-entry. CAP has complex requirement which can only be achieved by right combinations of plastic films. But, day by day, new sophisticated, multilayer engineered plastic films are coming in the market. The main advantage is CAP prevents spoilage and eliminates seasonal product availability. Different plastic films are used for CAP of which PVC and LDPE have the best 02/C02 permeability ratio for fresh produce and used for this application. In the last two decades, there has been a major change in food consumption habits. There has been a major shift and significant increase in the consumption of fresh fruits and vegetables., mainly due to health concerns. Today more than 15 million tons of apples are stored in CAP in different regions of the world. The industry of MAP and CAP is valued at more than 200 million dollars in Europe only. CAP has been restricted mainly to apples, banana, pears, kiwi fruit and cabbage.

Case study

Apples in CAP: apple storage in CAP is widely used in almost all apple-growing regions in the world. In USA only about 1.5 million tons of apples are stored in CAP annually. The latest recommendations indicate the advantage of using O2 concentrations at or below 2%. These concentrations provide a better quality retention, reduce the incidence of some physiological disorders such as scald, and extend storage life. The use of lower Oxygen concentration is at or below 1% to avoid the possibility of anaerobic fermentation. The use of oxygen concentration should be combined with lower concentration of CO2 to avoid injury, especially in sensitive cultivars.

Some example of products that benefit from MAP and CAP are given below.

Product	Temperature 0C	Oxygen (%)	$C0_2$(%)	Storage life in air (days)	Storage life in CAP/MAP (days)
Apple	0-2	1.5-2.5	1-5	120	180
Banana	13-16	2-5	2-5	28	49
Bean	4-8	2-3	4-7	7	14
Lettuce	0-1	2-5	<1%	21	28
Strawberry	-0.5-0	5-10	15-20	14	21
Pear	0-1	2-3	0-1	90	180

From Transicold (1995). CAP Handbook and Optimal Fresh (2000). CSIRO Publishing.k

Breathable Films Breathable Film is generally microporous film consisting of mainly Polyolefins in combination of minute special fillers. It is a porous film having minute uniform pores, high waterproof property and high flexibility. Main Features are:

Controlled air and moisture permeability.
Waterproof property
Chemical resistance to acids and alkalis
Good balance of strength for making bags, pouches and for withstanding other post extrusion processes.

CASE STUDY

PLASTICS & FOOD SHELF LIFE

Fast food chains dispense large quantities of lettuce. Refrigeration prolongs the shelf life of the lettuce somewhat, but browning sets in within a few days, creating all sorts of problems for the food chain operations

It was found that vacuum packaging increased the useful life of the product somewhat. However, after a few days, the lettuce suffocated due to lack of oxygen. The taste of the salad deteriorated markedly.

Packaging Unlimited in Atlanta resolved this problem with a breathable packaging material. Shredded lettuce was vacuum packaged in a plastic composit that retained its moisture content but permitted entry of enough oxygen to allow normal respiration to continue. Lettuce survived for 12 days.

Plastic packaging for sterilized / irradiated food products

Food Industry is the largest beneficiary of the development of packaging industry where plastics have constituted to a great extent. The processed food and pharmaceutical industry, however, use different means of sterilization for product package for long life requirements and maintaining aseptic conditions.

Different methods of sterilization like applying dry heal, superheat, steam, exposure to Ethylene Oxide or Hydrogen Peroxide have been traditionally used. However, sterilization by irradiation especially Gamma Radiation from Cobelt-60 source is becoming extremely popular for food/ pharmaceuticals sterilization and enhancement of shelf life because of the following reasons:

a) It is a clear and safe process,
b) Irradiation sterilization is a cold process,
c) Can be carried out as a terminal step,
d) Is an energy conserving or saving processes.

There are about 200 large-scale radiation sterilization plants operating in USA, Europe and Japan. There are a few constant radiation plants operating on commercial basis in India -ISOMED (Mumbai), RASHMI (Bangalore), among others.

The food/pharmaceutical products produced under Good Manufacturing practices by the manufacturers are hermetically sealed in impermeable sachets of radiation stable plastics or their laminates, then packed into boxes and sent for irradiation for Gamma-Ray-Sterilization. Packaging materials chosen should be radiation resistant and strong enough to withstand handling and transport requirements. Materials such as PVC, Polyethylene, Polypropylene. Polystyrenes, Nylon-6 & PET are suitable and hence recommended by major International Regulatory Bodies.

List of recommended plastics for radiation sterilization is given below.

1	Acrylonitrile/butadine/styrene (ABS)
2	Aromatic Polyesters (PET-PETC)
3	Aromatic and aliphatic polyamides (NYLONS)
4	Polycarbonates
5	Polyethylene
6	Polyphenylene sulphide
7	Polystyrene
8	Polysulphonate
9	Styrene acrylonitrile (BAN)
10	Polyesters
11	Epoxies
12	Phenolics
13	Polyurethanes
14	Rubbers
15	Specially formulated polypropylene & chloride

List of FDA approved packaging materials for gamma irradiated foods are shown below. List of packaging materials granted letter of "No Objection" by Health & Welfare Canada for use of radiation processing of food is given in subsequent table. The existing information can be used as a guide to develop specific packaging material for radiation processing of foods. The packaging industry should be an active participant in developing and working towards getting regulatory approvals for suitable materials.

List of FDA approved packaging materials for gamma irradiated foods: 21 CFR 179.45

RADURIZED FOODS (maximum dose: up to 10 Mrad)
Nitrocellulose coated cellophane
Glassing paper
Wax coated paperboard
Polypropylene film with or without adjutants
Ethylene-al kene-1-copolymer
Polystyrene film with or without adjutant substances
Rubber hydrochloridc with or without adjutant substances
Vinylidene chloride-vinylchloride copolymer film (Saran Wrap)
Polyolefin film with or without adjutant substances if vinylidene
Chloride coalings (Saran) or polyethylene coatings.
Nylon 11
Vinylidene chloride copolymer (Saran) coating cellophane
RADAPPERTIZED FOOD (maximum dose: up to 60 Mrad)
Vegetable parchment
Polyethylene film with or without adjutants
Polyethylene terephthalate with or without adjutants Nylon 6 film with or without adjutants
Vinyl chloride-vinyl acetate copolymer film with or without adjutants.

Source: Code of Federal Regulations (USA) 21, Pails 170 to 199 (1987)

Other countries especially, Canada, have also granted letters of "No Objection" for radiation sterilization of packed food in plastics.

Commercial Designation	Composition	Possible Uses
100/8	Polyolefin (High Density)[1] Polyolefin (High Density)[2] Polyolefin (High Density)[3]	Poultry, Shrimp meat
Polystyrene foam trays	Styrene 6854	Poultry parts, meat patties, fish filets, shrimps
Films: SSD 300, SSD 500 D 9000	Polyethylene ethylene-Vinyl acetate coextruded	Overwrap for tray packed meats, fish and poultry
Bags: L300, L500, 1.600, E300	Polyethylene ethylene-Vinyl acetate coextruded	Poultry, shrimps, meats fish
Boxes (Contact, no contact)	Fiberboard wax-coated Coated	Fruits (contact) Poultry, shrimps, meats (no contact)

1 Outer layer
2 Middle layer
3 Sealant layer
4 Trademark of the Dow Chemical Company

NATIONAL STANDARDS ON PACKAGING CODE FOR FRESH & PROCESSED FOOD

Selection and use of the right materials and the role it plays in preservation and protection of perishable products and foodstuffs has become very important in today's scenario. In the transportation and distribution of these products, safe handling and economy also play a vital role. In order to provide safe and high quality foodstuff to the consumers, handling of the raw materials and finished products, the hygienic conditions of the workplace as well as persons handling the product and the selection and use for a safe and clean packaging material, are of utmost importance. For perishables such as meat, fish, fruits and vegetables that are stored and transported under refrigeration or in frozen condition, proper maintenance of a cool or cold chain is imperative.

Bureau of Indian Standards has brought out a series of Indian Standards on Packaging Codes. IS: 10106 (Part 1/Sec.1): 1 990 is one such Indian Standard on packaging code where Part I deals with the product packaging and under Section 1, it covers Foodstuffs and Perishables. This code has classified foodstuffs and perishables in categories of decreasing order of perishability and laid down the guidelines for packaging of various foodstuffs in such a way so as to protect them from deterioration. For returnable containers, it has further explained the procedures to keep the containers cleaned for re-use. The code has recommended various types of packaging materials such as PET/LDPE, BOPP/LDPE, glassine/LDPE HDPE containers, cans, glass bottles, flexible laminated pouches, plastic film, corrugated fibre board box, LDPE liner bags, paper bags etc., and, in some cases, use of nitrogen or a mixture of nitrogen and carbon dioxide gases in hermetically sealed containers for packing various foodstuffs. Packaging of a few foodstuffs and perishables, which are commonly used by the masses, have been covered here. The code has classified foodstuffs and perishables into the following categories in their decreasing order of perishability.

a) Milk and milk products
b) Fruits and vegetables
c) Meat, Fish and Poultry
d) Bakery rich foods
e) Protein rich foods
f) Edible starches and starch products
g) Oils and fats
h) Foodgrains and foodgrain products
i) Sugar and honey
j) Stimulant foods
k) Alcoholic drinks and carbonated beverages
I) Food additives, and
m) Spices and condiments

INDIAN FOOD LAWS AND PACKAGING SPECIFICATIONS

There are a multitude of food laws like PFA, FPO, MMPO, Meat Products order, Vanaspati control order, Standards of weight & measures, AGMARK RULES etc. influencing packaging of food products. There is often no coordination between the government agencies enforcing them with an adverse impact on the Industry. Recently, a body of Central Ministers has been constituted to harmonize the existing food laws and bring them in alignment with Codex Alimentarius standards. As a support, BIS lays down the standards for the packaging materials for the food .For any agro or food industry, the end user of the food products is the deciding factor, so it is necessary to follow the laid down applicable guidelines. For a particular product, say spices, we may follow Indian Standard or, for the exports of the same product, we may have to follow the relevant standard of that country or the dual BIS standard if it exists. Some of the BIS Standards concerning Plastics in food Packaging are given below. Adopting the BIS specifications for Plastics as a Food Packaging material ensures safety.

Some BIS Standards related to plastics in Food Packaging

IS No. Year	Specification for
10141-1982	Positive list of constituents of polyethylene in contact with foodstuffs, pharmaceuticals and drinking water
10142-1999	Polystyrene (crystal & high impact) for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
10146-1982	Polyethylene for its safe use contact with foodstuffs, pharmaceuticals and drinking water
10148-1982	Positive list of constituent of polyvinyl chloride and its copolymers for safe use in contact with foodstuffs, pharmaceuticals and drinking water
10149-1982	Positive list of constituents of styrene polymers in contact with foodstuffs, pharmaceuticals and drinking water
10151-1982 food	Polyvinyl chloride (PVC) and its copolymers for its safe use contact with stuffs pharmaceuticals and drinking water
11704-1986	Ethylene/acrylic acid (EA A) copolymers for its safe use contact with food stuffs, pharmaceuticals and drinking water
14543-1998	Packaged drinking water (other than packaged natural mineral water)
10840-1994	Blow molded HDPE container for packaging of vanaspati
12724-1989	Flexible packaging material for packaging of refined oil
11584-1986	HDPE crates for milk sachets
14625-1999	Plastic feeding bottles
11805-1989	PE pouches for packaging liquid milk
12887-1989	PET bottles for packaging of edible oils
9845-1998	Determination of overall migration of constituents of plastics materials and articles intended to come in contact with foodstuffs
10171-1999	Guide on suitability of plastics for food packaging
10106-1990 Part 1/sec-l	Product packaging code for foodstuffs and perishables.
12247-1998	Specifications for nylon-6 polymer for its safe use in contact with food packaging
10151-1982	-do- for PVC
11434-1985	-do- for ionomer resins
14972-2001	-do- for Polycarbonate resins
13449-1992	-do- for EVA
Etc.	

Similarly Prevention of Food Adulteration Rules (PFA-1955) also stipulate the use of plastic for food packaging us under:

Containers made of plastic materials not conforming to the following Indian Standards Specification, used as appliances or receptacles for packing or storing, whether partly or wholly, food articles, namely:-

(a) IS: 10146 (Specification for Polyethylene in contact with food-stuffs);

(b) IS: 10142 (Specification for Styrene Polymers in contact with foodstuffs);

(c) IS: 10151 (Specification for PoIyvinylChloride (PVC), in contact with foodstuffs);

(d) IS:10910 (Specification for Polypropylene in contact with foodstuffs);

(e) IS:11434 (Specification for lonomer Resins in contact with foodstuffs);

(f) IS: 11704 (Specification for Ethylene Acrylic Acid (EAA) copolymer)'

(g) IS:12252 (Specification for Polyalkylene tetrephathalates (PET)),

(h) IS:(Specification for Nylon 6 Polymer).

(i) IS: 13601-Ethylene Vinly Acetate (EVA)

(j) IS 13576-Ethylene Metha Acrylic Acid (EMMAA).

Tin and plastic containers once used shall not be re-used for packaging of edible oils and fats:

EDIBLE OIL PACKAGING ACT

To ensure safe and undulated edible oil Govt. of India thing its notification has packaging of edible oil mandatory. However the act needs to be implemented by the respective state governments. Use of plastic for packaging has become significant for small packs of 1kg and below where 3/5 layer Polyethylene film pouches can be effectively used. Similarly Pet/HDPE containers are most suitable packaging methods in oil beyond 1 kg packs.

Restriction on manufacture, sale and usage of virgin and recycled plastic carry bags and recycled plastic containers (Gazette notification September 02,1999/July 2002 Ministry of Environment and Forest)

(a) Subject to the provision of Rule 8 :-

1. No person shall manufacture, distribute or sell carry bags made of virgin or recycled plastics below 8x12 inches (20x30 Cms) in size;

2. No vendor shall use carry bags made of virgin or recycled plastic below 8x12 inches (20x30 Cms) in size for selling any commodity;

3. No vendor shall use carry bags made or recycled plastics for storing, carrying, dispensing or packaging of foodstuffs;

(a) No vendor shall use containers made recycled plastic for storing, carrying, dispensing or packaging of foodstuffs.

PACKAGING, PLASTICS & ENVIRONMENT

Perceptions on Plastic waste and its disposal are the major Environmental concerns that need to be handled. There is a tremendous amount of environmental education activity at the elementary school level. Children are a receptive audience to environmental messages on TV and in the classroom. They raise issues like:

(a) Global warming
(b) Acid rain
(c) Eco-friendly packaging

(d) Dioxins etc.

On the other hand, the Media which derives their environmental information both from the Activist groups and the Industry sources, seem to be getting effective communication from the former so as to publish reports like:

a Say no to plastics
b 20 Kg of Plastic in Cow's stomach
c Plastic bags choke drains and kill animals such as dolphins, turtles, and even cows and horses that swallow them.
d Additives and dyes used during Plastic manufacturing are highly toxic.
e BMC jubilant over anti-plastic campaign.
f Go for green shopping etc.

Naturally, in any democracy, the above will lead to Government actions like "Banning of plastic bags".

As a professional, it is really painful when packaging is associated with environmental hazards. Somewhere, as a Packaging group, we have failed to educate the educators so that rational information is passed on to our children. Proactive role in communicating with media to bring out a balanced approach when writing on Packaging has totally been lacking. I sometimes feel Packaging is the victim of its own success because it is widely used, has a finite and often short life span, and is highly visible. With the arguments given somewhere down the line we have failed to give adequate attention to the following:

(a) Dissemination of information from the packaging angle
(b) Handling of littering menace
(c) Basics of good packaging

IS PACKAGING OR PLASTIC THE REAL CULPRIT?

On the basis of various studies and reports, contribution of packaging waste to our municipal solid waste system is estimated as 11.5 % and is divided among various Packaging media as shown in the table below.

Yearly Packaging waste in total MSW (Municipal solid waste)

Item	% Related to Packaging	Total Qty. (Metric Tons)
Paper/board	5	840000
Plastics	2.9	487200
Plastic film/laminates	0.8	134400
Glass	1.8	302400
Meta/tin plates	0.8	134400
Aluminium	0.2	33600
Total	11.5	1932000

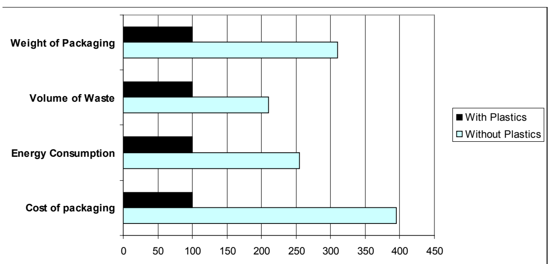
If we consider the present quantities of Plastic, which go into recycling, reuse, incineration etc as approximately 40%, contribution of Plastic waste in the total solid municipal waste is estimated to be around 2 %. With the position becoming clearer now we can say, "Plastic packaging waste is not the largest or most dangerous component of our municipal solid waste". However, effective & safe disposal mechanism for each area of operation needs to be defined. Other issues on the reported ill effects of Plastics on environment, on marine life, production of dioxins, life cycle analysis, etc are beyond the scope of this paper as such are not discussed.

The achievements of packaging have resulted in source reduction on one hand to minimizing the waste of essential commodities like food in developing countries. The energy used to produce this packaging is more than compensated for by the reduction in waste of food and energy inherent in its production. For example, packaging of one million ton of bulk commodity like wheat / sugar 333 GJ of energy one required in Jute sacks compared to 2.15 GJ in case of PP/ HDPE woven sacks and 670 GJ in paper sacks. (Life cycle analysis, TTT Delhi, reports). Similarly, 6 gms of PE are used to pack one litre of milk compared to 750 gms of glass bottle for the same packaging.

Packaging of Milk in Plastics Pouches

ECO-PROTECTION PROGRAMMES

Notwithstanding the above, the need to reduce the contribution is recognized by the Plastic Packaging fraternity and many programmes have been initiated. One of the organizations ICPE-Indian Center for Plastics in Environment is responsible for promoting the consciousness of environment protection. One interesting graph, which I could get from a study report by UP, is shown in the graph below. This gives the environmental impact of not using the Plastics as packaging material.



Due to inherent advantages like lightweight, durability, chemical inertness and recyclability, Plastics are and will remain an integral part of packaging. Packaging without plastics would result in significant increases in the cost of packaging, energy consumption, volume of waste and the weight of packing.

FUTURE: WHAT PLASTICS HAVE TO OFFER

Plastic packaging is going to be the largest growth area. There are Indian companies in particular which are now exporting printed and laminated, flexible, thermoformed containers and even IBCs and polybags in significant volumes. Future of food packaging is considered as "Evolution rather than revolution" and many new trends in food packaging with Plastics are being seen.

Packing in PET. In the past, we could not think beyond glass bottles. Look at the use of PET in packaging. Today, we are using multilayer PET bottles. Application of Silicon coatings have been mastered and new opportunities are created for non- conventional products like liquor, beer, pickles etc. Development & application techniques are going to create new possibilities. Similarly clarified Polypropylene has also been widely used for above mentioned packaging application.

High barrier food grade Polymers. Excellent barrier properties of polymers like PVDC, EVOH have opened opportunities for extended shelf life. New breed of PP (isotactic mPP Grades) with improved toughness, stiffness, heat resistant etc have been introduced and there is a continuous development leading to new materials.

Plastic Ketchup Bottles

Tailor made films and laminates. The unique ability to meet the new concept in packaging like, laminates for counter pressure retort, hot fill and aseptic fillings, MAP bags etc.; thanks to plastics, export of our Mangoes by sea route, which we could not even think of a few years ago, has been demonstrated.

Active, Intelligent and Novel Packaging. The term refers to a method of slowing down quality impairing processes within packaging, thanks to latest developments in Plastics chemistry. By binding oxygen, condensation or carbon dioxide, or by incorporating anti microbial substances via smart foils, packaged foodstuffs are able to retain a maximum level of quality and their durability is significantly extended. In future, rather than just providing passive protection, packaging will additionally play an active role. Examples of active packaging systems include the use of oxygen scavengers, ethylene absorbers, moisture regulators, taint removal systems, ethanol and carbon dioxide emitters, and antimicrobial releasing systems. Now, there is hope for us to export many exotic fruits, vegetables and herbs with extended shelf life.

Exciting areas of development could be using natural food components incorporated into active Packaging.

High visibility Packaging: Visibility is an important factor in food purchase decisions; high visibility packaging is ideal for displaying food products while maximizing product protection and shelf life. Plastics in the forms given below offer best visibility for food items like baked goods, prepared foods meats, cheese and other products.

Carded blister packs
Windowed packaging
Clamshell packaging
Skin packaging etc.

Cook in/ **ship in Plastics:** With an advantage of less handling, less wastage through food contamination and repacking, good barrier, such packs are created by using plastics like PVDC, EVOH and films of Nylon.

High performance at low weight: Constant fine tuning of conversion operations and reduced film gauges/wall thickness have spurred a steady rise in packaging unit totals from the same raw material volume. So while at the international scale, plastics today represent just 19°/) of total packaging material input; they score almost double in output. Over the past decade, the plastic wrapping unit total has just about tripled while tonnage has increased by a "mere" fifty percent.

New Polymeric materials for food products: Polymeric science is a continuous evolving process. Among the newer packaging like irradiated films, retortable laminates, antimicrobial films etc. many have been commercially in use, thanks to plastics.

CONCLUSION

Incorporation of Plastics Packaging along with other materials has benefited almost all in the value chain. The farmer is assured of round the year market for products, which once were seasonal. Packaging has given the retailer an opportunity to handle large number of products even with a low profit margin. The Processing Industry has been able to contain the losses for its product. The State has benefited by generating employment and also by boosting the economy. **But it is the consumer who has benefited the most.** Many of the product variants in convenient and hygienic form, safety and choice are available to him now which could not be imagined 10 years ago.

Polymer packaging in the country is at its evolution/growth stage. Presently, used plastic packaging materials for food applications are standardized by 618. Extensive work in local risk analysis modeling needs to be encouraged for newer product-packaging combinations. Government concerns and the initiative in forming a ministerial group to come out with Food Laws synchronized with codex standards will resolve many issues not only for safety of packaged food in Plastics but in other media as well. With further developments in food grade plastics-coupled with education of consumers, it is expected that use of plastics in food packaging will increase substantially.

Plastics should be encouraged as a choice of Packaging material and, disposal by recycling needs to be enhanced, ensuring induction of efficient technology.

Plastics - Materials for National Security

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Kanpur

PLASTICS - MATERIALS FOR NATIONAL SECURITY

Materials and materials development has been a fundamental key factor to the development of civilization and has played an important role in social, cultural and technological growth of the mankind all over the world. We even ascribe major historical periods of our society to materials; stone age, bronze age, iron age, steel age, silicon and silica age. This reflects how important materials are to us. Human beings have and always will strive to understand and modify the world around us and the stuff of which it is made. It has been understood that the predictive power that arises from knowing the relationship between material's behaviour, its form and routes of fabrication, so-called structure-process-property relationships, underpins society's engineering and technological advances.

Polymers are comparatively new class of structural materials which have been mostly synthesized in the laboratory. During the initial years of their discovery, polymers were considered to be light weight delicate materials usable mostly for decorative purposes in ambient conditions. Over past few decades, there has been tremendous scientific and technological growth in the area of polymer science and technology. Today, polymers and polymer based materials stand as major competitive structural materials even for high temperature applications and heavy duty performances. Polymeric materials have edge over other materials due to their lower density and corrosion resistance and multi-dimensional properties.

Today polymeric materials have improved the quality of life in the modern society and have become a natural choice in varied applications by virtue of their own merits. From the holistic point of view I believe that the polymers are basically environment friendly and can be recycled number of times and hence can save the forests and wood. However in recent times, due to misapprehension about the chemistry of a. vast family of polymeric materials, a negative impression about their impact on the environment is being created in the minds of the society. Though the average consumption of plastics in our country is only 3.5 kg per capita compared to around 100 kg in. the developed countries, even this waste is more visible because of poor waste management. The need of the hour is to educate our society by imparting proper guidance on disposal and waste management to the population at large.

There is a global competitiveness to make the combat systems for the armed forces more effective and efficient, lighter but sturdy and robust and mostly unaffected by the environmental deterioration. This helps the major systems to carry more pay load and adds to the combat efficiencies of soldiers and equipments. The move is to replace a heavy material with a lighter material having comparable functional properties. All the three wings of the Indian Defence Forces i.e. Army, Navy and Airforce are also major user of polymers as they find very wide application in new generation combat systems. Besides combat systems, polymers are also extensively Used in development of allied sub-systems, equipments, devices and personal protective systems. The effectiveness and efficiency of systems and equipments is intrinsically related to and depends on the performance of the material used.

Recent trend in materials science is to develop and utilize new and reliable materials totally devoted to desired end use functional requirements. The development of highly sophisticated major systems require specific materials with minimum variance in properties to ensure accuracy and precision in performance repeatedly. In several hi-tech areas, application of polymers and polymeric materials are preferred choice because of their unique functional properties and ease of their amenability to desired properties, and required shape. This requires the development of new polymers and polymer based materials and evaluate their functional properties for the specific applications such as high temperature, aerospace, electronics, acoustic control, structural etc. Several polymers both thermoset and thermoplastic type have been developed a.s structural and high temperature polymers, conducting polymers, polymers for electronics, specialty polymers in the form of blends, films, fibres, coatings and composite materials for wide variety of application in defence systems ranging from antiballistic application to synthetic fabric suit for protection in extreme cold environment at high altitudes.

Plastics have following typical properties

- **Corrosion resistance**
- **Light weight**
- **High mouldability/fabricability**
- **High intrinsic colourability — for camouflaging and stealth applications**
- **Ablation resistance**
- **Non-magnetic property**
- **Drag Reducing Property**
- **Ballistic Protection and shock resistance**
- **Combustible even in vacuum**
- **Integral Hinge Property**
- **Electrically Insulating/Semi-conducting**
- **Thermally Insulating**

Plastics are, therefore, the material of choice for several applications in defence systems, sub¬systems, equipment and devices.

APPLICATIONS IN THE ARMY

➢ **Arms and ammunitions**

- **Rifle-** high impact fabric filled phenolic compound for butt stock and pistol grip. Butt is filled with foamed in place polyurethane glass reinforced high impact heat resistant phenolic for front handguards
- **Light Machine Gun-** Hand grip (Injection moulded ABS)
- **Anti personnel mine casing —** LDPE + HDPE
- **Anti tank mine casing —** glass reinforced polyesters
- **Filament wound glass reinforced polyester barrel shrouds for tank and artillery guns**
- **Bullets for mob control —** Rubber/Nylon. 6
- **Combustible Cartridge cases —** from cellulose + celluse nitrate, poly(vinyl butyral), Polyuretarte based materials for higher caliber guns (155 mm.)
- **Ammunition containers -** LDPE
- **Striker pins in fuses -** Nylon 6

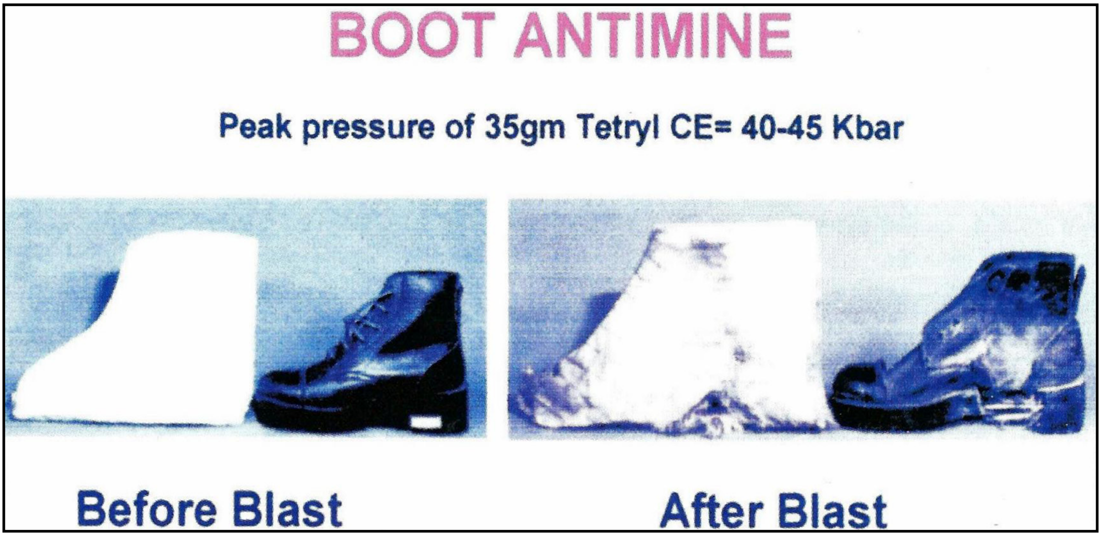
- **Army helicopters —** Composite blades and body structures
- **Camouflaging Nets —** PVC coated fabrics and Nylon twines
- **Parachutes —** Polyester and Kevlar fabrics

➢ **Tanks**
- **Tank armour-** composite glass modified phenolic or vinyl ester panels
- **Phenolic foam insulation**
- **Polysulphide sealing agents**
- **Kevlar nets**
- **Viton and nitrile oil seals**
- **Kanchan armour**

➢ **Trucks and jeeps**
- **Filament wound FRP ring inside rubber wheels**
- **One piece hood for drivers cabin and engine in trucks — glass polyesters, hand lay up**
- **Jeep body**
- **Other non-tyre applications**
- **Transparent armour for bullet proof vehicles**

➢ **Body armour**
- **Bullet proof armour for body and cars —** UHMWPE, Kevlar- 49, Kevlar and glass, polyethylene fibre reinforced modified phenolics, vinylesters
- **Bullet proof helmets —** glass/polyester with phenolic core, glass modified phenolic 9 **Boot antimine**
- **Anti Riot Polycarbonate Shield**

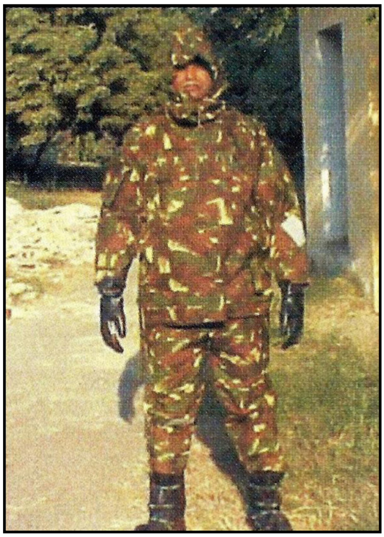
➢ **Inflatable systems**
- **Submarine self-**inflatable escape suits - nylon reinforced polyurethane
- **Life rafts -** polyimide reinforced butyl rubber to retain gas
- **Parachute training balloon -** helium holding PU coated polyamides avoid static build up, retain helium



- **Inflatable stretcher —** two ply polyamide butyl laminate
- **Inflatable rubber seals**

➢ **Protective clothing**

- **Bomb disposal suit also used for rocket servicing- must be acid resistant –**anti-static polyamide textile
- **Sleeping bag —** polyamide coated with neoprene forms outer, pigmented for IR camouflage and rain resistance
- **Survival suit- keep person afloat and enable body to retain heat —** neoprene coated fabrics
- **NBC shelter —** Composite Materials
- **NBC permeable/decontamination suit —** butyl polyester system — resistant to corrosive decontaminants
- **Flexible tank for water supply in NBC environment** - neoprene coated material with polyether based polyurethane collar floating on top
- **Mine blast protective suit —** Suit consisting of soft armour and hard armour to provide protection to whole body



➢ **General**

- **Large fuel tank —** nitrile, PVC —nitrile and polyurethane based
- **Optical —** acrylics and polycarbonate stretched acrylics for windshields, helmet visors, canopies
- **Shelters and buildings —** polyethylene coated aluminium foils with expoxy foam core

- **Cushioning materials –** foams
- **Containers –** HDPE, LDPE
- **Artificial limbs –** FRPs, PVC foams, silicones
- **Water pipes –** PVC
- **Kitchen wares –** melamine formaldehyde unbreakables
- **Sanitary wares –** HDPE, glass polyester
- **Tentage –** PVC coated fabric
- **Ropes –** polypropylene

ROCKETS AND MISSILES

- **Composite Materials**
- **Pressure vessels –** kevlar filament wound epoxy
- **Rocket launchers –** glass filament wound epoxy
- **Rocket casings (Milan) –** glass reinforced polyester made fire retardant
- **Red eye hand grip for launcher –** polycarbonate
- **Cover for telescopic sight-** thermo formed ABS plastic
- **Carbon –** Carbon heat shields

ROCKET PROPELLANTS

- **Double based (NC)**
- **Composite and CMDB (PV, HTPB, CTPB, NC, Fluoro polymers)**
- **Fuel rich Glycidyl azide polymer (GAP)**
- **Liquids-hypergolic**
- **Propellants igniting through cationic polymerization**

Prithivi Missile

EXPLOSIVES

- **Explosive polymers —** NC, poly vinyl nitrate
- **Plastic bound explosives -** Polyamides, polyesters, epoxides
- **Polyester based smoke compositions IR flares**

APPLICATIONS IN THE AIRFORCE

- **Bomb bodies —** DMC of glass polyester
- **Parachutes —** Nylon 6, Kevlar —26
- **Airfield repair —** Epoxy coaltar mix
- **Structural adhesives**
- **Sealants**
- **'O' rings –** rubber

APPLICATIONS IN THE NAVY

- **Mine sweepers — FRP skins with PVC foam core**
- **Suono Buoys**
- **Corner reflectors**
- **Torpedo casings —** filament wound epoxies
- **Unsinkable floats, buoys —** PV Foam
- **PVC pipes for radioactive waste disposal**
- **Composites for ship hull**
- **Binders for paints**

Use of PWS

Plastic Woven Sacks (PWS), because of their inherent advantages of water resistance, chemical resistance and strength to weight ratio are used in Security Bunkers and as cloth / nets for covering the fields, especially during warfare.

Recent Trends in Defence R&D

Conducting Polymers

Electrically conducting polymers are an extremely interesting class of materials that have become popular during last decade. Conducting polymers such as polyacetylene, polypyrrole, polythiophene and polyaniline have a number of interesting features that make them potentially important materials for various type of sensors such as chemical sensors, gas sensors, piezo sensors, thermal switches, opto-electronic sensors, bio sensors and hence are important for

all possible microsystems. Conducting polymers being new class of material open up avenues for the growth of new technologies like energy storage devices, electromagnetic interference and electro-chromic display devices. In the last few years, special attention has been given to the use of conducting polymeric composites as a fabricating material for sensor devices. Polymeric sensors can be made in surface cell form, thin film microelectrode, hybrid with silicon junction, flexible films or pellet forms.

Polymers for Electronic Applications

The development of novel polymeric electronic materials are also needed for defence. These materials are very important from the view of design and development of components for a wide range of defence, aerospace and industrial applications. One area of novel materials is electroluminescent (EL) polymers from which light emitting diodes (LEDs) are fabricated. The field of EL polymers is a class of semiconducting polymers which are fabricated in a special form to make LED devices.

LEPs are long chain of polymer molecules containing conjugated carbon backbone i.e. a series of alternate single and double carbon bonds that give out light when an electric current is passed through it. The colour of the light emitted on passing electrical current is determined by conjugation length and substitution pattern of backbone. The polymers, which are widely used in this field, are homo and copolymers of poly (para-phenylene vinylene) (PPV), Polyfluorene and substituted polythiophene derivatives. These LEDs find wide application in areas as large flat panel displays, signals and indicator lights on electronic equipments and can also be used in car dash boards, runway, camouflage, road signs and a paint like coating that can change colour. The main advantage after using these electroluminescent polymers is that, these show bright light, consume less power and have long life of up to thousands of hours. Because of the properties like low density, shock resistance, tough, transparent, flexible, bright, colourful, thin inexpensive and easy reproducibility, it is for sure that LEPs are materials that would replace many conventional materials as well as give a new dimensional reality for new range of products.

The demand for inexpensive, renewable energy sources is driving new approaches to the production of low-cost photovoltaic devices. Flexible polymeric photovoltaic cells will find extensive applications in defence sector as these materials have potential use in mobile phones, wearable PCs, fighter planes, backpacks, tents and large outdoor shelters. During last couple of years, a good amount of effort has been put in for the development of solar cells based on organic molecules and conjugated polymers like polythiophenes, polyanilines and poly (p-phenylenevinylenes). Polymer based solar cells would offer substantial advantage for the fabrication of low cost roll, to roll production of large area flexible solar cells. The development of polymer solar cells would have a major technological impact, even if the efficiencies of these types of photovoltaic devices up to now are smaller than the efficiencies achieved in inorganic solar cells. Although the research into polymeric photovoltaic is at a very primary stage, but the preliminary results are encouraging. Today, polymerization methods are. being developed. that will increase the structural order, producing more efficient charge transport properties at lower cost.

Polymers with different dielectric constant find extensive application in electronics field. Low dielectric constant polymers find applications as insulating layers for high speed integrated circuitry in a variety of space and aerospace applications. Selected flexible aromatic benzoxazole polymers containing the perfluoroisopropyl units, which exhibit lower dielectric constant, meet these stringent goals. Thermo-oxidative stability and low moisture uptake ensure that these materials are easily compatible with integrated circuit processing. These polymers also adhere to different types of surfaces and allow reduced feature sizes which are necessary for fast signal propagation for aircraft & space systems, low noise electronics and lower weight. This family of low dielectric constant polymer materials will provide air force with greatly improved insulator for wide variety of applications including space based radar, satellite communications, high resolution imaging, high speed computers and other miniaturized electronics packages.

Different organic conjugated materials are used as active semiconducting layers in thin film transistors (TFTs) to meet the requirement of high carrier mobility and low conductivity. TFTs are used for number of applications as displays and radio frequency identification tags etc. Advantage of using polymeric TFTs over inorganic is their lower cost, simpler packaging and compatibility with flexible substrates.

New Hybrid Inorganic — Organic Polymers

Materials possessing high thermal and oxidative stabilities are in high demand for their applications in the aerospace and related industries. Besides fibre reinforced polymeric composites, carbon — carbon composites are good choice for such applications due to their high thermal stabilities and strength to weight ratio, but these materials suffer from a relatively low oxidative stability. The area of inorganic — organic hybrid materials is coming up fast and is a field of growing interest. Hybrid inorganic — organic polymers are copolymers based on inorganic and organic co-monomers. A typical hybrid material will contain a cross-linked inorganic phase bound with an organic phase.

In the field of composite materials, inorganic — organic hybrid polymers also offer great promise as precursors to ceramic materials. in these cases, high purity ceramics are often not necessary as pre-ceramic polymers allow the introduction of inorganic elements such as silicon and boron in quantities that can be directed by polymer structure and stoichiometry.

New technological route for synthesis of ceramics based on the use of polymers as precursor has opened up a frontier for development of new generation ceramics materials. Pre-ceramic polymers, the precursors of ceramic materials are products with an inorganic chain skeletal structure and organic side groupings. On pyrolysis, the inorganic skeleton changes into a ceramic material and the organic groups are removed as gaseous products. Eventually on pyrolysis, a ceramic of desired shape is obtained. This technology offers number of advantages such as forming of complex shape ceramic structures, spinning it into fibres, depositing it as thin layers, employing it as a matrix for composites etc.

Silicon carbide fibres, the first ceramic fibres, are made from polycarbosilane through polymer route. These fibres are being used for making ceramic composite of high temperature structural materials. The ceramic fibres obtained through polymer route have enormous potential in developing the entire spectrum of composite materials and structures for variety of applications in hyper plane, thermal structure, supersonic combustion chamber, liquid propellant rockets and breathing engines hot gas valves and tubes etc. However, silicon carbide fibres have a drawback that their mechanical properties deteriorate at higher temperature.

Advanced Polymers for High Temperature and Aerospace Applications

Polymers have special significance in space programme due to their high specific strength and low weight. Polyimides are a class of promising high temperature polymers for aerospace applications. Structurally modified polyimides are of recent interest for specific applications in the aerospace industry. For such purposes, the materials with crucial properties like high temperature resistance for prolonged periods, excellent chemical resistance, low flammability and good mechanical strength are needed. Several polyirnide systems particularly, PMR (polymerization of monomeric reactants) or bismaleimide systems have been commercialized to meet these requirements. However, the major limitation of PMR-15 is its brittleness. The recent trend of research in this area is to modify polyimides with siloxanes to improve their mechanical properties. Hence, the R&D efforts are being directed towards the development of modified polyimides containing silicon. Moreover, fluorine-containing polymers are known to exhibit better oxidative stability. Hence, in order to obtain excellent thermal and oxidative stability, polyimides having silicon as well as fluorine make a better choice and suggest a new research area.

Several polyimides have been developed which find use in fabrication of composite materials for aircraft and other structural applications. Fibre forming polymers and matrix resins are used in making these composites. Expertise has been developed in fabricating composite motor cases, pressure vessels, inter stages, payload adapters, ablative liner and nozzle throat inserts. Silica and carbon cloth are successfully used as reinforcements for the ablative liners. A special type of phenolic resin has been developed to realize the nozzle throat inserts for liquid engines meeting the required mechanical properties at elevated temperatures.

In the area of space, the next generation solid propellant will have emphasis on high energy oxidizers and binders like ammonium dinitramide (AND) and glycidyl azide polymer (GAP). It is expected to improve the specific impulse with attendant payload gain and combustion products being chlorine free and eco-friendly. Novel synthetic routes are being devised in order to bring down the cost of increased safety.

In the case of composites, new matrix resins like cyanate ester and bismalemides are being developed with a view to increase the service temperature of the composite motor cases and other structures. High modulus carbon fibres required for light weight satellite structures and carbon fibre reinforced composite materials are under development for variety of structural applications. PEEK (Pol)7 ether ether ketone) is a new class of thermoplastic structural material. PEEK has several aerospace applications. PEEK, as a matrix resin retains certain degree of flexibility up to cryo temperature and is therefore, a candidate for making composite cryo tanks for storage of liquid hydrogen.

The re-entry experiment programme will demand development of newer materials, especially thermal protection system involving ceramics, high resistant silicon materials, etc. Carbon-carbon composites and its oxidation protection is an area of development of this programme. 15R0 has mounted technology Development Programme and Advanced Research Programmes towards achieving these objectives. DRDO is also working on development of carbon-carbon composites for strategic applications.

High Performance Thermoplastic Blends for Engineering Applications

The growing demand for polymeric materials with good mechanical properties, high service temperature, and improved chemical resistance has led to active research in the development of new high performance polymeric materials. A particularly interesting way to obtain new engineering polymers is blending. This enables us to provide ensemble of properties to be obtained that are difficult to achieve in a single polymer. Further more, blending gives rise to a range of properties in the final product by changing the blend compositions. Hence, blending of polymers has important applications.

PEEK has been blended with several other polymers like PET, PES, Nylon 6, LCP, ABS, PTFE etc. to obtain a unique set of properties which have important applications in defence related products.

Elastomer Blends for Vibration Damping and Acoustic Control Applications

Elastomers are used in various forms for acoustic attenuation and isolation of continuous vibration and shock. The areas of application are automotive engine and body, load bearing pads for machinery, rail roads, bridges, and ships and naval vessels etc. These materials have unique combination of mechanical properties i.e. low moduli and inherent damping including other features such as the ability to perform at large strains without fracture and to carry high loads in certain modes of deformations

Vibration and acoustic damping blends are being developed that may comprise of two or more elastomers/polymers. The effectiveness of the blending would depend on the compatibility of the components and the phase morphology that is produced. In developing vibration and acoustic damping blends, chemical crosslinking and various reinforcing fillers are used to design microstructure to meet stringent quality requirement of dynamic mechanical properties. Besides the choice of base polymer and the compatibility, the other features which have been studied are easy curing, interface bonding, method of mixing and the amount and type of fillers added. Along with appropriate blending, the balance between dynamic and other properties such as creep and fatigue have also been optimized.

Smart Materials

The science and technology of the 21st century will rely heavily on the development of new materials. Such materials are expected to be innovative with regards to structure, functionality and design. One concept in achieving this goal is what has been termed as 'Smart Materials'. A smart material is defined as a material which has been atomically or molecularly engineered with embedded sensors, actuators and controlled mechanism, giving it the capability of sensing and responding to external stimuli in predetermined and controlled fashion. Smart molecules are designed to receive a stimulus, transmit and process it, and then to respond by producing a useful effect. Stimuli may be stress, strain, temperature, pH, environment etc. New or advanced materials to reduce weight, eliminate sound, reflect more light, dampen vibration and handle more heat will lead to smart structures and systems that will definitely enhance the defence capabilities. Polymers offer many ways of creating smart materials.

One of the first attempts to use the smart materials technology involved materials constructed to do the work of electromechanical devices. Since then many types of sensors and actuators have been developed to measure or excite a system. This technology is still in its infancy. The technology of smart materials and structure is a highly interdisciplinary field, encompassing the basic sciences-physics, chemistry, mechanics, computing and electronics as well as applied sciences and engineering such as aeronautics, and mechanical engineering. This may explain the slow progress of the application of smart structures in engineering systems.

The prospects of smart technologies are new sensing materials and devices, new actuation materials and devices, new control devices and techniques, self detection, self diagnostic, self corrective and self controlled functions of smart materials/systems. Smart materials can be grouped into various categories viz. piezoelectric, electrostrictive, magnetostrictive, shape memory alloys, optical fibres, smart composites, textile materials that can detect a variety of signals from the human body and weather conditions so as to allow for greater comfort.

Number of distinct military applications of smart materials and smart systems may be related with development of (i) Smart Clothing (ii) Smart Skin (a shirt for soldier in battle field that is made of special tactile material that can detect a variety of signals from the human body and can suggest and take some corrective actions) (iii) Smart aircraft (smart materials and systems for cabin noise reduction, vibration dampening and impact detection, engine monitoring, central control unit, flutter suppression/flap positioning for use in aircraft).

Stress sensitive, strain sensitive and healing type polymers with specified response have already been developed and their applications are now being looked into which will enhance the performance capabilities of aircraft structures, robots, remotely controlled vehicles and structures required in defence applications.

Nanostructured Polymers and Composites

During the last few decades, the material development has been largely based on using two or more dissimilar materials to generate a composite material which usually has much better performance properties than either of its constituent alone. Variety of metal matrix materials, polymer matrix materials and ceramic matrix materials are examples of this class. Another approach in materials development is based upon the structure - property relationship, particularly related to particle/grain size and grain boundaries. In such cases, the properties are enhanced and controlled by affecting the grain size and composition along the grain boundaries. The concept of size related dependence of properties in materials has given rise to development of nanostructured materials.

Conceptually uniform nanomaterials will have enormous potential in near future. They are also unique tools for learning about the electrical, magnetic, optical and biological behaviour of nanosized matter. The ability to make nanoparticle structures in polymers and other materials, is now reaching a high level of sophistication; and applications are becoming increasingly exciting. Potential applications currently being envisaged include nanoelectronics, anti-microbe nanocomposites, fire-suppression agents, fire retardant materials, novel optoelectronic devices, sensors, ultrasoft magnets, advance healthcare diagnostic and therapeutic materials, single site catalysts and other nanodevices which have considerable applications in the area of defence.

In recent years, considerable interest has been shown in the structure, properties and chemical reactivity of C60 owing to its potential applications in various new fields. Due to the richness of unusual structures and outstanding electric, conducting, magnetic and photo-physical properties, including UV/visible absorption, photoluminescence and photoconductivity of C60 and its derivatives, intense interest has been globally focused on covalent fullerene chemistry The development of covalent fullerene chemistry will provide an unprecedented diversity of tailor-made three-dimensional building blocks for technologically interesting materials. Obviously, the combination of the outstanding characteristics of C_{60} with the desired properties of other materials such as the polymers like polystyrene, poly (N-vinyl carbazole), poly (alkyl amine), poly (alkyl thiophene) etc., is expected to be of great technological importance for future materials. The dendrimer based and fullerene based materials and nanocomposites are the up comings in this area.

The initial studies on PMMA fullerene composites have revealed that this material behaves as a good optical limiter. Photoconductive composite made of substituted poly (p-¬phenylenevinylene)s and fullerenes have also been investigated. The first main-chain conjugated polymer, an electrically conducting polythiophene with covalently bound fullerene, was prepared by electro chemical polymerization method. One of the potential areas of interest in associating a p-type conjugated polythiophene and an n-type fullerene lies in the possibility of charge-transfer between these two moieties.

The reaction of living polystyrene carbanion with C_{60} gives star like material. They are highly soluble and melt processable and as such may be spin-coated, solvent cast or melt extruded to give films and fibers having high concentration of fullerenes covalently bound to the polymer matrix. A star polymer containing six C_{60} as end caps was synthesized by functionalization of star polymers with azido and amino groups with C_{60} to produce a hexafullerene star polymer_ Most recently, the reactivity of C_{60} towards free radicals has been exploited to obtain C, containing polystyrene using standard free radical polymerization method. Random copolymers with different C_{60} contents using bulk and solution polymerization methods have been used to prepare star like C_{60} styrene copolymers. Such materials have high potential in development of specialty electromagnetic materials and coatings. The possibilities of employing other form of fullerene like structures such as single and multi walled open ended and closed ended carbon nano-tubes, carbon nano-onions etc in development of new polymeric materials are also being examined.

Nanocomposites have changed the perception towards the concept of polymer composite. The importance of these products is growing from the industrial and research point of view_ Nanocomposites show drastic improvement in the properties derived from the addition of a few percent of the clays such as montmorillonite in the polymer matrix. These composites exhibit new and improved properties as compared to their micro and macro-composite counterparts. The improvement in the properties is the result of the ultra fine phase dimension of the filler which is in the nanometer range of 1 to 100 non with up to 5% filler loading. This gives much higher stiffness and toughness. The filler should be properly dispersed in the system.

Nanocomposites are being rapidly commercialized for different applications. Nylon —6 and PP nanocomposites find use for packaging and injection molded articles. Semi-crystalline nylon nanocomposites are used for barrier films, containers and fuel tank and other automobile applications. Layered silicate promote rapid crystallization; hence better clarity is obtained as compared to pristine nylons, which makes them ideal for film applications. Polymer clay nanocomposites, being stiff and tough, are now being considered for light weight structures required for transportation vehicles in the defence sector.

Material testing for Defence

All materials in general and plastics in particular have to meet stringent specifications for approval for various defence applications. Some of the leading Defence Research institutions in the country involved with such activities of material testing and approval are DMSRDE – Kanpur, DRDO – New Delhi, DRDL / DMRL – Hyderabad, Institute of Armament Technology – Pune.

Conclusions

Certainly the key to the success of our future research lies in better understanding of the underlying science in the structures and properties of polymers and related materials at the macro, micro and nano levels. Using the enormous knowledge acquired in organic and polymer chemistry it may be possible to modify and assemble more sophisticated template structures and further modify these structures into novel compositions, shapes, and sizes to study their physical, chemical, mechanical, electrical and biological characteristics. This will enhance the capabilities of scientists, technologists and engineers to develop materials, devices and systems precisely suiting to the end use requirements and will build up confidence towards technological independence and self-sufficiency required for the land based, naval and aerospace applications.

Fuel Efficient Modern Automobiles Contribution of Plastics

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FUEL EFFICIENT MODERN AUTOMOBILES CONTRIBUTION OF PLASTICS

The oil crisis of 1970's and later on free global market economy introduced in 90's remain the major driving forces for the vehicle manufacturer to have technology edge over their competitors to produce cost effective and better quality product. The auto designers are thus faced with the task of producing a snug, functional and lightweight vehicle at an economical price without sacrificing safety, strength, reliability and comfort. The application of lightweight materials has shown significant effect to meet these needs of auto designers. It is now, thus essential to look upon the weight / power ratio as a fuel economy factor in addition to vehicle performance index. The oil crisis also led to consider the conservation of fossils, environment protection, reduce pollutions due to NOx, CO emitted by the vehicles. In lightweight materials technology the plastics are finding growing importance in automobiles due to the safety regulations, legislations on emission control and recent NVH (noise, vibration & harshness) requirements.

Why Plastics for the Automobiles?

The automotive engineers, designers and specifiers look at the alternate material not simply as replacement materials. A consensus view of the automotive industry, based on technical merits, cost and benefits, makes plastics a suitable candidate due to the following factors n order of importance :

- Economy
- Weight reduction
- Styling potential
- Functional design
- New effects
- Reduced maintenance
- Corrosion and chemical resistance

Economy

When we talk of price per kilogram, then plastics is a less favourable material. However, translating the cost to volume price redresses the benefits of plastics over other traditional materials, since potential benefits of plastics accrue though following critical cost parameters:

- Total number of parts
- Cost of sub-assembly
- Assembly line costs

A classical example is engine manifold assembly, which has process capability to manufacture by blow moulding or by the injection moulding process. Here, the tooling cost can be saved to 15% and 10-20% faster cycle times can be achieved when blow moulding process is selected and compared with the conventional materials in application.

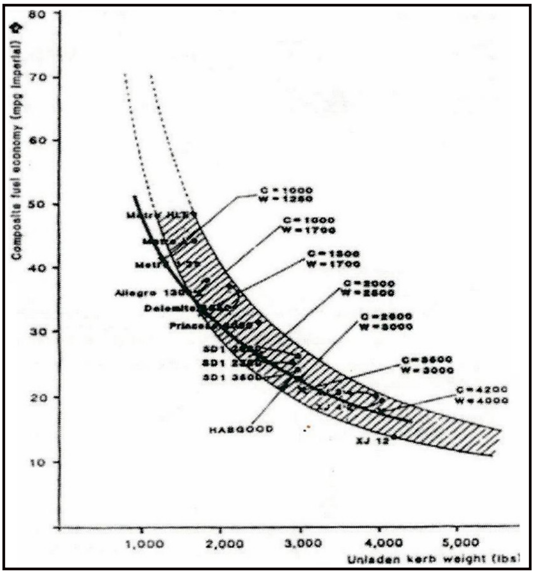
Weight reduction

Weight saving is not necessarily of direct interest to the vehicle manufacturers. However, fuel economy is of interest to customers and vehicle manufacturers. In the USA, the legislation on fuel economy was brought in force in 1985, which is known commonly as Corporate Average Fuel Economy (CAFÉ). According to this legislative requirement, every car sold in the market by the vehicle manufacturer should average 29 miles to the US gallon (m.p.g.) of petro, (11Km per litre). This legislation initiated development programmes to introduce lightweight materials in the United States.

The equation derived by British Leyland based on tests on 270 cars run for 5.4 million miles, the fuel economy can be worked out as follows :

$$\text{m.p.g.} = Kc^{-0.25}\, w^{-0.40}$$

where, c : engine capacity in cm3 m.p.g. = miles per gallon
w: kerb weight in kg K : constant
For urban driving K = 3500 and for motorway driving K = 4600



Vehicle weight Vs Fuel Economy

Based on this equation, the vehicle weight vs fuel economy on individual British Leyland cars of different engine size and kerb weight are shown in Figure. The graph shows the greater sensitivity of the fuel consumption of small cars to unit weight savings. Thus, weight reduction of 30% improves fuel economy by 6 m.p.g. or 2.1 Km per litre. To meet such legislative requirements the plastics & composites got importance for the construction of modern vehicles. It is calculated that automotive weight reductions directly attributable to plastics lead to a 5% savings of fuel. It is estimated that, on average, 100 kg of plastics replaces 200 – 300 kgs of conventional materials, reducing the fuel consumption by 750 liters over a life span of 1,50,000 kms running of a car. Globally, this could amount to a saving of over 21 million barrels per year over the average lifetime of cars. Additional calculations suggest that it reduces CO_2 emissions by 50 million tones per year for the automobile industry.

The figures speak of potential applications for plastics in future to reduce gvw (gross vehicle weight) and make fuel economical vehicles.

In some metal replacement applications the weight saving is spectacular e.g. a fuel tank in high density polyethylene (HDPE) represents saving around 40% battery boxes represent saving of around 70%.

Styling potential

Plastics possess unlimited shaping potential & aesthetic appearance to provide various aerodynamic shapes desired by the modern vehicles integrated along with the functional requirements e.g. door mounted mirror, exterior panels, bumpers, etc.

Functional design

The design freedom & component consolidation makes plastics unique material of choice e.g. fuel tank design in highly asymmetrical forms to accommodate the available space with severe re-entrant angles and variable wall thickness. Another example is under bonnet front-end support assembly involving more than twenty steel shaping operations replaced by a single plastic part.

New Effects

This includes wide range of characteristics such as sound dampening, thermal and electrical insulation, energy absorption, colour, gloss, texture etc. The safety standards of the modern vehicle, with improvements designed for passenger protection derive from these characteristics of plastics. So does the level of comfort and passenger-friendliness of car interiors.

Reduced Maintenance

The demands imposed on future generation vehicles such as reliability, maintenance free design, specialized characteristics like lubricity & load spreading, balanced properties of rigidity & resilience with useful resistance to abrasion, temperature, fatigue and chemicals, etc are seen with the engineering plastics. Hence, they find applications in wide variety of moving parts like gears, cams, bearings, ratchets, sliders and valve seats as few examples.

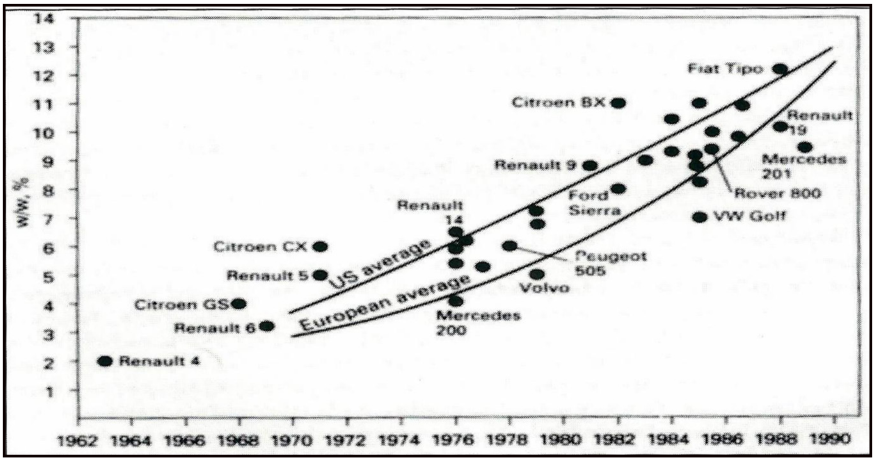
Corrosion resistance

The traditional sheet steel used require corrosion protection, however, none of the plastics is susceptible to factors like acid rain, sea spray and road salt. The corrosion resistance provided by plastics ways out to extensive automotive applications. Due to distinctive chemical nature owned by each polymer, selection of engineering plastics should be critically accessed for each application. This is because, some of the plastics get affected by fuels and lubricants, others are attacked by battery acid and all are affected to some degree by weathering. However these shortcomings in plastics are minuscule in comparison to the corrosion resistance and the related advantage to steel

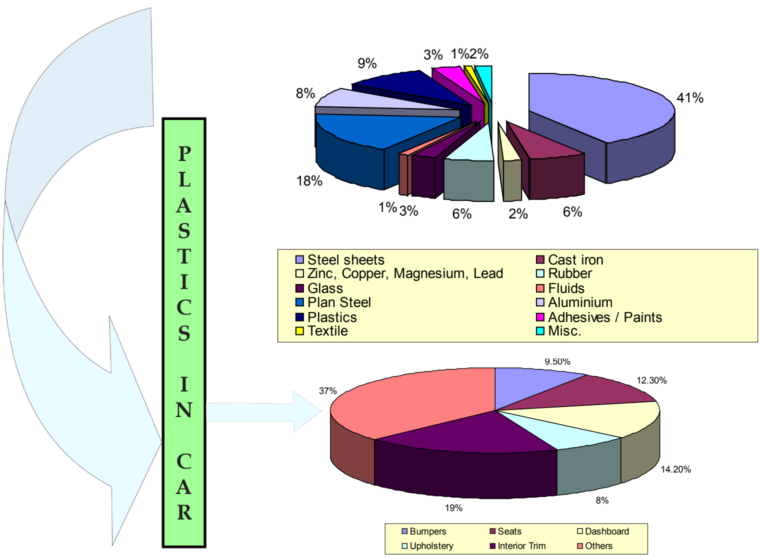
History of Automotive Plastics

The major growth of plastics in automobile as said earlier is increasing since 1970s' oil crisis as shown in the following figure. Though the steel and cast iron will continue to play their major role as main material of construction of a vehicle as shown in the graph below, the aluminium & magnesium alloys and new generation of engineering plastics & composites (fiber reinforced plastics) are steadily replacing the traditional materials. The share of iron & steel from 75-78%

In 1980s has been drastically reduced to 58-63% in today's generation car. The use of plastic is increased from 4% in 1970s to 9.3% and will further increase to 12 – 15% for the new generation of cars including fuel cell, electric and hybrid vehicles. The automotive industry has demonstrated 114% growth over last 20 years in use of plastics. Some of the historic milestones in the development of plastics for the automotive industry are listed in subsequent table in a subjective manner, as they cannot be claimed comprehensively due to continued technological growth. This is the scenario in the developed countries like USA, Europe and Japan, while in India, the plastics and composites have yet to penetrate the market to that extent and there is potential scope in future due to safety, emission and NVH legislative requirements that vehicle manufacturers will be needed to meet.



Growth of Plastics content in Automobile by weight percentage



Materials used for manufacturing an average vehicle

Plastics Milestones in the Automotive Industry

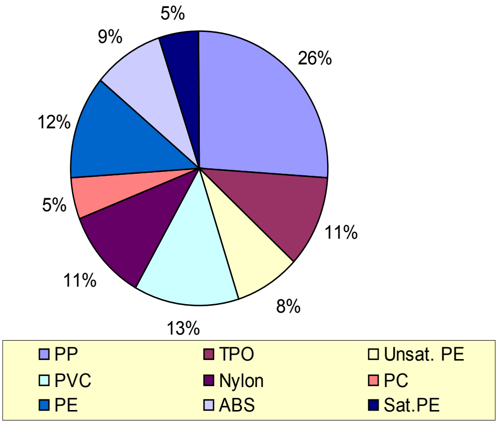
Date	Innovation in Plastics	Material	Model Source
Pre - 1950	Distributor, switches, etc	PF	
	Steering wheel should	PF	
	Coloured knobs and handles	CA, CAB	
	Leather cloth	PVC	
1950 – 1954	Cable sheathing	PVC	
	Car body (panels)	GRP	Chevrolet
	Battery case (in car)	PS	Corvette
	Gear wheels (wipers, speedo etc)	PA	NSU Prinz
	Rear light lenses	PMMA	
1955 – 1959	Roof	GRP	Citroen DS
	Truck cabs	GRP	
	Rotationally cast arm rests etc.	PVC	
	Vacuum formed interior panels	ABS	
	Foam-backed fascia skin	PVC	Mercedes
	Trim fasteners	PA	
1960 - 1964	Integral hinge: gas pedal etc.	PP	GM USA
	Injection moulded cooling fan	PP, PA	Rootes, BL
	Improved distribution cap	GR Alkyd	
	Carpet backing	LDPE	
	Door and window components	PA, POM	
	Rigid fascia covers	PP, ABS	
	Kick plates	PP	Vauxhall
1965 – 1969	Injection moulded heater case	PP	
	Seat foam	PU	
	Front grille	ABS	Renault 6
	Expansion tank	PP	
	Hydraulic fluid reservoirs	PP	
	Headlamp lenses	PC	USA
1970 – 1974	Battery box (engine compartment)	PP	Lucas
	Solderless radiator end tanks	GR-PA	Sofica, for UW
	Bumpers (rigid)	SMC	Renault 5
	Lateral protection panels	SMC	Renault 5
	Fuel tank	HDPE	VW Passat
	Front and rear spoilers	PU	BMW
	Two piece car body	GRP	Lotus Elite
	Headlamp body	DMC	Lucas, for Vauxhall
1975 – 1979	Painted RTM panels	Epoxy	Matra Murena
	Door-mounted mirrors	GR-PA	Renault 4
	Painted grille	SMC	Fort Cortina
	Flexible lateral protection strip	PU	Mercedes
	Flexible bumper covers	PP/EPDM	Fiat, Citroen
	Engine compartment under-panel	GMT (PP)	USA
	Oil pan	STX	GM USA
	Estate car seat-back/load floor	HDPE/GMT	USA

Date	Innovation in Plastics	Material	Model Source
1980-1984	Bonnet and tailgate (volume prod.)	SMC/XMC	Citroen BX
	Self-supporting bumper	PC/PBT	Ford Sierra
	Painted thermoplastic panel	ABS,GR-PA	Ford Sierra
	Full-face wheel trim	GR-PA	Ford Sierra
	Slush-moulded fascia	PVC	Audio Quattro
	Bumper beam	SMC	Ford Australia
	Car body (panels, volume prod.)	Various	Pontiac Fiero
	Painted PP bumpers	PP	Rover 200
	Painted thermoplastic body panels	PC/ABS	Honda CR-X
	Steering wheel + integral skin foam	PU	USA
1985 – onwards	On-line-painted TP body panels	PPE/PA	Nissan Be-1
	Painted RTM panels (volume prod.)	Epoxy	Renault Espace
	Inlet manifolds (fusible core)	BMC/GR-PA	Ford, BMW
	Body platform	GR-PU/Epoxy	BMW ZI
	Injection moulded under panel	GR-PP	Volvo 400
	Composite drive shaft	CR+CREpoxy	Renault Espace (Quadra)

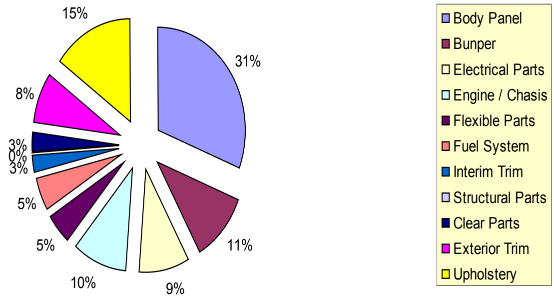
Automotive Plastics and Applications

The automotive sector is one of the major consumer of plastics and consumes over 8% of total domestic/engineering plastics manufactured in the world. Varieties of engineering plastics are used in motor vehicles and more being developed everyday. Major plastics and where they are used are shown in subsequent figures. Examples of plastics use and related weight savings in main car components is also illustrated. It shows that substituting conventional materials with plastic lead to a direct primary weight reduction. Then they also have a secondary effect as chasis, drive train and transmission parts can be made lighter as a result. Application of plastics for automotive components can be classified as follows:

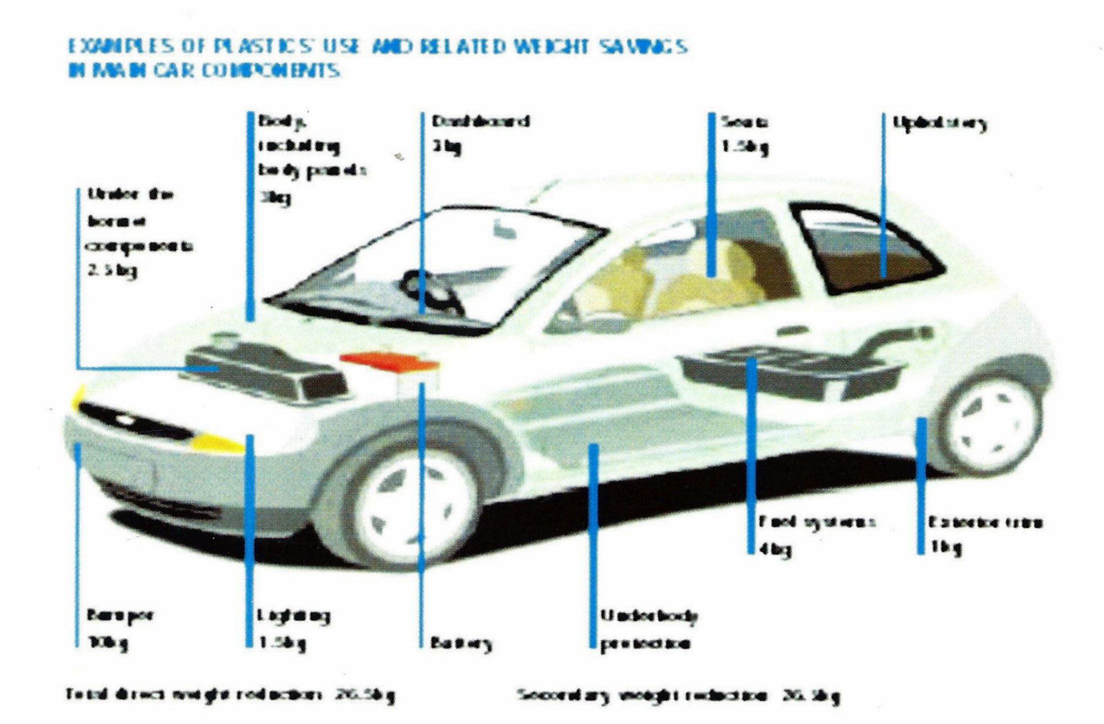
Interior Applications	Seats, Door panels, Instrument panels, Steering wheel Roof-liners, Interior trim, Upholstery, Climatic controls/Air ducts, Air bags, seat belts pedals
Exterior Applications	Bumpers, Weather-strip seals, Headlamps, tail-lamps & Reflectors, Window glass, Door sill panels, Body panels & components, Exterior trim
Engine, Power Train and Chassis	Engine components, Cooling system, Under bonnet structures, Transmission, Engine 'hang-on' parts, Engine manifold, engine interiors, Suspension, Steering, Brakes, Fuel tank
Electricals	Ignition, Battery boxes, Circuitry, Lighting & instrumentation, Other electrical equipment, Electronics



Top 10 Plastics in Cars



Plastics Application



Automotive Plastics Applications

Plastics use by type and weight in an average car

Component	Main Plastics Types	Weight in avg. car (kg)
Bumper	PP, ABS, PC	10.0
Seats	PUR, PP, PVC, ABS, PA	13.0
Dashboard	PP, ABS, PA, PC, PE	15.0
Fuel systems	PE, POM, PA, PP	7.0
Body (including body panels)	PP, PPE, UP	6.0
Under the bonnet components	PA, PP, PBT	9.0
Interior trim	PP, ABS, PET, POM, PVC	20.0
Electrical components	PP, PE, PBT, PA, PVC	7.0
Exterior trim	ABS, PA, PBT, ASA, PP	4.0
Lighting	PP, PC, ABS, PMMA, UP	5.0
Upholstery	PVC, PUR, PP, PE	8.0
Other reservoirs	PP, PE, PA	1,0
Total		**105.0**

Interior Applications

Automobile buyers choices in a new car are increasingly influenced by the desire for comfort, safety, noise levels, styling, aesthetic appeal, and ergonomic layout. To improve safety, components like instrument panels, steering wheels, consoles, interior door trim and seats must be flexible in order to absorb energy from an impact in the event of an accident. Seats must combine comfort with anatomically correct design. Plastics provides a means to address all these aspects and more in a remarkably effective and efficient manner

Seats

Automotive seats are crucial to both the comfort and safety of drivers and passengers, making demands on the materials used in their manufacture correspondingly high. More important than the individual material is their overall combine performance.

Flexible moulded foam, for example, ensures ergonomically designed seating combined with good vibration dampening properties and a high degree of comforts in terms of ride and "seating atmosphere". Dual hardness characteristics of foaming material yield automatically correct seats with improved lateral stability to support the driver in all situations. The cushioning sections can be moulded to good load bearing and long¬term performance properties, and can be produced in virtually any desired shape. Widely used materials in the production of automotive seating include PC-ABS, polyurethane RIM systems PA-6 acrylic fibers.

Thus, plastics plays key role in impressive and innovative seat design. The back of integral safety-belt seat uses polyamide (PA-6) material and the seat pan ABS. The uses of such thermoplastics have several advantages. For example, they enable the production of parts that fulfill numerous functions, thereby reducing the number of individual components required for the production of one seat. This means fever assembly operations and lower production costs. In an event of an accident, the steel reinforced seat back (based on hybrid technology combining plastic and metal) also transmits impact forces to the lower part of the seat structure, from where they are passed into the base of the vehicle. The enclosed PA6 backrest also increases the lateral rigidity of the seat system. Side impact leads to only minimal deformation of the seat, so passenger is more secure. In addition, in new concept design with its integral safety belt, considerably passenger safety is enhanced. Also integral safety-belt is multifunctional. It can be easily removed and re-installed, folded. These materials possess good recycling properties.

Upholstery

Urethane foams are the most common plastics used in upholstery cushioning due to their recyclability combined with their ability to fulfill design and economic demands. Arm rests; headliners arid cushioned instrument panels are classical examples of use of polyurethane foams.

The carpet padding typically used in automobiles consists of needled vinyl-based fiber that lies between the floor panels and the carpet itself. Such insulating carpet padding greatly reduces NVH and provides better comfortable surface.

Instrument Panels

Traditionally, instrument panels were made from several separate components that needed to be painted and a steel-supporting beam that lay behind the panel held that together. Today, thanks to modern plastics technology, instrument panels are made of ABS, ABS / PC alloys, PC, PP, modified PPE and SMA resins. These plastics allow complex designs in items such as: airbag housings, center stacks for instrument panels, and large, integrated instrument panel pieces. They are also used in manufacturing the rest of the automobiles interior Figure shows Instrument Panel trim. These plastics are also capable of eliminating the need for a steel support beam, allowing manufacturers to save dramatically on the cost of the instrument panel while substantially reducing its weight.

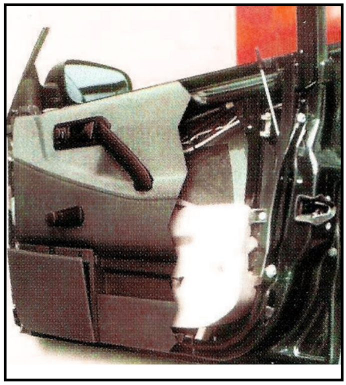
Figure shows Instrumental Panel

Wholly integrated single-piece units can be manufactured from all-urethane and all- polypropylene resins. The results in a seamless instrument panel with greatly reduced NVH levels, moulded-in colour and with significant cost savings for the manufacturer. Cost effective post-consumer and in-plant recycling is also achievable.

Steering Wheels

Steering wheels are manufactured from either moulded, pigmented vinyl resins or from RIM pigmented urethane when ductile material is required. Plastic has helped make possible modern interior steering columns made from a variety of in-mould thermoplastics and metal components. The use of coils and magnets in modern steering columns requires an injected material that seals off magnetic areas off all together, while ensuring limited interference with the magnetic fields. For example, in case of acetyl, its low friction, high strength, and naturally smooth finish make it an ideal material to use in a steering column's switches, levers, and bearings. Similar metal products can be made but are generally heavier and require extensive polishing to ensure the low friction surface necessary for their smooth operation.

Door Panels



The various demands that door interim trim panels have to meet necessitate the use of a combination of different materials. This applies both to the interior trim and the underlying areas. In addition to the need for an attractive appearance in harmony with the rest of the interior, trim panels must also be able to withstand the same sort of loads as the instrument panel. The most suitable plastic materials used for door panels are PC-ABS blends, EA, ABS, etc.

Climatic Controls / Air Ducts

Heating and air conditioning ducts and consoles now provide temperature regulation to rear as well as front passenger seats.
Consoles themselves are typically manufactured from ABS resins, as well as PP and SMA resins. Both blow-moulded and injection moulded PP is used to manufacture the air ducts that feed the console outlets. The air ducts themselves are complex and odd-shaped, yet at the same time lightweight and durable. They would be difficult to reproduce using any other family of materials.

Other Interior Applications

Other interior applications for plastics include seat bases, headliners and load floors of glass mat thermoplastics (GMT) composites (PP/fiber glass), door trim panels of ABS or GMT composite, and rear package shelves of PC / ABS or GMT composite materials.

Exterior Applications

Lightweight engineering, aerodynamics, improved safety and surface finish are all crucial factors in development of plastics for exterior applications.

Body Panels

Large exterior body panels are taking on increasing significance as manufacturers strive to produce lighter, less expensive cars. Depending which materials they are made from, these composites have considerable potential for weight reduction.

Bumpers for example are moulded from RIM polyurethane or from elastomer-modified thermoplastic PBT. Lightweight bumpers made of these materials withstand impact test at -20°C without damage under specified conditions. Body parts moulded from RIM-PU can withstand temperatures as high as 180°C. Other high performance thermoplastics suitable for body panels include PC-ABS blends, PA and TPU. Polymer pigment coatings on surfaces to improve gloss finish, aesthetic appearance, and colour stability the PU raw materials offer optimum level of quality, economy and value retention. Paint repair, weather resistance and resistance to yellowing & chalking is also provided by PU coats.

Weather strip seals

Weather strip seals have to be capable of withstanding wet and dry conditions and extremes of heat and cold. They must also be UV light resistant and retain their rebound resilience after countless opening and closing cycles. Modern seals are manufactured from thermoplastic polyurethane. Seals can also be flocked with polyamide fibers to impart particularly good anti- friction.

Door sill panels

Significant advances have been made in door sill panel engineering thanks to thin-wall technology - a development in which RIM polyurethane plays important part. The material enables wall thicknesses of as little as 2.5 mm, bringing perceptible savings in materials, weight and of course cost efficiency - all with no sacrifice in strength, elasticity or weatherability.

Headlamps and Reflectors

Optimum optical properties and high heat resistance are absolute 'must for materials used in headlamps and reflectors. Plastic headlamp lenses are made from PC resins weigh far less than glass lenses and offer far greater freedom of design and able to withstand temperature as high as 205°C are available in the market.

Engine, Power Train and Chassis

Engine components

Using plastic in engine rocker arm covers is a tremendous advantage to manufacturers seeking to save tooling time, assembly time, and material cost. Plastic's typical lightweight and component integration possibilities help save on weight and NVH levels. Not only does a reduction in NVH allow for a more pleasant driving experience, but by putting less stress on connecting components it can help increase the life span of these components. Plastic engine rocker arms are typically made from compression molded vinyl ester, or injection molded nylon. Both allow for the possibility of molded-in color and little or no post-fabrication machining. Plastic's ability to form integral, yet complex shapes allows for the inclusion of air cleaners and even oil-fill baffles into the same molded unit.

Plastic throttle bodies are a new innovation to engine management. Electronic throttle bodies are being designed to replace current mechanical bodies. Plastic plays a key role in this exciting performance-enhancing technology by allowing the integration of these complex bodies with air intake manifolds. The high performance thermoplastic polyetherimide provides dimensional stability, and thermal and chemical resistance, allowing for improved performance and increased single-piece integration of air management systems.

Engine oil pans can be made of similar plastic. Vinyl ester and nylon help allow designers to create integrated oil pans that provide savings in cost, assembly time, and weight. The possibility of integration allows manufacturers to engineer the inclusion of windage trays, gaskets, strainers, and sensor interfaces in large, integrated, easy-to-assemble units that would not be possible to make without the diverse advantages of plastic.

Cooling systems

Radiators used to be one of the heaviest components in a car. Today, thanks to innovations in cooling technology and the incorporation of plastic into radiator end tanks, radiators are lighter than ever before. Plastic's ability to be formed into complex shapes helps make radiators more space-efficient and designer- friendly. Plastic's high resistance to corrosion helps prevent leaks occurring in plastic-based radiator end tanks. The main plastic used in this application is injection molded nylon.

Injection molded nylon and polyphenylene sulfide (PPS) are also used in water pumps. Water pumps help force coolant through the engine block. Nylon and PPS both offer strong corrosion-resistance. Their ability to withstand high levels of pressure make them ideal materials to use in water pump applications.

The growth of plastics in engine applications illustrates a trend towards lighter, more fuel- efficient vehicles. Car manufacturers recognize the need to create products that are less expensive to assemble, and that give them more freedom to innovate. It's just one more example of how exceptional engineering solutions like these deserve an exceptional material-plastic.

Under-the-hood

The engine compartment contains a very large number of different materials within a very restricted space, materials which are subjected to exceptionally high levels of stress and temperature. Great importance therefore attaches to their functional performance and dimensional stability. Elastomeric materials must also exhibit permanent elasticity.

Exacting demands are also made on heat aging, dynamic strength, tolerance behavior and resistance to oil, fuels and service media. The developing field of electric/electronic engine management also presents a tough challenge to materials, as does the trend towards fully enclosed engines, which involves the use of automotive systems.

Chassis Components

A chassis is the supporting frame of a car. It gives the car strength and rigidity, and helps increase the car's crash-resistance through energy absorption. If a car were a human body, the chassis would be the skeleton. During a fall, a person with strong bones is likely to be hurt less than someone with weak bones. The same goes for a car in an accident. The chassis helps keep a vehicle rigid. A strong chassis will keep the back end of a car from falling out of alignment with the front end, while remaining as stiff and unbending as possible.

The chassis is especially important in ensuring **low levels of noise, vibration, and harshness (NVH)** throughout the vehicle. Not only does a reduction in NVH allow for a more pleasant driving experience, but by putting less stress on connecting components it can help increase the life span of these components. The key determinant permitting reduced levels of NVH is energy absorption. By having a high level of energy absorption, NVH levels are lowered, but more importantly, passenger protection can be enhanced in the event of a collision.

Plastic is making an inroad into the chassis market. Innovations in plastic technology have brought about the development of successful chassis applications that would not be possible using any other family of materials. In fact all plastic vehicles are having a plastic composite chassis. The vehicle is ideal for off-road tropical environments where its composite body and chassis resist sand and seawater. It's combined thermoplastic and thermoset skin and frame take advantage of plastic's strength to manage energy, enabling it to pass both the United States' and the more stringent European computerized crash tests. The chassis' light weight is a tremendous advantage to manufacturers, since weight savings makes parts easier to transport. It also provides consumers better fuel economy, and with the fuel savings that light weight brings, helps preserve resources and protect the environment for us and our children.

Power Train & Transmission

One of the most complicated parts of a car is the power train. It is made up of bearings, shafts, and gears that transmit the engine's power to the axle. Plastic helps minimize the number of parts needed to assemble these complex components and helps reduce the weight of the vehicle, which helps reduce assembly costs while increasing the fuel-efficiency of the vehicle.

Phenolic resins with glass fiber reinforcement have been used successfully to manufacture stationary transmission parts with attached revolving rotors in revolutionary one-piece designs. The single-piece design replaces several separate metal components that would otherwise be needed, resulting in a substantial reduction in assembly time and underscoring the outstanding design efficiency attainable when using plastic.

Plastic can also be used to manufacture transmission oil screens and other components requiring exposure to hot transmission oil. As with fuel tanks, plastic helps free designers from the space constraints that arise with the use of sheet metals.. The use of plastics in front-wheel drive transmissions also helps lessen the weight in the front of the vehicle, improving vehicle handling. Polyetherimide resins are used extensively in transmissions sensor and valve solenoid applications because of their resistance to high temperatures and creeping.

Plastic has found remarkable acceptance as a substitute for metal in transmission components. Plastics offer engineers a variety of materials featuring an excellent combination of physical properties, including heat and chemical resistance, high strength, impact strength and molding ease. These performance characteristics can be tailored by materials suppliers to meet particular needs. The use of additives, fillers and reinforcements will vary the properties of a plastic to meet specific customer requirements. Polyetherimide, for instance, is used extensively in transmissions for its superior dimensional, heat, and creep performance, while a single piece of nylon can replace several steel washers.

A key factor behind the strong and steady growth of many of these plastics is recyclability. The use of the large quantities of the same or similar materials greatly improves the economics of recycling. As more plastics are used in automobiles, we are likely to see a trend towards the increasing recycling of these plastics.

Drive shaft

The drive shaft connects a transmission to the differential. Thanks to plastic's excellent energy-management characteristics, a single-piece plastic-based drive shaft can lead to a reduction in noise, vibration, and harshness (NVH). Not only does this allow for a more pleasant driving experience, but by putting less stress on connecting components it can help increase the life span of these components. Additionally, this can help enhance passenger protection, by helping to manage energy in a collision.

Bearings

Bearing-grade nylon is used extensively as housing for bearings. Nylon's flexibility allows it to be compressed during assembly and expand once it has been placed in position. Its low friction over a wide range of temperature makes nylon an ideal substitute material to use in, for instance, transmission ball bearing shift sockets, flywheel clutch system wheel locator plates, and speedometer gears. Its high durability and chemical resistance help extend the life of the bearings while helping reduce the overall weight of the vehicle. The transmission seal rings used in most vehicles are made from flouropolymers, which come with the typical advantages we expect to see in plastics, as well as having extremely low permeability.

Flywheel

The flywheel is an energy-storing device that helps maintain rotation momentum of the crankshaft between piston firings. The flywheel is also especially important in electric and hybrid-electric vehicles, where it can be used to manage the vehicle's energy efficiently. Plastic- based flywheels can help reduce the weight of the vehicle. Using plastic minimizes the danger of a released spinning flywheel, since the material's properties suggest it would make the flywheel less likely to break off into sharp pieces in the event of a collision.

CV. Joints and 'U' Joints

Constant Velocity (C.V.) joints and Universal ('U') joints are used to permit flexibility between two shafts. Universal joints are generally used to allow for the necessary flexibility between the transmission, the drive shaft, and the differential when, for instance, driving over a pothole in the road. Similarly, C.V. joints are used, mainly in front-wheel drive cars, as a connecting joint between the steering mechanism and the drive train. Acetyl's naturally low friction coefficient and inherent strength make it an ideal material with which to manufacture 'U' joints and C.V. joints. Acetyl polymers are capable of withstanding under-hood temperatures and may not need to be machined like their metal counterparts.

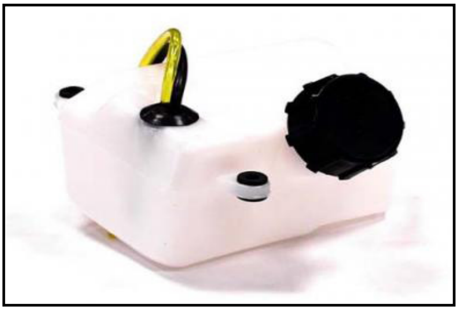
The power train is one of the most complex elements in an automobile. Materials used in this application must have a variety of attributes in order to perform well. Plastic's ability to withstand high temperatures and exposure to a variety of chemicals are vital to this application. In addition, the material's light weight, low cost, and design flexibility make it an ideal material for use in power train components. For almost every power train application, there is a plastic.

Fuel System Components

Plastic has several inherent advantages as a material that enables it to outperform metals. Consequently, it is becoming the material of choice for automotive fuel system components. Plastic cost-effectively frees engineers from the design constraints that metal imposes. The environment benefits from plastic's light weight, which makes cars more fuel-efficient, and from innovative techniques which minimize vapor emissions. We all benefit from the peace of mind of knowing rupture-resistant plastics with high impact strength are helping keep the fuel systems in our cars safe, leak-proof, and reliable.

Fuel tanks

Plastic fuel tanks are made from high density polyethylene (HDPE), a strong, light weight material that has allowed manufacturers to substantially reduce the overall weight of their vehicles, thereby making their cars more fuel-efficient. In addition to its light weight, there are numerous other benefits to using plastic in fuel tanks.



Plastic blow molding allows complex shapes to be created. The complexity attained is far greater than that cost-effectively possible using sheet metal forming. This gives fuel tanks maximum volume of fuel capacity for a given assigned space. Plastic aids in the design of these complex fuel systems that fit into the ever-constrained chassis environment. This unique ability of plastic fuel tanks to be fit into the most optimal spaces in a vehicle chassis allows for the additional room that can be used to accommodate other components, provide passengers with a larger interior, or expand the size of car trunk or a truck bed.

Plastic fuel tanks are produced via a multi-layer blow molding process which uses both virgin and reground HDPE. The barrier material of ethylene vinyl alcohol (EVOH) used to achieve the permeability requirements allows for an important reduction in polluting hydrocarbon emissions from the fuel tank. With more stringent emission requirements pending, plastic meets tough requirements through innovative fuel tank sealing processes and technologies.

Plastic fuel tanks are corrosion resistant; **HDPE tanks will not rust, and will not contaminate the fuel in use**. The high melt strength of the plastics used also gives fuel tanks high impact strength over a wide range of temperatures. These properties ensure a durable product, and provide the vehicle with increased safety while reducing emissions caused by high in-tank fuel temperatures. Lower manufacturing costs are an added bonus for car manufacturers, who in Europe now use plastic more than any other material to make their fuel tanks. Car manufacturers in the United States forecast a high US growth rate in blow molded HDPE fuel tanks over the next few years, predicting a sweeping switch to plastics with a 75 percent market penetration by 2004.

Fuel lines

The main plastic used in fuel lines is nylon. Variations of nylon used generally include a barrier layer similar to that used in fuel tanks in order to minimize polluting vapor emissions. The increased usage of barriers in nylon tubing is possible thanks to the development of multi- layered extrusion techniques. Their flexibility, light weight, low cost, and low permeability are attributes that manufacturers find appealing. Their availability in different colors also allows for easy supply line placement, connection, and tracking.

The most important feature of plastic fuel lines, however, is their contribution to vehicle safety. The flexibility and rigidity of nylon allows for greater safety in crashes. Nylon fuel lines are resistant to tube vibration and moving, while resisting corrosion, crushing, abrasion, and cracking. Their excellent bend radii and pressure ratings top off a strong list of advantages and safety reasons for using plastic fuel lines. Plastic fuel lines will continue to enjoy a huge growth trend.

Vapor recovery systems

The amended **Clean Air Act of 1990** requires that all 2000 - year model cars include a vapor recovery system to trap escaping vapor occurring due to the thermal expansion of gasoline during the refueling process. **These vapor recovery systems will help reduce refueling emissions from levels as high as 6 grams to as little as 0.08 grams of gasoline vapor per refueling.** The emissions canisters used to make this possible are largely made out of glass- reinforced nylon or polypropylene, with trapping valves made of polyketones, polyethylenes, or acetyl.

Fuel-filter pipes

Compared to their metal equivalents, plastic fuel-filter pipes are light in weight. Using plastic fuel-filter pipes saves on the overall weight of the vehicles. Flexible fuel-filter pipes give car manufacturers greater freedom in the positioning of the fuel tank for both practical and safety purposes. Flexible fuel-filter systems also allow for increased safety in the event of a crash since, unlike metal fuel-filter pipes, many can bend and flatten, rather than tearing and rupturing and spilling gasoline, thereby safely eliminating fuel leakage as the cause of a fire or explosion.

Innovations in plastic fuel-filter pipe technology allow for safe, cost-effective high temperature operation with high permeation resistance to both gasoline and vapor during refueling. All this remains possible while safely minimizing any static charge produced during the refueling process, and ensuring foreign elements such as rust particles are not introduced into the fuel mixture.

Fuel pan (sump)

Plastic fuel pumps are available that offer an integrated system which can even include resident integrated electronic noise suppression components, as opposed to noise suppression components mounted on the fuel pump's exterior. The tremendous advantages of having an integrated product are not only to be found in weight savings, but also in space savings, cost savings, and in a reduction of the number of components used. Plastic allows an integrated design that fits together tightly, thereby avoiding any fuel leaks into the circuitry or other parts of the pump.

Fuel modules

The plastic fuel modules that house the pump, filter and fuel level sender offer engineers far superior low-level fuel handling performance. With a plastic module, the fuel is housed in a self-contained area that ensures a constant delivery of fuel to the system without enduring pressure loss due to the unavailability of fuel while cornering or in inclined park positions. This performance allows for improved customer satisfaction with lower manufacturer investment and substantial warranty savings.

Fuel rails

Plastic offers significant advantages to fuel rail applications too. The fuel rail is the pipe that carries the fuel to the electronic injectors and the cold start valve. Composite rails offer multi-point fuel injection capabilities. For instance, together with options for different kinds of fuel flow (return or return less). Plastic fuel rails are cost-effective, and are easily integrated in the air fuel induction modules the industry is beginning to incorporate with the nylon air intake manifold, and carry the characteristic corrosion resistance, weight savings, and dimensional stability that we see the material make possible every day.

Air & Fuel Intake System

Plastic plays an important role in making a modern car engine. From air-intake systems to cooling systems to actual engine parts, plastic helps make engine systems both easier to design, easier to assemble, and lighter in weight.

Air-intake systems

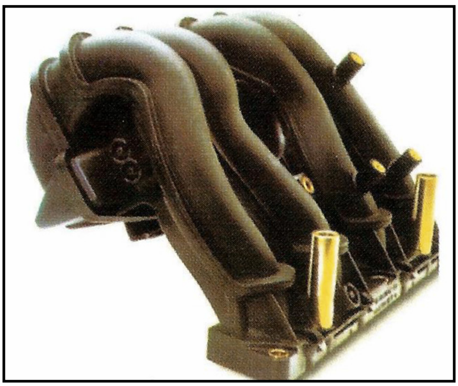
The quantity and quality of the air being mixed with fuel is of vital importance. It helps determine the longevity of an engine, as well as an engine's power and smoothness when running. Nylon, as well as polypropylene, is used to make air cleaner systems. The air cleaner helps separate dust and particles from the air that would otherwise end up in the engine. Since thousands of cubic feet of air pass through an engine, it is important to keep this air as clean as possible in order to prevent build-ups and deposits of foreign particles on delicate engine components, and to maximize the engine's performance. Deposits can, for instance, build up around a sparkplug and prevent it from firing, block an intake manifold airway, or prevent a cylinder valve from opening or Air-intake system shutting.

Air - intake system

Air cleaner housings contain a large amount of plastic that originated from nylon carpeting. Production of mass airflow bodies and of throttle bodies has recently incorporated the specialty plastics polybutylene terephthalate and polyetherimide.

Recent innovations in plastics production has allowed manufacturers to incorporate the air cleaner into the same plastic piece used to make rocker arm covers, giving manufacturers savings in material and assembly costs, as well as substantial savings in weight. Plastic allows engine systems to be substantially lighter, contributing to an overall lighter vehicle and improved gas mileage.

Fuel-intake systems



The intake manifold allows for smooth and even distribution of a fuel/air mixture to the engine. The correct design of an intake manifold is essential to the smooth running of an engine. Plastic helps make the task of designing the intake manifold easier by giving design engineers greater freedom to design and position the intake manifold. Plastic intake manifolds are made almost exclusively out of injection molded nylons using lost-core and sonic welding techniques. Nylon allows for a smooth, even surface, while reducing noise, vibration and harshness levels (NVH) and weight, and giving designers more flexibility when trying to maximize a car's performance.

In the production of air-intake manifolds for petrol and diesel engines, there is a clear trend towards multiple-shell technology in preference to the lost-core molding method. PA 6 resin gives superior welding performance and enables the internal geometry of complex air-intake manifolds to be molded accurately, reliably and economically. Apart from increased processing efficiencies, the principal benefits are higher bursting pressure, exceptional tightness and a lower investment in testing.

Suspension

Suspension tubing and links connecting the suspension system to support structures use plastics' strength and smooth surface with no need for machining or polishing. Additionally, plastics' light weight successfully helps complete a suspension system that is strong and rigid, yet light in weight and fully functional. Injection molded acetyl, nylon, and polypropylene are among the plastics used to make these components.

Brakes

The braking system is one of the most important systems in a car. In certain situations, accident prevention can be virtually impossible without fully functioning brakes. Modern braking systems put thousands of pounds of pressure on each of the four brakes. Plastic helps make today's braking systems possible. Automatic Braking Systems (ABS) housings are molded from plastic, and the electronic circuit boards controlling the brakes are made of an efficient, flexible plastic. Plastic-based brake pads are oftentimes made from a tough aramid fiber, employing the same material used to make bullet-proof vests.

The chassis is fundamental to the proper functioning and safety of a car. Plastic is helping make the chassis lighter, stronger, and more crash-worthy, while reducing manufacturing costs, integrating multiple components into single units, and substantially reducing NVH levels.

Electrical System

Traditionally, electrical components in a car have been limited to alternators, batteries, solenoids, front lights, brake lights, and spark plugs. The electrical anatomy of a car has undergone a major revolution in the last 20 years. Electrical components are now more prevalent than ever. Computer chips regulate and monitor everything from ABS brakes, fuel injection, and oxygen sensors, to the latest in navigation equipment, obstacle sensors, and state-of-the-art car stereos. Plastic makes the inclusion, operation, interconnection and housing of these devices possible.

Component housing

Alternators, solenoids, ignition components, fuse systems, and battery cases are typically housed in plastic shells. The most common plastics used are nylon, styrenics, polypropylene, and polyester, some with various property-altering additives such as glass fibers. Plastic provides electrical components with a strong, consistent, durable, and lightweight housing material whose interference with magnetic fields is negligible. This is especially important, for instance, in the case of solenoids.

Plastic magnets are an innovative concept whereby plastic is compounded with magnetic particles. The ability to replace existing metal magnets with lightweight, inexpensive plastic magnets can reduce the cost and weight of small electric motors found throughout a car.

Switches & sockets

Made primarily from nylon, polyester and acetyl resins, the switches used to operate the electric components in vehicles are of fundamental importance to the aesthetic appeal and practical operation of the finished product.

Acetyl is a good example of how plastic can be used effectively in switches and sockets. With low friction, high strength, and a naturally smooth finish, acetyl is an ideal material to use, for example, in a steering column switch.

Sockets, such as those made for lamps, are made from a variety of high performance plastics such as PPA, PPS, and SPS. These materials have the ability to survive extended exposure to very high temperatures without degradation. Their light weight and corrosion resistance makes them ideal replacements for metal in these applications.

Connectors

Polybutylene terephthalate (PBT) is a thermoplastic polyester whose physical properties are ideal for use in electrical fuel injector connectors. PBT has proven to be a fantastic insulator, is both strong and stiff, and holds up well against the high temperatures found underneath the hood of a car. European car manufacturers, however, are beginning to use recycled polyethylene terephthalate (PET), the same kind of thermoplastic polyester used to make soft drink bottles. The European manufacturers have found “recycled” PET to be as strong, stiff, and temperature- resistant as “virgin” PBT. Both plastics are high flow and warp-resistant, and are ideal for use in electrical connector applications.

Nylon is also used extensively to make electrical connectors. Recent innovations have improved the moisture-resistance of some nylon products, allowing for increased hydrolysis resistance in electrical connectors as required. A new generation of high-flow hydro-resistant PBTs has made great strides in meeting stringent USCAR standards for a wide range of vehicle electrical applications.

Lighting systems

Major changes in the future of both head and tail light systems are imminent, with the incorporation of plastic-based Light Emitting Diode brake-light systems and “light box” systems, whereby an easily accessible, single light source is used to provide exterior lighting for the car via acrylic fiber-optic wires. The current conversion of BMC reflectors to polyetherimide cut cost by eliminating virtually all secondary operations required with this material.

Circuit boards and wiring harnesses

Acrylic fiber optic cables can enhance the illumination and ambience of the interior of a car, as well as simplify connections between a car's battery and any lit accessories. Plastic fiber optic cables are being introduced in and between car stereo components, providing a car's occupants with unmatched high-fidelity sound. Plastic fiber optic cable is also being used to speed interference-free data transmission in complex electronic car components such as GPS navigation equipment and ABS sensor components. By using plastic fiber optic cable and minimizing the amount of copper wire used, the overall weight of the vehicle is reduced, applications work better, and are made safer and easier for plant operators to install.

15 or 20 years ago, a dashboard would have been crammed full of heavy copper wiring. A car manufacturer today saves space behind the dashboard by installing flexible plastic circuit boards instead of a bulky wiring harness. This allows for more interior room within a given frame and leads to a reduction in overall vehicle weight.

Electrical components are becoming more and more prevalent in the cars we drive. From fuel injection to lighting systems, to electrical switches and circuit boards, plastics help house, connect, and simplify these complex instruments. This simplification leads to manufacturer savings in weight, assembly time, and cost, all of which would not be possible without the power of plastics.

Automotive Plastics and Safety

Safety regulations, which are being tightened up more and more in the form of **Federal Motor Vehicle Safety Standards (FMVSS)** provide the challenges and opportunities for plastics. They have to play a major part in meeting legislative requirements with regard to the car body, exterior vehicle components as well as interiors. A typical example is the development of **plastic fuel tank,** which has to meet ECE R 34 regulation, and other regulations as summarized in Table 4.5 Similarly other components have to meet various legislative requirements.

Bumper is another component which, when manufactured in plastics has to meet the safety regulation ECE R 42 for pendulum impact test. In this test, the bumper must not be damaged by a pendulum hitting it with an impact speed of 4 km/hr (as per specified Pendulum Test). Further more, no part of the car body must not be damaged as a result of the dynamic deformation of the bumper system. These demands apply down to temperature of -30°C. The outside radii must comply with EEC 74/483. Polypropylene and RIM-PU are the materials which meet these safety demands.

The **automotive seats** have to comply with the requirements of ECE R17, R21 & R25 and with the equivalent FMVSS 201, 202 and 207. The seat has to survive 50 km/hr. rear impact along with these safety regulations. The effectiveness of all - plastic structures demonstrate ability, reliability and cost effectiveness with the styling, comforts, aesthetics and ergonomic structure. In interiors, the instrument panels need to meet FMVSS 201 and 208 for selection of plastic for meeting following requirements:

- Head impact testing on instrument panel and pillar trims.
- Knee impact testing on certain areas of the instrument panel.

- Body impact testing on seat backrests.
- Side impact testing against door and side trims.
- Collapsibility of steering column.

The most important safety and legal requirements for the design of a plastics fuel tank

USA	FMVSS 301	Frontal and oblique crash (fixed obstacle) Rear and side crash (movable obstacle)
	USA-Part 86 (FR Vol. 43. No. 165)	Hydrocarbon evaporation losses for entire Vehicle (Shed test)
	Title 13 California Administrative Code Section 2290	Suction regulation for petrol vapours whilst filling tank.
Europe	STVZO 45 (W. Germany) EG-Directive 70/221/EWG	Press tightness Corrosion Static roll-over
	ECE-R 34 F 13 (Sweden) BOF 07 (Sweden)	Position and construction, front and rear crash, regulations plastics and fuel tanks (including fire test) Frontal crash (fixed obstacle) Characteristics and fuel lines
Japan	Circular of Jisha Nr. 1327 Art. 15	Fire regulations according to ECE-R 34
	Nr. 23-4 Art. 31	Hydrocarbon evaporation losses (trap test)

The drive for plastic instrument panel not only meets the demands of safety legislations but also structural integrity of vehicle, 'soft feel' touch, 'leather-grained' finish and 'styling' pressures demanded by end users.

In addition, to promote plastics in automobiles they have to meet the legislative requirements for flammability as per FMVSS 302 standard, Fogging test as per DIN 75 201 and Weather resistance or UV test as per SAE, ASTM, ISO or DIN standards. Such requirements are not seen with the conventional materials.

The flammability one of the important regulatory requirement for the automotive plastics. In US, under jurisdiction of Department of Transportation (DOT) under 49 CFR 571.302, the flammability is covered for S3 application. This standard applies to passenger cars, multi purpose passenger vehicles, trucks and buses. The test is S4.3 defines horizontal burn rate test and specifies that a sample 102 mm W x 365 mm L x <13 mm thickness should not burn at a rate of exceeding 102 mm / minute. In the test, the sample is ignited by a gas burner for 15 seconds.

The FMVSS 302 standard has been adopted by many countries under other designations e.g. ISO 3795, BS AU 169 (UK), ST 18-502 (France), DIN 75200 (Germany), ASTM D 5132 and SAE J 369, etc. The flammability can be classified according to JIS D 1201 for interior components of motor vehicles in two parts as follows :

Classification	Flame Spread
Slow burning I	<50 mm/min.
Slow burning I	50 to <75 mm/min.
Slow burning I	75 to < 100 mm /min.
Self extinguishing	all specimens extinguish before the first reference mark, or the flame extinguishes at burn length <50 mm and burning time <60 s.

Classification	Oxygen Index
Fire retardant I	> 30
Fire retardant II	> 27 to 30
Fire retardant III	> 24 to 27
Fire retardant IV	> 21 to 24
Fire retardant V	<=21

In the natural (virgin) state, flammability characteristics of commonly used automotive polymers are as follows :

Material	Burn rate (mm/min.)	Oxygen index (% O_2)	Auto-ignition (°C)
SBR	57.15	16.9	208
TPO	33.53	17.5	159
LDPE	39.12	18.4	176
HDPE	23.37	18.3	--
PP	33.53	17.7	174
HIPS	55.88	17.9	--
ABS	55.88	18.6	243
PC / ABS	41.91	24.0	--
Nylon 6	0	23.2	259
PVC (Flex)	Pass	20.6	239
Urethane film	55	--	--

Conclusion

With this, one can conclude that there is growing importance of plastics in the automobiles of tomorrow, and in particular India needs to have task force to promote it and become global partner in technology and ingenuity.

References

1. "Plastics in the automotive industry", James Maxwell; Jaico Publishing House.
2. "Plastics in automotive engineering", Edited by H.G. Haldenwanger and L. Vollrath; Hanser Publishers.
3. "Plastics uses in cars and commercial vehicles" VDI — Verlag GmBH.
4. "Plastics in Cars" VDI — Verlag GmBH.
5. "Automotive collective know-how for automotive engineering" Bayers publication.
6. "Designing with plastics and advanced plastic composites", Special Publication SP6, Editor in chief M.A. Dorgham, Proceedings of the International Association for Vehicle Design, 1986.

Chapter 7

Plastics and Resource Conservation Land, Waster, Forests & Energy

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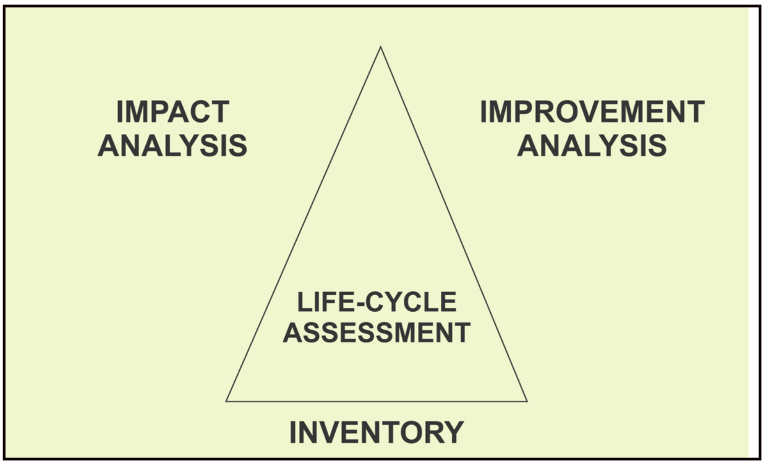
PLASTICS AND RESOURCE CONSERVATION LAND, WATER, FORESTS & ENERGY

POLYMERIC MATERIALS AND ENVIRONMENT

There has been a growing recognition that earth's resources are limited and finite and it is our responsibility to preserve these scarce resources for the future generations[1]. Unfortunately, no clear single-path solution is obtainable because the environmental issues, generally solved locally, are on short term bases. In a new age of science and technology, Chemistry will have a significant role in creating new materials because it manipulates and creates new substances on the molecular level. The twenty first century is regarded as the new material age and new advanced materials are designated on the molecular level. During the past decade, there has been an ever-increasing environmental awareness amongst the general public. The chemical industry, in general, and, the polymer industry, in particular, has come under scrutiny. The concern about the polymer industry's role in air, ground and water pollution has been highlighted. In order to be environmentally responsible and accountable for its products and processes worldwide, the Polymer Industry has to implement a strategy based on a frame work deemed to be practical and workable. There are several examples where it has been amply proven that Polymer not only help in sustainable development but also in conservation of resources.

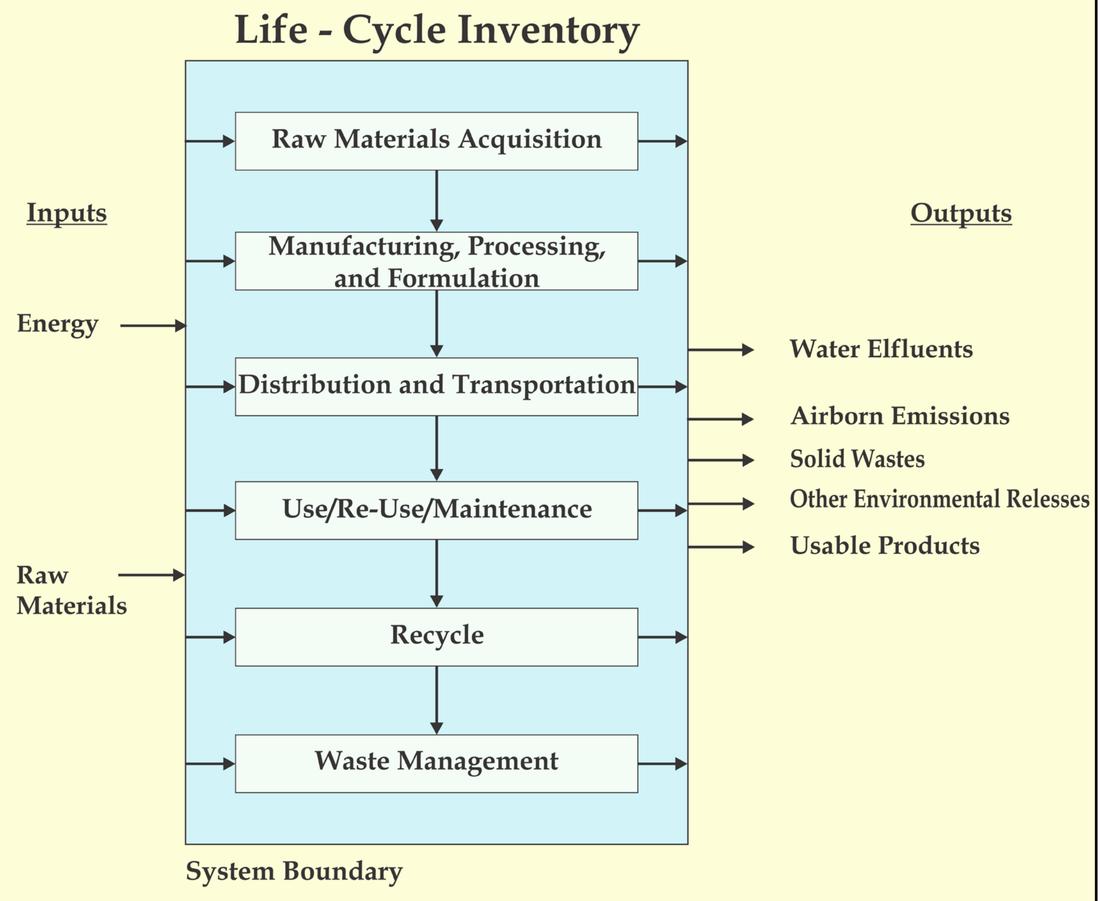
A life cycle assessment model put forward by the Society of Environmental Toxicology and Chemistry in U.S.A is appropriate among various models to provide an insight into the environmental aspects of materials. A complete life cycle assessment consists of three interrelated components i.e. life cycle inventory, life cycle impact analysis and life cycle improvement analysis(as shown in the adjoining figure).



Life Cycle Assessment

Life cycle inventory quantifies the energy and raw materials requirements, air emissions, waterborne effluents, solid waste and other environmental releases incurred during the life cycle of a product, process or activity. Life cycle impact analysis is a technical quantitative and/or qualitative process to characterize and assess the impact of the environmental loadings identified in the inventory component. Life cycle improvement analysis involves a systematic evaluation of the needs and opportunities to reduce the environmental burden identified in the inventory component above. Such analysis may include qualitative and quantitative measures of improvements such as the changes in product design, raw materials used, industrial processing, consumer use and waste management.

The inventory side of the above triangle is, perhaps, the one which has received the most attention so far and considerable work needs to be done to develop the impact and improvement analysis components. What follows onwards is an attempt to link the inventory and improvement sides of the triangle. Life cycle inventory is a data-based process with inputs and outputs as shown in the figure below.



Life - cycle inventory

It is apparent from the above figure that this framework has six stages, namely,

1) Raw Materials Acquisition
2) Manufacturing, Processing and Formulation
3) Distribution and Transportation
4) Use/ Reuse/Maintenance
5) Recycling
6) Waste Management

Each stage receives inputs in the form of Materials and energy, produces outputs of the materials to the subsequent stage alongwith wastes that may or may not be discharged into the environment. An attempt has been made to analyse qualitatively polymers vs. other competing materials under the above mentioned life cycle analysis.

Polymers are organic materials that are manufactured from petroleum feed stock, natural gas and oil using processes that are environmentally benign or that can be made more environmentally compatible. Plastic feed stocks account for only 3 to 4 percent of oil and gas production; processing energy uses another 2 to 3 percent. Use of fossil feedstock for plastics represent no additional drain on resources; some areas refer to plastics as the by-products or even waste product of fuel production. Plastics during their entire course of life cycle not only conserve the scarce resources but also impact less environmental burden.

One of the most exciting areas for the future involves green chemical processes and products namely the development of benign chemical processes. The area covers themes such as the development of in vivo and vitro processes based on new types of catalysts for environmentally benign chemical synthesis and polymerization processes, polymerization in the absence of solvents or in the environmentally benign solvents such as super critical carbon dioxide as opposed to organic solvents; the synthesis of polymers by plant and micro-organism; and the development of biodegradable materials. The polymer industry has successfully adopted many environmentally favourable processes providing advantages over traditional materials.

The quest of Polymer Technologist has been to manufacture polymers in an environmentally friendly manner and help in the conservation of natural scarce resources like water, forests, land and energy, thereby imparting least burden on the environment. This paper discusses in detail the benefits of plastics for conservation of resources.

Advantages of Polymers For Their Use In Conserving Land, Water, Forest and Energy Resources

In India, presently, the polymer consumption is around 4 kg per head per year. It is expected to increase to 8 kg per head per year by 2007-2008. The plastics, in general, are being used in agriculture mainly in water pipes, part for irrigation pumps, sprinklers and drip irrigation systems. Green Houses are being built by polymeric films. Plastic film is also being used for mulching and canal lining. Plastics or plastic based composites are also being used to make farm houses and cattle shed roofing. Parts made of plastics and composites are increasingly being used in farm machineries and transport systems.

Interesting investigations have been made at LIT Kharagpur which foretell the tremendous potential of drag reducing polymers in conserving water, energy and forests.

Plastics in Agriculture - Fuelling Growth and Conserving Resources

Plastics can do a great deal of environmental good and help in conserving resources like water & land through use in agriculture. The introduction of plastics-based irrigation systems, greenhouses and films has increased manifold the agricultural and horticultural output worldwide and transformed the economies of many countries, especially those of developing countries. This growth has led to the setting up of an infrastructure that, today, includes produce co-operatives, marketing services, plastics film manufacturers, agricultural equipment suppliers, greenhouse and irrigation specialists and plastics recycling facilities.

The salient features of plastics used for agriculture are –

- Light weight & higher strength to weight ratio
- Tough, flexible and good impact properties
- Chemical/corrosion resistance
- Gas, Vapour and moisture resistance
- Good weathering & stress cracking resistance
- Resistance to fatigue, good creep properties
- Colouring possibilities
- Low cost production due to less energy cost in conversion
- Non-toxic, odourless
- Transparent/translucent
- Electrical & thermal insulation
- Greater Production design freedom
- Adaptability to intricate shapes
- Minimal secondary and finishing operations
- Low co-efficient of friction and wear resistance
- Pollution free, recyclable and reusable.

Applications of plastics in various branches of agriculture like horticulture, crop management, water management, storage etc. is termed as Plasticulture. Plasticulture is one of the latest technologies, which helps in increasing the growth and production at lower cost.

Major Plastics used in Agriculture:

- Liner Low Density Polyethylene (LLDPE)
- Low Density Polyethylene (LDPE)
- High Density Polyethylene (HDPE)
- Ethylene Vinyl Acetate (EVA)
- Poly Vinyl Chloride (PVC)
- Poly Propylene (PP)
- Poly Methyl Metha Acrylate (PMMA)
- Poly Carbonate (PC)
- Fibre Reinforced Plastics (FRP)

APPLICATIONS OF PLASTICS IN AGRICULTURAL

1. Plastics Lining of Water Storage Pond:

LDPE & LLDPE heavy-duty films are recommended for the lining of storage ponds for enhancing water retention capacity of the soil by serving as water barrier in sandy and porous soils. The LDPE/LLDPF film used for pond lining should meet the quality standards for density, MFI, Mechanical properties, etc., as per Indian Standard, 1S:2508-1984.

2. Prevention of Soil Erosion:

HDPE strips can be installed at regular intervals along the riverbanks and rainwater channels to impart resistance to flow to prevent soil erosion.

3. Plastic Film for Mulching:

The biggest use of agricultural plastics is for simple polyethylene films & sheets more commonly known as Mulch film. Laid atop the ground, the mulch film raises the temperature of the soil, so that seeds can be sowed and tender sapling transplanted earlier in the spring. That promotes more rapid crop development and, thus, raises yields. Plastic mulch can mean extending the ability to grow crops farther onto cool plains like those of Canada and northern China. In central China, it can mean an extra rice crop each year. In southern China, it can mean a crop of vegetables in addition to two rice crops from the same land.

Similarly, in tropical and arid regions like India, where water is a scarce commodity, Mulch film can help in conservation of water besides inhibiting the growth of unwanted weeds. The plastic sheeting has other virtues as well:

- It prevents weeds from competing with the crop plant, without either pesticides or hand
- weeding.
- It cuts water evaporation and makes the use of fertilizers safer and more effective. That
- can make the difference between 25 bushels of wheat per acre and 50 to 60 bushels in arid
- regions
- It helps cut soil erosion wherever it is used on slopes or in windy areas
- It can reduce losses to rot in crops like strawberries and tomatoes

Use of Plastics film for mulching

Effect of Plastics on Economising irrigation water in field crops has been demonstrated through extensive research. A two year experiment conducted at Navsari, Gujarat, has shown that about
50 % of irrigation water can be saved by adopting alternate furrow method of irrigation along with the use of plastic material in cotton. At different locations, the increase in sorghum yield was possible by 8% with 28% saving in water. Similarly, in sugar cane, based on soil moisture depletion, it has been observed that instead of irrigating sugarcane in all the furrows without mulch, if the crop is irrigated by alternate furrow with plastic mulch, there was about 55% saving in irrigation water.

The mulching film should meet the properties criteria as indicated in the BIS Standard, 15:2508-1984.

4. Water Lifting

Tube Wells : In tube wells, the PVC casing pipes are most suitable. HDPE pipes arc also used for submergible pump systems. The plastic well screens are resistant to corrosion and having enough structural strength, they prevent excessive movement of sand into the well and offer minimum resistance of flow.

Plastic components in pump installation: The various components such as plastic foot valves, fittings, suction and delivery pipes/hoses are widely used in the installation of pumps since they are lighter and more convenient than any other alternatives available.

Wind mills: The fibre reinforced plastic rotor for water pumping wind mills has inherent advantages viz. reduced starting torque, reduced weight, greater efficiency since water can be pumped at low wind speed, negligible maintenance due to lower friction & wear on moving mechanical components, freedom from corrosion & longer life.

5. Water Conveyance & Distribution

Plastic film lined canals : The loss of irrigation water in the canal system occurs during its conveyance in the canal, distributory, minor, watercourse & field channel. Lining of distributors and channels with LLDPE/LDPE not only accretes seepage losses but also lessens weed growth and soil erosion. Canal lining with plastics keeps water clean and, at the same time, it is economical as compared to other lining materials. The applicable testing standards for lining material based on polyethylene is the same as that of mulching films i.e IS: 2508-1984.

Conveyance of irrigation water: Loss of irrigation water from trenches are about 20-22%. This can be avoided by means of plastic piping.

PVC water stops: Metal water stops made of copper, bronze, aluminum are allowing lower elongation and thus are prone to damage. PVC water stops allow more expansion and are available in longer lengths promoting better water retaining properties of hydraulic structures.

6. Water Replication (Drip I Sprinkler irrigation)

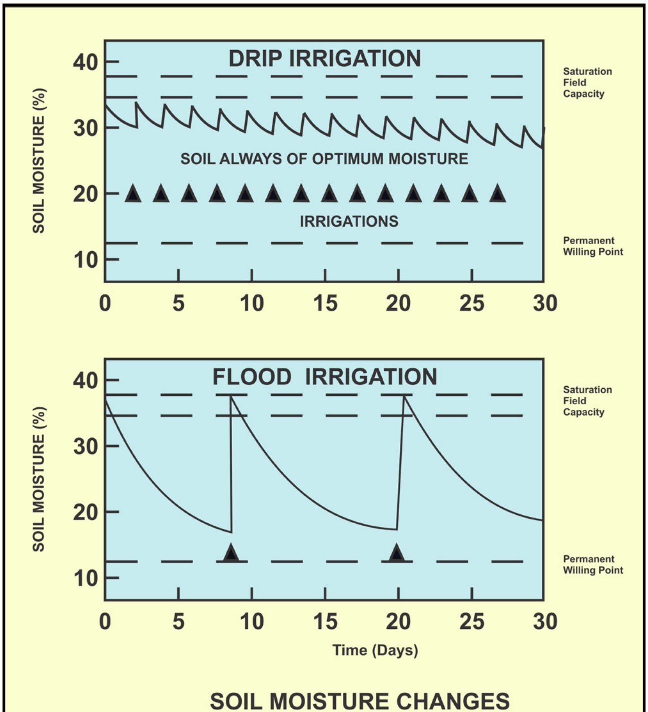
The principle of drip irrigation or trickle irrigation is based on supplying filter water directly

into or onto the soil. This involves keeping the soil in the vicinity of the root zone at or just below field capacity. Water is carried through an extensive pipe network to each plant. The outlet device that emits the water into the soil is called an emitter. The lateral lines are generally 12 mm to 32 mm in diameter and made up of LDPE or LLDPE hose. The emitters are the heart of the trickle system form, in which water drips at constant low discharge at atmospheric pressure. It may be either a dripper, or a micro tube or a nozzle or any other type of commercially manufactured outlet. These are made up of LDPE or PP. Sprinkler irrigation is the other technique widely used for tea estates and other hill stations where plastic sprinklers arc used in the main line and the sub line of HDPE pipes, having diameters of 125 mm, 110 mm, 90 mm, 75 mm and 50 mm. The testing specifications for ensuring quality are revealed in BIS standard, IS: 4984-
1995 and IS:14151-1999.

The traditional Flood irrigation or ridges and furrow method of irrigating farms suffer from numerous problems such as

- Poor discharge causing salinity
- Considerable seepage, conveyance and evaporation losses
- Higher energy costs
- Faster soil erosion
- Greater wastage of fertilizers and other nutrients
- Higher weed population
- Increased operational difficulties and costs
- Uncontrolled, unmeasured and uneven water supply
- Supply driven rather than crop-demand driven causing mismatch between the need of the crop and the quantity supplied

All the above factors either result in higher incidence of diseases and pests or increased cost of cultivation, which ultimately lowers the production substantially. The soil moisture changes in drip and flood irrigation system are shown in the adjoining figure. A comparative study of the micro irrigation system & the conventional irrigation system is given in the subsequent tables.



Soil Moisture Changes in Drip Irrigation & Flood Irrigation

Comparison of yield per Ha and water used in mm under flood and drip system

Crops	Yield MT/ Ha Traditional method (flood)	Drip system	Increase in yield	Water used (mm) Traditional method (flood)	Drip system	% of water saving
Fruit crops						
Banana	57.50	87.50	52	1760	970	45
Grapes	26.40	32.50	23	0532	278	48
Citrus	100.00	150.00	50	1660	640	61
Vegetables						
Tomato	32.00	48.00	50	0300	184	39
Brinjal	28.00	32.00	14	0090	042	53
Chili	04.20	06.10	44	0100	042	62
Cash Crops						
Sugarcane	128.00	170.00	33	2150	940	56
Cotton	2.30	2.90	27	0090	042	53

Water use and yield for various crops in drip and conventional irrigation methods

Sl. No.	Crops	Yield (Q/ha) Conven-tional	Drip Irrigation	Increase yield in %	Water supplied (cm) Conven-tional	Drip Irrigation	Increase yield in %
1	Banana	575.00	875.00	52	176.00	97.00	45
2	Grapes	264.00	325.00	23	53.20	27.00	48
3	Mosambi (lOOOnos.)	100.00	150.00	50	166.00	64.00	61
4	Pomegranate (lOOOnos.)	55.00	109.00	98	144.00	78.50	45
5	Sugarcane	1280.00	1700.00	33	215.00	94.00	56
6	Tomato	320.00	480.00	50	30.00	18.40	39
7	Cotton	23.00	29.50	27	89.53	42.00	53
8	Ladies finger	152.61	177.24	16	53.68	32.44	40
9	Brinjal	280.00	320.00	14	90.00	42.00	53
10	Water melon	240.00	450.00	88	33.00	21.00	36
11	Bittergourd	153.34	214.71	39	24.50	11.55	53
12	Ridgegourd	171.30	200.60	17	42.00	17.20	59
13	Cabbage	195.00	200.00	02	66.00	26.67	60
14	Papaya	134.00	234.00	75	228.00	73.30	68
15	Radish	70.45	71.86	02	46.41	10.01	77
16	Beet root	45.71	48.87	07	88.71	17.73	79
17	Chillies	42.33	60.00	44	109.71	41.77	62
18	Sweet potato	42.44	50.00	39	63.14	25.20	68

Cost benefits, payback period of micro-irrigation for various Crops

Crops	Spacing of Crops (mtrs)	Cost of the system (Rs/ha)	Water used (lpd/plant)	Yield (T/ha)	Pay back period	BC ratio
Banana	0.91x1.5x1.8 Pair row	47500	15-20	75	1 year	3.00
Grape	3.03x4.3	44000	15-20	45	<1 year	3.28
Pomegranate	4.3x4.3	30000	50-60	25	<1 year	5.16
Ber	4.5x4.5	30000	60	25	1 year	4.56
Tomato	0.45x0.45x1.65 Pair row	30000	40000 (lpd/ha)	75	6 months	1.09
Papaya	1.81x1.81	40000	15	60	1 year	4.09
Cotton	0.9x1.5x1.8 Pair row	47500	8-10	1.5	1.5 year	1.83
Sugarcane	0.83x0.83x1.66 Pair row	47500	30000 (lpd/ha)	200	1 year	3.45

Cost estimate of micro-irrigation system for different crops (Drip system)

SI.No	Crop Type	Spacing (mxm)	Cost/ hectare (Rs.)
1.	Mango	9.0x9.0	16,360.00
2.	Tall coconut/Oil palm/ Litchi	7.5x7.5	18,300.00
3.	Lemon/Orange/Guava/Cashew	6.0x6.0	24,062.00
4.	Pomegranate/Bcr/Dwartcoconut	5.0x5.0	25,925.00
5.	Dwart banana	2.0x2.0	37,747.00
6.	Banana/Papaya	2.5x2.5	31,127.00
7.	Hybrid tomato/Brinjal/Chilli	1.0x1.0	46.838.00
8.	Betelvine	1.0x0.75	2,48,144.00
	Mini sprinkler	**---**	**50,000.00**

7. Plastics As An Aid To Improve Cultural Practices Of Crops.

Plastic Film - Green House

A green house is an agriculture structure designed or rearing delicate plants protected from unfavorable weather conditions. It protects plants from storm, frost and cold waves. It also helps in raising early and out of season crops by providing controlled light and heat inside it. It provides control over evapotranspiration, loss of moisture, diurnal temperature fluctuation, a large carbon dioxide (CO,) enrichment possibilities over infestation. The green houses are made up of UV stabilized polyethylene films of 125-200 micron thickness and quality checks are carried out in accordance with the IS specifications, i.e IS: 2058-1984.

Millions of yards of plastic sheeting are used to cover greenhouses. Stretched over a light framework, the plastic film is far less expensive than glass greenhouses with their costly glass and glazing (it may also take more fossil fuels to produce that glass than the plastic).

A big advantage is that if the plastic greenhouse is hit by a hailstorm, the farmer can simply stretch a new roll of plastic over the frames. With a glass greenhouse, a storm means a huge reinvestment in rebuilding and reglazing.

Greenhouses grow many of our fruits and vegetables, both for growing them to harvest in cold weather and for starting seedlings early to fill gaps in the produce market Thus, they play an essential role in supplying good nutrition the year round.

Greenhouses are especially important in cold climates and dry ones. China, again, is a major user. Chinas internal transportation system is still underdeveloped, and most of its population centers have had to grow most of their own food. Chinese consumers have to get their produce from their local region, simply because they cannot have fruits and vegetables brought in from another climate zone.

In the Middle East, the latest greenhouse technologies are using seawater to help grow indoor crops. Forced air is blown through a mist of seawater and then into the greenhouse. The air picks up moisture but not salt. Some of the best designs get 90 per cent of their crop moisture from salt water

Economic feasibility of raising seedlings and producing vegetables in low cost greenhouses has become very common in India since timely availability of vegetables flowers and seedlings is a major problem due to adverse weather conditions during rainy reasons. A plastic greenhouse with 200 micron thick U.V stabilised Polyethylene film has been found effective for raising seedlings and early cultivation of crops like cabbage, cauliflower, etc.

Reference:
Economic Feasibility of Raising Seedlings and producing vegetables in a low cost plastic Greenhouse: K.N. Tiwari, Ajai Singh, P.K. Mai, Plasticulture Development Centre, Agricultural Food Engineering Department, Indian Institute of Technology, Kharagpur, (W.D.) India

Greenhouses have proved to be the most effective agents or drying of fruits like grapes thereby saving a lot of energy. Conversion of grapes into raisins has been made fast and effective with greenhouses.

Reference:
Prof. O.P. Singhal, Department of Agriculture Engineering, Indian Agricultural Research Institute, Pusa, New Delhi.

Plastic Tunnels: Seedlings can be grown easily inside the plastic low tunnels and can be protected from rain and storm during rainy season. The seedling inside the tunnel can be ready for transplantation 3-4 days earlier than that developed under atmospheric conditions. Covering materials for the tunnels are generally UV stabilized LDPE films.

Cloches: Like green houses and tunnels, bell shaped polyethylene domes and portable polyethylene shelves called cloches are also popular or raising crops under adverse weather conditions.

Polyethylene films used for Greenhouse cover

Plastic row covers: It is the only substitute to low tunnels and is extensively adopted for crops like cucumber and tomato under the drip irrigation system.

Plastic frames: On plastic frames, small U and V shaped closed structures may be made to preserve delicate nursery beds and for easy folding and dismantling.

Mist chamber: It is similar to a green house with the provision of the misting system. In this case, water is pumped through a filter from the storage tank to lateral pipes provided along the length of the green house at a certain height. The mist sprayers are filled so as to provide complete mist inside. The misting is generally created for high relative humidity with internal cooling inside the green house. It is useful for plant propagation particularly in hot dry weather conditions.

8. Plantation / Nursery Bags

Plants have been observed to grow better in polyethylene film nursery bags than in traditional clay pots because of better conservation of water. These are cheap, light in weight, easy to transport and non-fragile. LLDPE film is used as a soil container or rearing of young plants at the seedling or nursery stage. In such cases, black and transparent bags are used.

9. Seed Bed Cover

Watering the seedbeds is a common problem in agriculture. If a polyethylene film is laid over a seedbed which has been sown and watered in a normal way, no watering will be required until germination. Once the plants come up, a raised plastic cover can be provided. The plastic cover provides protection not only against frost and other natural hazards, which are common at high altitudes and cold regions, but also beat from bird attacks. In certain countries, while polyethylene is used or shading young plants like tobacco; white sheet transmits 40-60 percent of light. Clear PE film can be used to accelerate growth of grass.

10. Soil Sterilization

LLDPE film can be used to fumigate soil to keep infestation and weeds under control. A thin film is tightly spread over the prepared soil and methyl bromide or any other similar fumigant in proper doses is injected between the film and soil. It should not be disturbed or 5-6 days.

11. Plastics in Air Layering and Grafting

Air layering (Gootee) is a process of vegetative propagation where the bark is removed from a twig just below a potential node tied with some rooting media around the lesion and wrapped by a polyethylene for facilitating root initiation from the nodal end after which the rooted twig is transferred to a pot. Such pots are now a days replaced by an airtight sleeve of polyethylene film of 40-100 micron thickness. Grafting is a method of uniting two plants out of which the supporting one is termed as rootstock and the mother (desired) plant is called the scion. In this case also, the aforesaid polyethylene wrapping is done around the joint to establish the two in one.

References:

1. *S. Raman, R.G. Patel, Effect of Plastic mulch on economizing irrigation water in various field crops. Water Management project, Gujrat Agriculture University, Navsari, Gujarat, Proceeding XI International Conferences on use of Plastics in Agriculture, 26"' February - 2 March 1990, New Delhi.*
2. *Dr. Sushil K. Verma, R.K. Dwivedi, S.K. Jain, Role of Plastics in Enhancing Agricultural Productivity, Central Institute of Plastics Engineering & Technology, Chennai, Proceeding All India Seminar on "Advanced Technology for Optimum Agricultural Productivity" September 14, 2002.*

12. Improvement in Ground Nut Crop Through Mulching

In the post rainy reason, low temperature (<19° C) at the time of sowing affects germination. This problem can be overcome by use of a polyethylene mulch film (5-7 micron) which increases soil temperature by 5-6"C. This results in quicker germination (5-6 days after seeding) as compared to non-mulch control. This mulch technology is very useful in low temperature post-rainy season areas particularly rice fallow/river bed residual moisture situations to achieve high yields.

Reference:
All India Co-ordinated Research project, on Ground Nut - M.S. Basil, Director, National Research Centre for Ground Nut, Junagadh - 362 001 - Gujarat

Improvement in Crops Through Mulching

Another major use of sheeting is for soil fumigation. Intensively farmed fields can build up high population of destructive soil organisms like nematodes. Crop rotation is not very effective against nematodes, because they can lie dormant in the soil or up to 20 years waiting for the right crop to be planted and emit the correct feeding signal. To combat the nematodes and other subsoil pests, farmers sometimes have to fumigate the soils. Plastic sheeting seals in the soil fumigant, giving the soil pests a toxic dose while decreasing chemical usage.

Plastic for Irrigation

One of the most water - efficient irrigation systems is drip irrigation. It uses permanently installed plastic tubes to feed water directly to the roots of orchard trees and other high-value plants. A modified drip irrigation system can be easily rigged by laying plastic tubing on the ground with holes at the appropriate places where the plants or trees are growing.

A newer irrigation system, with even higher water efficiency is called dual-level irrigation. Developed at Iowa State University, it is the closest thing to a close irrigation system that can be achieved outside a greenhouse. A combination of drip irrigation and mulch film has shown outstanding results in terms of higher yield in agriculture and horticulture.

Reference:
Influence of Drip Irrigation on Yield of Cabbage (Brassica Oleracea L. Var. Capilala) under Mulch and Non Mulch conditions - K.N. Tiwari, P.K. Mai, Ajai Singh; Plasticulture Development Centre, Agricultural Food Engineering Department, Indian Institute of Technology, Kharagpur - (W.B.) India

Polyethylene Drip Laterals used for Irrigation and Higher Yield

Novel Applications of Drag Reducing Polymers in Agriculture

Drag Reducing polymers reduce the drag in turbulent flow while increasing the drag in a laminar flow due to an increase in the shear viscosity. This feature of drag reducing polymers has been utilized in reducing the energy requirement of sprinkler irrigation systems where the flow is in the turbulent region in distribution pipes, risers and ejected water jets. Their use also increase the water throughout and the area of coverage of the sprinkler irrigation system. The water containing drag-reducing polymers percolates slowly in the soil, thus reducing the loss of water through percolation. Utilising this aspect, a slow release urea has been developed by blending urea with minute quantity of guar gum[1] which has yielded net gain in crop yield of wheat and paddy by 20 - 25% with positive residual effects in the latest field trials at IIT Kharagpur.

A number of studies have been conducted to probe the effect of drag reducing polymer in reducing the energy requirement in sprinkler irrigation system. It has been demonstrated that the polyacrylamide reduces the drag upto 22-28% at 80 ppm concentration and there is no adverse effect on plants and soils. Due to economic considerations, the use of polymer has been restricted to peak power consumption during the maximum growth period.

The major loss of water in the soil of the lateritic belt is due to percolation. Hence, a reduction in percolation would be very beneficial for agriculture. The drag reducing polymers increase the viscosity of the water in laminar flow, thus, slowing down the laminar flow. When the polymer added water percolates through the soil, its movement is restricted by frictional forces of crystalline ice on the surface of the soil particle as well as by the increase in its elongational viscosity in porous media flow.

An extensive programme of applications of drag reducing polymers in these aspects of agriculture was initiated at IIT Kharagpur almost two decades earlier by Prof. R.P.Singh and Prof. Jaswant Singh (Ex-head Agricultural Engineering Department, IIT, Kharagpur). In the past three years, most of the ticklish problems have been solved and an integrated, useable technology has been developed. The following is the gist of the same.

The use of drag reducing polymers in sprinkler irrigation set up has been studied and various system and material parameters have been optimised. It has been observed that the presence of bends in the sprinkler irrigation set up and flow though Centrifugal pumps has had adverse effects on the efficacy of drag reducing polymers both, in reduction of energy requirement and enhancement of area of coverage. A new injection system for polymer solution in outlet has been designed and fabricated by Prof. F. Durst of LSTM, University of Erlangen-Nuremberg, Germany which increases the area of coverage by 2.5% in comparison with inlet injection in case of lOO ppm purified guar gum. The reduction of energy requirement is 255% in an identical situation by using purified guar gum. A series of very efficient polyacrylamide grafted polysaccharides have been developed as drag reducers. It has been observed that polyacrylamide grafted amylopectin at one third of concentration of purified guar gum (100 ppm) provides reduction in energy requirement more than 240% in comparison with guar gum[3]. Cost benefit analysis shows that with the use of drag reducing polymers in sprinkler irrigation, it requires a reduction in pipe diameter and power of centrifugal pump which reduces the installation costs besides reduction in energy input. The drag reducing polymers reduce the percolation losses which further cuts down the total requirement of irrigation water[4.]

Use of Plastics in Conservation of Water Resource

Water resources in India are limited and experience has shown that their development and maintenance is also very expensive. In view of the ever growing need for food and fibre, full efficient and economic utilisation as well as conservation of available water has assumed great significance.

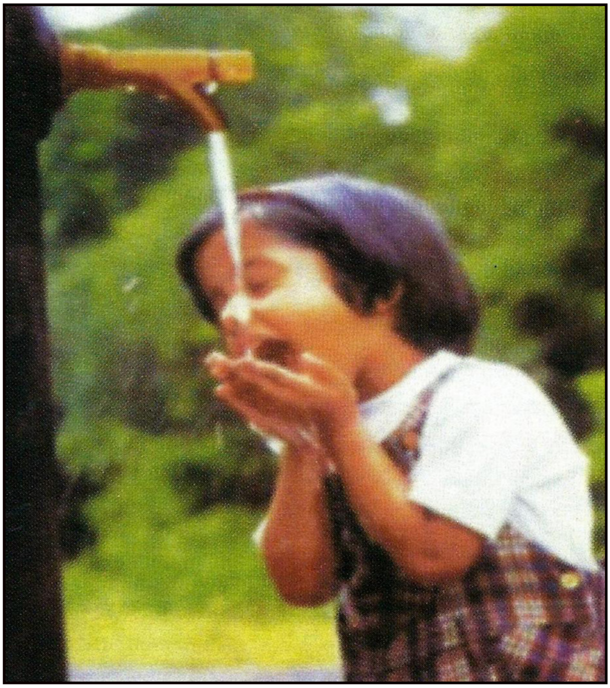
Polymer Based Solutions to Desert Irrigation

Plastics-based subsurface drip irrigation systems during the 1980s have seen water efficiency increase to almost 95 percent from 60 percent, so that now almost no water is lost in the irrigation process. Drip lines are buried 20-25 cm in the soil and emit small amounts of water directly into the plant root area, leaving the soil surface dry and resistant to evaporation. Knock-on effects include 50 percent less energy use due to reduced reliance on deep well turbines and an increase of up to 50 percent in crop yields.

Solution of Water Distribution in the Developing World

There are many communities around the world in which the only form of transport is by foot. This creates real difficulties in effective water distribution in the mountainous regions of Nepal, for example, where communities implement their own sanitation systems and rely on gravity-fed water supply, Plastics are the only sensible solution in such cases.

Plastic Pipes for Water Supply : HDPE, the Versatile Material

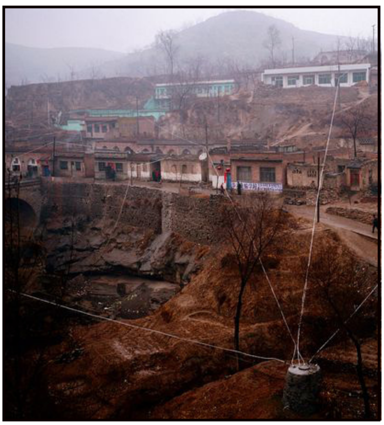


Plastic pipe ensure safe and hygienic potable water

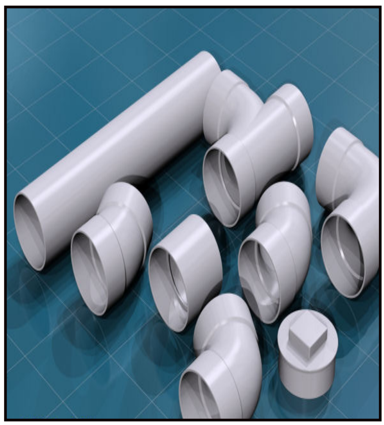
It is widely recognized that there is a crucial and urgent need to use water supply resources more efficiently. Plastics can play a crucial role in this endeavour.

In many countries, the PE pipe is the standard choice for drinking water mains as well as for service mains. The new generation material in the form of PE 8, PE 100 has also made it possible to use thinner pipe walls and reduce the weight and cost per meter of the pipe for both smooth walled and structured wall pipe system. Until the World Bank stepped in to prevent water leakage from corroded metal pipes, the Metro Boards of Chennai and Hyderabad had not even thought of PE pipes.

HDPE transmission mains are economical even up to 630 mm because of their flexibility, smooth inner surface and low modulus of elasticity (low surge pressure). They are, thus, ideal for rural water supply mains. The properties of PE make the pipelines suitable or areas subject to ground movement caused by seismic forces, mining subsidence, and compaction of filled sites or the disturbance caused by the activities of other utilities in the vicinity.



Plastics piping system for water transport



Plastic pipe fitting

Large Diameter PE pipe for potable water transportation

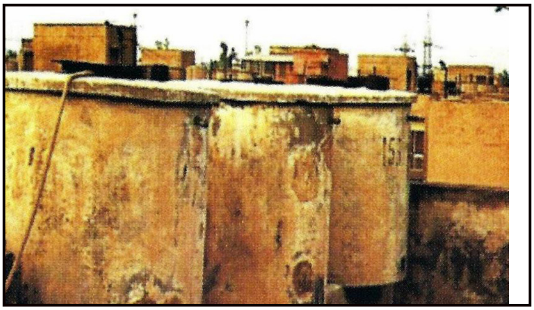
Optimizing water usage - and increasing agricultural output in China

Plastics film is helping Chinese farmers grow high-yield paddy rice on stretches of the Badain Jaran desert between Inner Mongolia and Gansu. The process saves 60%-70% of desert water and increases crop yield by between 1500 kg and 3000 kg per hectare compared with the ordinary farmland practice.

The plastics sheeting are used to line 20 cm deep furrows into which the rice is planted and helps to preserve both water and nutrients. The sheeting can be used for five years and irrigation costs can be cut by between one and two thirds. **The scheme has received a Best Practice Award from the United Nations Development Program on World Desertification and Drought Prevention Day.**

Solution to safe drinking, water storage & conservation

Plastics ensure safe and effective storage of water for household and industrial use. Polyethylene Rotomoulded tanks have replaced traditional concrete / metallic storage tanks thereby helping in conservation of water. This system also has the additional benefit of maintaining the water quality free from bacterial growth over a longer period of time and reducing the spread of water borne diseases like jaundice, typhoid and other gastro-intestinal diseases.



Conventional concrete Tanks- containing water

Plastic roto - moulded Tank- Safe and hygienic

Water Conservation through canal lining

Canals, like arteries of the human physical system, work as carriers of water for the farmers or crop production. A large quantity of water 35-40% is lost through seepage in the irrigation canal system and also causes water logging and salinity In recent years, buried membrane lining in the form of a plastic film for canal lining has been adopted worldwide, and, in India, as well. In India, use of LDPE, LLDPE and HDPE films have been effectively used. WAPCOS study, way back in 1987, has shown that benefits accruing from saving of water from Plastic canal lining have been highly effective in case of agriculture production due to additional water available which would have been lost due to seepage.

Reference:

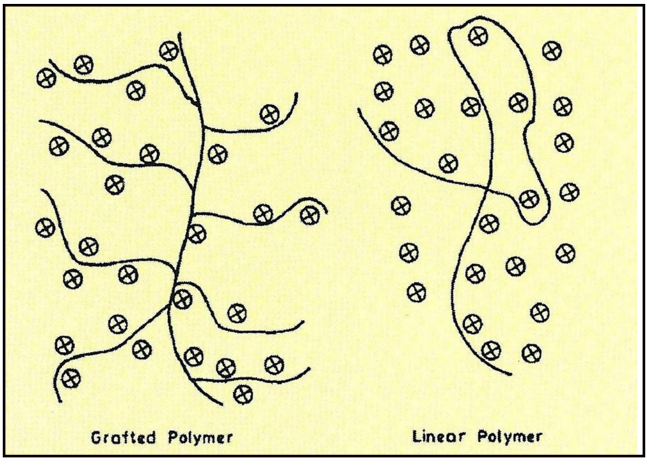
C.V.J. Verma, K.R. Saxena, Central Board of Irrigation and Power, Govt of India, New Delhi in Plastic film canal lining, IX International Conferences in the use of plastics in Agriculture, Feb 26-Mar 2,1990

POLYMERS IN TREATMENT OF INDUSTRIAL EFFLUENTS

Use of polymer helps in conserving water indirectly by use as flocculating materials or effluent treatment.

Polymeric flocculents are extensively used for treatment of industrial effluents and mineral processing mainly because of their characteristic attributes. Polymers are convenient to use and don't effect the pH of the medium. They are used in very small quantity (nearly 1-5 ppm) and the flocs formed during flocculation are bigger and stronger. Anionic, cationic and nonionic synthetic polymers and natural polymers are in vogue. Among the natural polymers, polysaccharides such as guar gum and particularly starch have been used extensively. Polyacrylamide and polyacrylamide based synthetic polymers are very efficient flocculants and are mainly used for treatment of industrial effluents and mineral processing. Polysaccharides are easily biodegradable and hence, it was envisioned that by grafting flexible polyacrylamide chains on polysaccharides such as guar gum, xanthan gum and starch, it is possible to develop efficient shear stable and biodegradable flocculants for the treatment of industrial effluents and mineral processing.

In these flocculents, the flexible chains of polyacrylamide are grafted on the rigid backbone of polysaccharides, hence the approachability of polyacrylamide chains or metallic and nonmetallic contaminants increases significantly. (Fig. below)



Approachability of grafted and liner polymer to be contaminants in an effluent.

Thus, they offer highly efficient flocculating attributes. The graft copolmer having fewer and longer grafted chains are found to be more effective flocculants. Among the grafted guar gum, xanthan gum, carboxy methylcellulose grafted starch is the most efficient flocculent. Amylose and amylopectin grafted with polyacyrlamide chains has been found to have best flocculation efficiency, giving credence to the proposed model.

Scientists at the Indian Institute of Technology in Kharagpur are expecting a big market for a new class of flocculent by grafting synthetic polyacrylamide branches onto the backbone of natural polymers.

Plastics Conserve the most important Natural Resource - Forests & Wood

As per the latest state of forests report of the Forest Survey of India, the actual forest cover of India is 19.27% of the geographic area, corresponding to 63.3 million ha. Only 38 million ha of forests are well stocked (crown density above 40%). This resource has to meet the demand of a population of 950 million people and around 450 million cattle. As such, the country has to meet the needs of 16% of the world's population from 1% of the world forest resources. The same forest also has to cater to the 19% of the world cattle population.

Among the environmental issues, deforestation in India has attracted maximum concern. The forest cover, against the ideal 33.33% despite massive afforestation programs and tight Government regulation on projects, now stands at a paltry 22% of the total land area including degraded forest land with less than 40 % crown density and scrubland. The dense forest cover stands at about 2% only.

Forest : Natural Wealth

Inspite of having big landmass of 329 million hectares, the per capita forestland in India is only 0.09 hectares and is decreasing rapidly against the world average of 1.0 hectares. (Source: Teddy 2000/2001)

The national forest policy (1952 and 1988) stipulates - forest cover should be 33% in plains and 66% in hilly and mountainous areas (Source : Teddy 2000/2001). However, if the present trend continues, the demand for wood will grow resulting in the depletion of forests as shown in the table below:

Demand for wood is expected to grow for all the sectors:

Total projected demand for wood (million cubic meters)

Industry	**1998**	**1999**	**2000**	**2005**	**2010**	**2015**	**2020**
Paper & paper board	4.49	4.48	4.48	8.96	15.4	26.64	35.84
Construction	13.6	14.6	15.9	19.4	22.1	26.3	28.5
Packaging	4.36	4.49	4.62	5.54	6.4	7.55	9
Furniture	2.25	2.38	2.52	3.36	4.62	5.9	7.53
Automobile	0.17	0.18	0.19	0.28	0.41	0.5	0.87
Agricultural implements	2.06	2.12	2.33	2.5	2.5	2.5	20
Others	24.99	26.3	27.68	33.88	43.66	53.67	51.06
Total	51.91	54.55	57.72	73.92	595.09	123.16	152.8

In India, most of the fruits are packed in wooden boxes or efficient handling & distribution. In the State of Himachal Pradesh, Apples are being packed in wooden boxes. Each box is made out of 1.5 Cu. feet of wood and in the last 4 years, around 20 million boxes were used for this application and resulted in the cutting of trees to the tune of 30 million. Cu. feet volume of usable wood. In the face of such great loss & danger to the ecological system, replacement, i.e. PP corrugated crates will result in substantial saving of wood.

However, the Central Govt. had taken some corrective steps & put a restriction on usage of wood in Govt. construction departments such as PWD and issued a circular to use substitute products for wood such as plastic windows, doors, partitions, etc.

Plastic Technology brought in a revolutionary change in the field of basic material & helped to create many substitute products replacing the conventional wooden products, thereby contributing substantially in reducing deforestation. Plastics, as a substitute, are very ecofriendly, light, recyclable, termite free, washable, and help in reducing deforestation.

Replacement of Wooden Crates by Plastic Crates in the Soft Drink Industry in India

With the entry of Coke & Pepsi in the market over the last 10 years, plastic crates have substituted almost 90% of wooden crates in the soft drink industry. Presently Coke and Pepsi consume approx. 6 million crates per annum. This has resulted in substantial saving of wood and consequently the precious forest cover.

Plastic Crates

Wooden Crates

Alternatives to Wooden Furniture

Wood requirement for furniture applications is expected to grow to 345 million cubic meters annually by the end of this decade. When there is a shortage of wood even today, the future requirements will become more and more difficult.

The only viable alternative, thus, left is plastic furniture. Plastics have been coming up as replacement of wood in furniture in a major way in the recent past though a lot remains to be done. Plastics provides major advantages in furniture especially over wood.

1. Mass production, Light weight & Flexibility
2. Built in colours, Less assembly & Reusability
3. Less cost and diminishing price trends, Less maintenance & No corrosion, rust or stain
4. Conservation of forests

Energy usage with plastic material is about 20% lower than with metal. Energy usage is also less compared to wood. Also with anti-flammable additives, polymers can meet strict fire standards. Plastics are durable and have long life. Plastics is also recyclable though there may be consequent degradation of properties. It is said that **6000 MT of plastic furniture saves 140000 cubic meters of wood or 32000 hectares of forest.**

Plastic furniture, durable and aesthetic

PLASTICS & ENERGY CONSERVATION

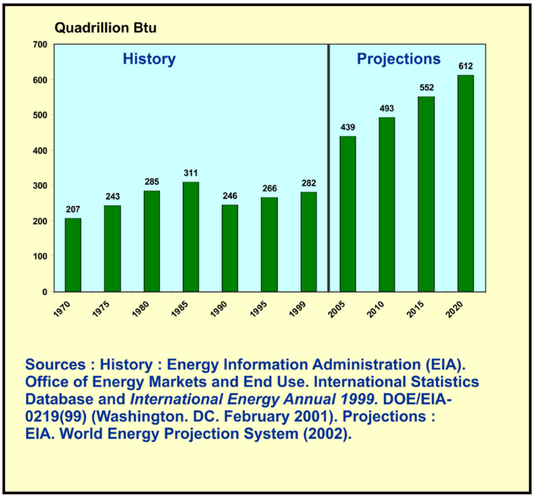
Energy is one of the most fundamental parts of our universe and integral part of our daily lives. Energy is being consumed at every moment by all, albeit, in different forms. We use energy to do work. Energy lights our cities. Energy powers our vehicles, trains, planes and rockets. Energy warms our homes, cooks our food, plays our music, gives us pictures on television. Energy powers machinery in factories and tractors on a farm. Without energy, our society would decay into pre-historic times.

Energy - its sources and the way it is used has been one of the most important parameters of human development. The rate of energy consumption on a per capita basis is considered as a measure of economic development. Today, the ready availability of plentiful & affordable energy allows people to enjoy comfort, mobility and productivity. Energy consumption in the developing countries has been on the rise as a result of life-style changes made possible by rising disposable incomes and higher population growth rates.

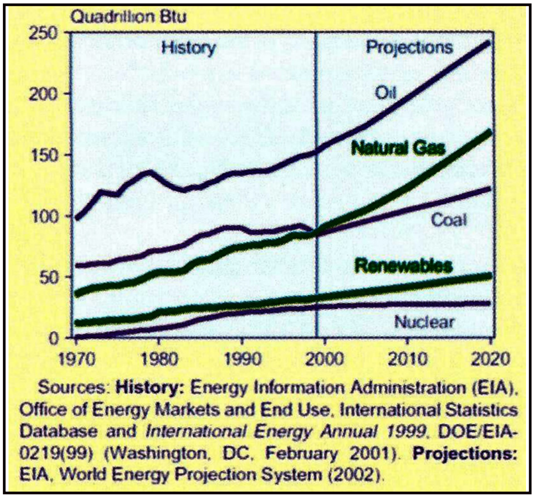
Much of our energy requirements are based on fossil fuels like coal, oil & natural gas constituting

nearly 80% of the total fuel mix of global commercial energy consumption. It is seen that energy consumption in the world has been doubling every 30 years. Over the next 2 decades, total world energy usage is projected to grow to about 612 quadrillion Btu. (Source: EIA, World Energy Projection System, 2002).

Oil is expected to remain the dominant energy fuel in the coming years, maintaining a 40% share of total energy use by 2020. This is mainly because fossil fuel prices would remain relatively low and the cost of generating energy from non-fossil fuel sources like water, wind, solar, nuclear, hydrogen, biomass, etc. will not be competitive.



World Energy Consumption 1970 - 2020



World Energy Consumption by Fuel Type 1970 - 2020

However we all know that fossil fuels are a finite source of energy. Various studies indicate that these resources could last another 50-100 years. There, is thus, a need to work towards "Energy Security" - availability of energy at all times, in various forms, in sufficient quantities and at affordable prices. Energy produced and used in ways that support human development over the long term, in all its social, economic, and environmental dimensions, is what is meant in this report by the term sustainable energy. We need to look at the production and use of energy resources in ways that promote long-term human well-being and ecological balance. More efficient use, especially at the point of end-use, is one of the main options for using energy in ways that support sustainable development and address environmental concerns.

Environmental Issues - Greenhouse Effect

The other major challenge facing today's society related to energy is the Greenhouse Effect. It is the rise in temperature of the Earth's surface due to the trapping of sun's energy within the atmosphere on account of increased presence of gases like carbon dioxide, nitrous oxide, methane and water vapour. Without these gases, heat would escape back into space and the Earth's average temperature would be about 60°F lower.

The greenhouse effect is important. Without the greenhouse effect, the Earth would not be warm enough for humans to live. But when the greenhouse effect becomes stronger, it could make the Earth warmer than usual. A warmer Earth may lead to changes in rainfall patterns, a rise in sea level, and a wide range of impacts on plants, wildlife, and humans. When scientists talk about the issue of climate change, their concern is about global warming caused by human activities.

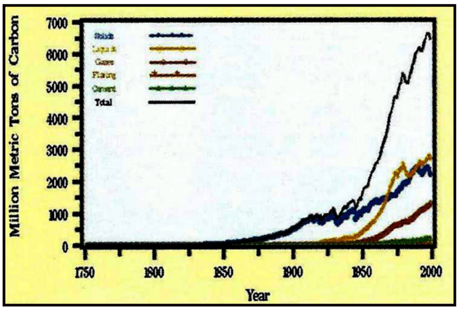
According to recent studies, the Earth's surface temperature has risen by about 1°F in the past century, with accelerated warming during the past two decades. There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities.

Human activities have altered the chemical composition of the atmosphere through the build-up of greenhouse gases - primarily carbon dioxide, methane, and nitrous oxide.

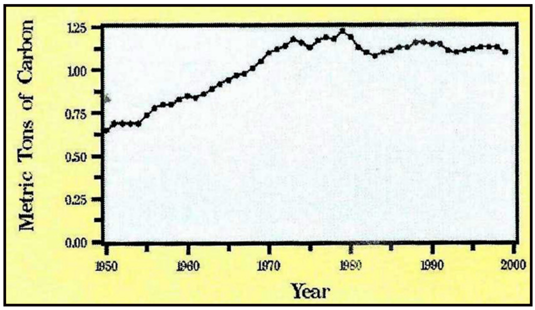
Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. These increases have enhanced the heat-trapping capability of the earth's atmosphere.

Fossil fuels burned to run cars and trucks, heat homes and businesses, and power factories are responsible or about 98% of carbon dioxide emissions, 24% of methane emissions, and 18% of nitrous oxide emissions in the U.S. Increased agriculture, deforestation, landfills, industrial production, and mining also contribute a significant share to emissions.

Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Scientists expect that the average global surface temperature could rise 1-4.5°F (0.6-2.5°C) in the next fifty years, and 2.2- 10°F (1.4-5.8°C) in the next century, with significant regional variation. Evaporation will increase as the climate warms, which will increase average global precipitation. Soil moisture is likely to decline in many regions, and intense rainstorms are likely to become more frequent. Sea level is also likely to rise by two feet along most of the coastlines.



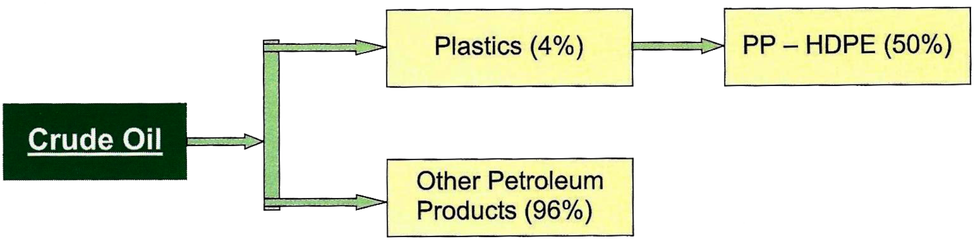
Global CO_2 emissions from fossil fuel burning, Cement production, and gas flaring for 1751-1999



Global per capita CO_2 emissions estimates

Plastics Help in Energy Conservation & Reducing Greenhouse Emissions

It is estimated that about 4 % of the total energy consumption is used to produce plastic raw materials, including feedstocks.



This is quite a small percentage in comparison to energy's other uses. However it is estimated that the use of plastics as a whole actually saves more oil than needed for their manufacture. Products made from plastics, including packaging, reduce our use of these resources (i.e. oil & gas) in the major consuming areas like energy & transport in many ways e.g. food production is energy intensive, but minimizing food loss by packaging in plastics is preventing wastage of energy. In addition, it often takes less energy to convert plastics from a raw material into a finished product than comparable products. For instance:

- During their life cycle, plastic bags require about one-third less energy to make than paper bags.

- Foam polystyrene containers take 30 percent less total energy to make than paperboard containers.

- 53 billion units of electricity are saved annually by improvements in appliance energy efficiency made possible by plastic applications. Without the benefits provided by plastics insulation, these appliances would use up to 30 percent more energy. ("Resource and **Environmental Profile Analysis of Polyethylene Milk Bottles and Polyethylene-Coated Paperboard Milk Cartons,"** Franklin Associates, Ltd., 1990.)

- Studies show that the use of plastics in buildings can increase energy efficiency wherever insulation is done for air conditioning.

- Plastic woven sacks consume — % less energy for packaging of bulk commodities when compared to Jute / paper bags for same applications

- Plastic pouches consume one-tenth the energy for packaging and delivering milk compared to glass bottles

- PVC pipes are much more energy efficient in terms of manufacture and usage over GI / CI pipes in water supply systems

Plastics due to their unique properties of being light-weight, durable and malleable they have enabled manufacturers and users to conserve energy in the production of various products like disposable cups, packaging films, automobiles, etc.

Plastics have been helping in the more efficient use of energy in applications in buildings, electric appliances, vehicles, and production processes. From production, trough use and by waste management, plastics help conserve energy resources.

Without plastics, the energy used to produce packaging would double. A 1992 study found that by using plastic packaging rather than alternatives such as glass, paper or metal, American manufacturers saved 336 trillion Btu. This is a difference equivalent to 58 million barrels of oil, 325 billion cubic feet of natural gas or 32 billion pounds of coal. **("Packaging Without Plastics: Ecological and Economic Consequences from a Packaging Material Market Without Plastics,"** The Society for Research into the Packaging Market (Germany, 1992)

Energy required by different packaging materials

Product & Input	Total Energy (MJ)
1 kg Pulp from Cut Timber	28.59
1 kg Base Paper from Standing Paper	83.91
1 kg. Coated Paper from Standing Timber	99.95
1 kg of PET bottles from PET Resin	13.20
1 kg of PE Bottles from PE	11.00
1 kg of Glass Bottles from Glass	18.50
1 kg of Three Piece Tin Can from Tin	62.00

Source: ENERGY & PACKAGING - Boustead & G.F. Hancock, Ellis Harwood Press

Plastics are the material of choice because they make it possible to balance modern day needs of higher efficiency with minimal use of fossil fuel resources - making it possible to use less but do more

Lighter & stronger plastics use less space, requiring fewer vehicles to transport it to the supermarkets and **reducing energy consumption.** Plastic Shopping bags as compared to alternate packaging materials like paper bags weigh about 1/10th. A stack of 1,000 paper bags is 1.5 ft high and weighs 63 kgs while that of plastic bags is only 0.14 ft tall and weighs 7 kgs. There are significant savings in weight and volume reductions and resultant transportation efficiencies of about 85%.

The increasing use of plastics in the automotive sector also means vehicles are benefiting from their light -weight directly — and this leads to fuel savings. It is estimated that 100 kgs of plastics have replaced 200-300 kgs of conventional materials in the typical car — resulting in a 750-litre fuel consumption saving over a life span of 150,000 km. This translates into 12 million tons of oil saved annually across Europe whereas only about 3.25 million tons of oil is required every year to produce the plastics used in this sector.

The consequent effect on emissions from lighter vehicles and lighter goods for transportation — thanks to plastics — is clear. It has been estimated, for example, that the fuel saving vehicles as cited above due to use of lightweight plastics in cars lead to a very significant reduction of CO_2 emissions in Europe.

The natural consequence of reduced material consumption and lighter thinner plastics now than ever before is that proportionality less waste is generated. Use of liquid detergent refill pouches have reduced material use by 70 %. It has been calculated that the volume of packaging waste would increase by 158%* if plastics did not exist (*Gesellschaft fuer Verpackungsmarktforschung, 1991).

Car manufacturers have introduced a plastics air intake manifold reducing weight by 30-60 per cent and creating a production cost saving of 30 per cent. There is also an improvement in performance, especially when the engine is still cold.

CASE STUDIES IN ENERGY CONSERVATION

Energy Consumption

One of the methods to derive the energy consumption of Plastics vis-a-vis the traditional materials like glass, pipe, steel & jute is through life "cycle analysis". The energy requirement at different stages of production and distribution and waste management of Plastics and other materials can be measured. Life cycle analysis is hence an effective tool to measure the impact of a product or process on the environment. A few case studies can suffice to quantify the energy consumption from manufacture of resin, conversion and fabrication of plastic products, transportation and end usage (to cover entire life cycle, cradle to grave) and comparison vis-a-vis other materials like paper, glass, metal, jute and wood, etc.

Case Study 1

Plastic Pouch vis-a-vis Glass bottles for Milk Packaging: - IIT Delhi Study

A study carried out for producing packing with PE products for one lakh litre of milk.

The Total Impact Assessment

The study discloses that for producing packaging with Plastic Pouches for one lakh litre of milk, the raw material required is only 0.40 Mt But for the same quantity of packaging with Glass Bottles requires 45.4 Mt of Glass. The results of this analysis are organised in two categories: resource utilization and atmospheric emission.

Energy Consumption

This analysis by steps identifies the production of Glass (Table -1) and subsequently manufacture of Bottles (Phase I and Phase II) or energy consumption (~1202 GJ per one lakh litre of packed milk) as compared to Plastic Pouches (~37 GJ per one lakh litre of packed milk). Energy consumption related to transportation (Phase III) of milk shows that transportation in Glass Bottles requires significantly more amount of energy. Energy consumption is about ~ 115 GJ per one lakh litre of packed milk where glass is being used as packaging material, compared to ~ 63 GJ per one lakh litre of packed milk for transportation in plastic pouches.

Life Cycle date for Different Materials used for Packaging One lakh litres of Milk

	Glass		Plastic Pouches	
Material Required (Mt)	45.4		0.40	
	Energy*	**Water***	**Energy***	**Water***
Phase I:				
Production of Raw Material	671.92	1608	32.22	25.6
Phase II:				
Production of Bottles/ Pouches	530.27		4.56	
Total	1202.19	1608	36.78	25.6

	Glass		**Plastic Pouches**	
Phase III: Filling and Distribution	**Fuel***	**Energy* Single (Return)**	**Fuel***	**Energy* Single (Return)**
	2049	114.75(213.43)	1120	62.73(106.64)

Phase IV: Waste Management Recycling Percent	**Glass Energy Consumption***	**Plastic Pouches Energy Consumption***
100%	501.67	4.56
80%	401.34	3.65
60%	301.00	2.74
50%	250.83	2.28

Reuse (Including Transportation)	**Energy Consumption**	**Water Consumption**	**Energy Consumption**	**Water Consumption**
95%	277.8	509.1	143.4	25.6
80%	457.5	675.4	(New Plastic	(New Plastic
60%	697.0	897.2	Pouches)	Pouches)
Incineration	Energy Recovered		Energy Recovered	
100%	Not applicable		20.73	
80%			15.58	

**Units Energy (GJ), Water (Thousand Litres), Fuel (Lilies)*

Another major resource utilisation is being demonstrated in terms of consumption of water. The manufacture of Glass Bottles is found to be responsible for the overall greatest consumption of water :~ 1608 (thousand litre / lakh litre of packed milk) in case of Glass bottle production. This is about 63 times higher than that for Plastic Pouches for the same amount of packed milk.

Re-use of Glass Bottles has also been considered as one of the options to reduce waste. It has been found that even for 95% re-use of glass bottles, the energy consumption is double than that consumed in making new plastic pouches. Further the water consumption in case of 95% reuse of glass bottles is 20 times of that used in new plastic pouches. More importantly, attention is also given to two end-of-life cases i.e., 100% incineration (waste to energy, energy recovery) and/or 100%-50% recycling (energy usage). According to this phase, energy recovery due to incineration is about 15.8 MJ/kg for Plastic Pouches, while there is no incineration or waste Glass. It should also be noted that in case of recycling of plastics, the waste enters into a new life and if this waste management technique is considered, the life cycle analysis of plastics/ glass bottles can be termed as "Cradle to Cradle" approach instead of "Cradle to Grave".

Case Study - 11

Plastic bag vs Jute Bag for "Atta" Packaging - IIT Delhi Study

The study discloses that for producing packaging with Plastic Film Bags for one lakh tons of "Atta", the raw material required is only 680 MT. But or the same quantity of packaging with Jute Bags, requires 1960 Mt of material. The results of this analysis are organised in two categories: resource utilisation and atmospheric emission.

Energy Consumption

The analysis by steps identifies the production of Jute and subsequent manufacture of Bags (Phase 1 and Phase II) as being responsible or the higher consumption of energy (-68.69 thousand GJ per one lakh metric ton of packed "Atta") as compared to Plastic Film Bags (-62.58 GJ per one lakh metric ton of packed "Atta"). Energy consumption related to transportation (Phase III) of "Atta" shows that transportation in Jute bags requires significantly excess amount of energy, being about -261 GJ per one lakh metric ton of packed "Atta", compared to that in Plastic Film Bags.

Life Cycle data for Different Materials used for Packaging One lakh ton of "Atta".

	Jute Bags		**Plastic Film Bag**	
Material Required (Kgs)	1960			680
	Energy* ('000 GJ)	**Water* ('000 GJ)**	**Energy* ('000 GJ)**	**Water* ('000 Tons)**
Phase 1:				
Production of Raw material	21.50	1677	38.36	264
Phase II:				
Production of Bags & Liners	47.19	1506	24.22	296
Total	68.69	3183	62.58	560
Phase III:	**Jute Bags**		**Plastic Film Bag**	
Distribution	**Fuel (Tons)**	**Energy (GJ)**	**Fuel Energy**	
	4663	261.29	Taken as Basis	

Phase IV: Waste Management	Jute	Plastic Film Bags
Recycling Percent	Energy Savings*	Energy Savings (thousand (GJ/680 ton)
100%	Not Applicable	17.20
80%		13.76
Incineration	Energy Recovered	Energy Recovered (thousand GJ/680 ton)
100%	Not Applicable	35.24
80%		28.12

**Units Energy (Gj), Water (Thousand Tons), Fuel (Tons)*

Atmospheric Emission: About ten components dominate the category of atmospheric emission for Jute Bags and Plastic Film Bags: Co, C02, SOx, NOx, CH v HCI, dust, heavy metals, suspended solids and chlorides. For all of these, the plastic pouch produces less emission than the Jute bag. Tables II and III list atmospheric emissions.

Another major resource utilisation is being demonstrated in terms of consumption of water. The manufacture of Jute Bags is found to be responsible for the greatest consumption of water overall; ~ 1608 (thousand ton/lakh ton of packed "Atta") ii case of Jute Bags production. This is about 63 times higher than that for Plastic Film Bags for same amount of packed "Atta".

Reuse of Jute Bags has also been considered as one of the option to reduce waste. It has been found that even for 95% reuse of Jute Bags the energy consumption is double than that consumed in making new Plastic Film Bags. Also the water consumption in case of 95% reuse of Jute Bags is 20 times of that used in new Plastic Film Bags, More importantly attention is also given to two end-of-life cases, i.e. 100% incineration (waste to energy, energy recovery) and/or 100% recycling (energy usage). According to this phase energy recovery due to incineration is about 15.8 MJ/kg for Plastic Film Bags, while there is no incineration for waste Jute. It should also be noted that in case of recycling of plastics the waste enters into a new life and if this waste management technique is considered the life cycle analysis of plastics/Jute bags can be termed as "Cradle to Cradle" approach instead of "Cradle to Grave".

Case Study - III

PP / HDPE Woven Sacks vis-a-vis Jute Bags and Paper Sacks: IIT Delhi

The study discloses that or producing packaging with PP-HDPE woven sacks for one million tonne of bulk commodities, the new material required is only 2310 tonne. But the same quantity of packaging with jute and paper requires 12290 tonne of jute and 7200 tonne of paper. This is almost six times more consumption of raw material in case of jute and three times in case of paper compared to PP-DHPE.

Resource Consumption and Recovery

The present analysis identifies the production of jute and paper (Table 1) and subsequently manufacture of sacks (Phase 1 and Phase ll) being responsible for the greatest consumption of energy (around 669.6 thousand GJ/Mt of packed product) in case of paper sacks and 333 thousand GJ/Mt of packed product in case of jute sacks as compared to around 226.8 thousand GJ/Mt of packed product in case of PP-HDPE woven sacks. Energy consumption related to transportation (Phase III) of bulk goods shows that compared to transportation in PP-HDPE woven sacks, jute packaging requires excess energy to the tune of about 2036 GJ/Mt of packed product and paper bags require excess energy of about 928 GJ/Mt of packed product.

Another major resource utilization is demonstrated in terms of consumption of water. Manufacture of jute and paper sacks involves significantly higher consumption of water about 22,000 lakh litre / Mt of packed product in case of jute and sacks production and about 18,000 lakh litre/Mt of packed product in case of paper bag production. This is about ten and seven times higher or jute and paper respectively compared to the water consumption in case of PPHDPE woven sack per Mt. of packed product.

Life cycle data for packaging of one million tonne of bulk commodities

	Jute			**PP HDPE**			**Paper**		
Material Required (tonne)	12290			2310			7200		
	Energy '000 GJ)	**Water ('000 lakh litres)**	**Chemical (tons)**	**Energy ('000 GJ)**	**Water ('000 lakh litres)**	**Chemical (tons)**	**Energy ('000 GJ)**	**Water ('000 lakh litres**	**Chemical (tons)**
Phase I (Production of Raw Material)	153.6	12.0	258.5	178.3	1.4	0.014	612.0	18.0	4647
Phase II (Production of Sacks)	179.4	9.7	Negligible	48.5	1.0	Negligible	57.6	Negligible	Negligible
Total	333.0	21.7	258.5	226.8	2.4	0.014	669.6	18.0	4647

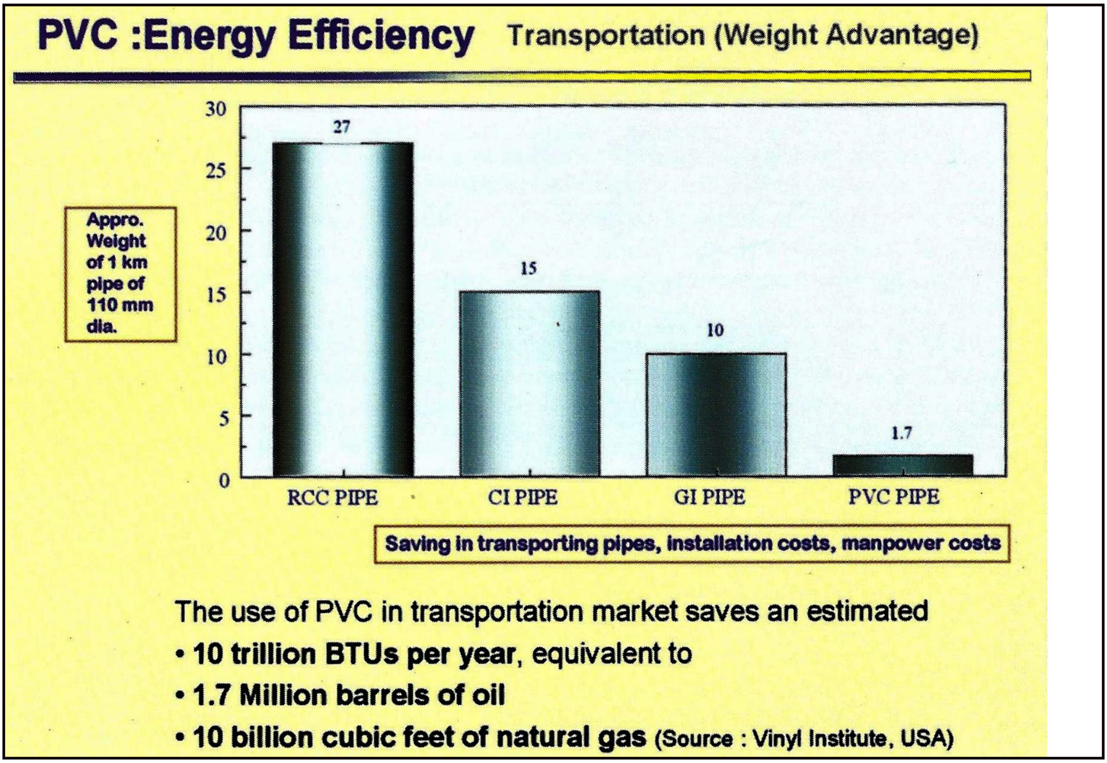
Phase III Usage (Transportation per 100 km distance. 9 tonne truckload and 3.05 km/fuel consumption)	**Jute**		**PP HDPE**		**Paper**	
	Excess Fuel (thousand litters)	Excess Energy (GJ)	Excess Fuel (thousand litters)	Excess Energy (GJ)	Excess Fuel (thousand litters)	Excess Energy (GJ)
	36.3	2035.9	Taken as basis (Zero Consumption)		16.6	927.9

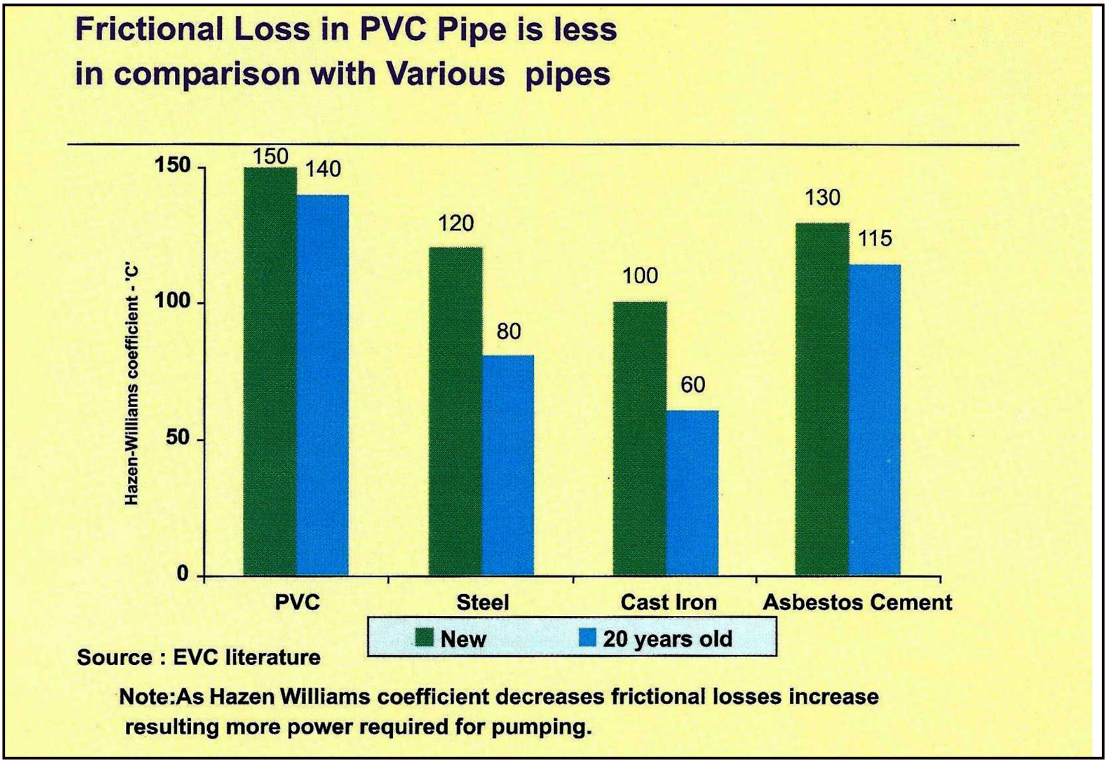
Phase IV Works Management	Jute		PP HDPE		Paper	
	Recycling (Energy saving thousand GJ)	Incineration (Energy recovery thousand GJ)	Recycling (Energy saving thousand GJ)	Incineration (Energy recovery thousand GJ)	Recycling (Energy saving thousand GJ)	Incineration (Energy recovery thousand GJ)
	___	___	46.75	95.31	32.26	169.11

Case Study - V

PVC Plastic Pipes & Energy Conservation

PVC pipes have replaced traditional materials like GI, Cl, Cement, etc. to a great extent. These can be fabricated at low temperatures as compared to other materials and hence require very low energy as compared to Steel pipes. Being light in weight, they save transportation energy as well. Similarly, with lower coefficient of friction, water transport through these pipes is smoother saving pumping energy. PVC pipes also do not develop scales, maintaining pipe diameter integrity and ensuring proper water flow.





Conservation of Energy & Material through PET Packing of Beverages

The advantages of PET containers to be include :

- Superior packaging to product ratio. PET container being 63% and 47% more energy efficient than glass bottles and aluminium cans respectively.
- PET bottles are 32% more energy efficient than glass bottles during delivery of 1000 gallons of soft drinks.
- Glass bottles and Al-cans generate 230% and 175% times more atmospheric emissions compared in PET.
- PET bottles contribute 68% and 18% less solid waste by weight compared to glass and Aluminium containers.
- 100 kg of oil is required to produce 1000 1-litre PET bottles as against 230 kg for 1000 equivalent glass bottles.
- PET bottles help in fuel saving due to their lower weight.

Currently more than 90% of PET is consumed in food packaging with beverages / drinks forming nearly 8%.

Reference:

K.R. Kumar, Head Food Packaging Technology, CFTR1 (Mysore), Packaging India, Dec 2000 - Jan 2001

Preserving other Valuable Resources

Plastics play a vital role in preserving and distributing essential food and water economically and reliably to a growing world population.

- Over 1 billion people lack routine access to water supplies and around 35 per cent of all developing world deaths are due to contaminated water. Around 3 billion people have no basic sanitation services. In many areas of the world where water is scarce, conservation and irrigation systems help retain water and distribute it- either for domestic or industrial use or for growing crops. Plastics are a favoured choice in many of these applications due to their cost effectiveness, ease of transportation and assembly and durability.

- Plastics-based agricultural systems provide effective solutions to crops growing in many areas of the world, which demand special growing conditions for food cops.

- Food wastage in Europe is kept low (two per cent) - due in part to plastics packaging (which accounts for 60 per cent of all food packaging). It is estimated that food wastage in the developing world - where plastics packaging and refrigeration are much less wide-spread - stands at 50 per cent. Not only does this lead to food shortages, but also to further wastage of the energy used to produce food in the first place.

- Some 42 per cent of plastics consumption in Europe is used for packaging. Food packaging is a significant part of that total and while preserving food, plastics prevent wastage both of the food itself and the energy used to create it in the first place. In fact, energy balance studies of the food energy chain show that using plastics for food packaging can lead to energy savings which total well over twice the energy needed to produce, fill and transport the packaging in the first place. Because of their ability to pack more using less, the energy efficiency of plastics packaging is unrivalled compared to other materials.

- Plastics help in non conventional resources

Solar Energy - Plastics : Contribution to a Clean, Alternative Energy Source

Tapping the sun for energy (photovoltaic energy) is bringing clean and efficient energy to around 2 million people worldwide who do not have access to national transmission systems. Photovoltaic cells, which help convert the sun's energy to usable domestic power, are made from plastics. Some examples include:

- The Philippines, where a scheme is underway to bring electricity to 400 people on two islands.
- A project to install solar power in remote villages in the Algerian Sahara
  Ethiopia - where solar energy is providing a reliable power source for medical refrigerators
- and lighting kits in remote areas.

The production of polycrystalline cells for solar power has in itself become a thriving industry sector, leading to significant employment opportunities.

Alternative, renewable energy sources such as solar and wind power, are an important contributor to preserving fossil fuel reserves. Plastics are integral to the design of environmental technologies such as these - for example, wind turbines, solar panels - and in this way, they also help extend the life of our fossil fuel reserves. In India department of Non Conventional Energy (DNES) is taking and active role and plastic find a relevant role.

HDPE pipes has been effectively used for transportation of Bio-gas. Plastics have been used as holders for Gobar gas because of the inherent properties of light weight and chemical resistance.

Solar Heaters

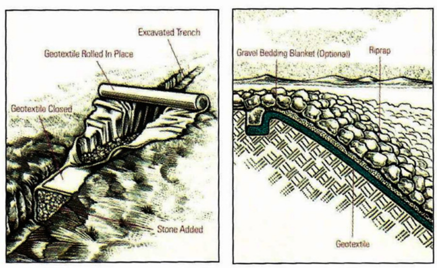
Windmill

Plastic Windmill

Use of Plastics in non-conventional source of energy

Plastics in conservation of Land resources

Plastic help in conservation of land resources by helping in prevention of soil erosion by reinforcement with geotextiles. Similarly use of plates is extended to canal lining, river embentement, flood prevention thereby helping conservation of land.



Plastics help in soil Conservation (Erosion control)

Conservation of Materials through use of Plastics

Plastics as packaging material are weight efficient thereby conserving materials

Conservation of Material Jute vs PWS'

Packaging Commodity (50 kg)	Wt. Of Jute Bag (gm)	Wt. Of PWS (gm)
Sugar	630	125/155
Fertilizer	560	130
Food Grain	665	135
Cement	530	70

As per BIS standard - IS 14887:2000, IS 14968:2001

Plastics vs Paper

- Contrary to the popular belief that traditional materials like Paper & Jute are environmentally friendly, these materials consume more energy for production and use and also release more pollutants during their production. Paper, in particular, which is made from trees also deplete forest cover and consume lot of chemicals during processing resulting in release of toxic & harmful effluents into the environment. (The world produces over 300 Million Tonnes of paper every year using more than 14 million hectares of forest cover).

Consider the case of paper vs plastics'. When deciding which product is more environmentally friendly, the environmental consequences of all the steps of its manufacture, use, disposal and eventual degradation must be considered and the results are surprising. Several studies of comparative life histories have shown that the use of paper may be more polluting than the use of plastics.

Paper is made of pulp, a renewable resource and a plastics such as Styrofoam is made from nonrenewable fossils fuels. But the manufacturing of a paper container consumes as much fossil fuel as goes in making a Styrofoam one, so the raw material tolls of making a paper box includes all the hydrocarbon cost of ma king a plastics clamshell plus whatever forest degradation is caused by timber harvesting. Clear cutting and other unsound logging practices greatly increase their toll by increasing erosion and fouling streams. The manufacturing process uses other resources, too. One study estimates that manufacturing a Styrofoam clamp shell uses 30 percent less energy, generates 46 percent less air pollution and 42 percent less water pollution. Paper products that have been treated to repel grease have very low recycling value as the coating agents interfere with recycling process. Plastics can easily be recycled into new products or use as a fuel that burns cleaner than coal and oil, thus recovering the fossil fuel value of petroleum in the plastics. Chlorofluorocarbons (CFCs), that harm the ozone layer, had been discarded many years ago. **So, paper or plastics?** Making the correct decisions requires a comparative analysis of environmental impacts of the life histories of the alternative products.

Plastics, during its production, not only consume less energy but are also less polluting.

Traditional Packaging Materials - Paper as Pollutant

Product	Sp. Energy Consumption	Unit (Kwh)
Paper processing	Ton/Ton of Paper	1600
Plastic Processing	Ton /Ton of Polymer	400

Paper Industry - Contribution to Pollution.

- Particulate : 4%
- Sulphur : 15%
- Nitrogen : 11%
- Surface water : 10%

Source : TERI report 2001

PLASTICS Vs JUTE

Use of jute for packaging of commodities require more material compared to plastics as shown in the table. Similarly, jute contributes to water and air pollution (during cultivation and processing) resulting in adverse effects on Biota and Jute processing workers.

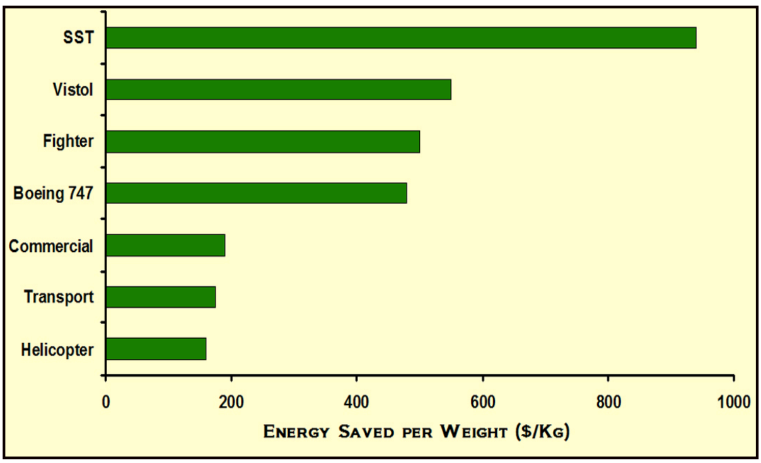
Jute as a Polluting Material

RETTING	**- Water pollution**	**-**	**Microbes**
	- Air Pollution	-	Organic Acids
	- Adverse Effect on Biota (eg. Fish culture)	-	Methane Gas
		-	High water demand
BATCHING	- Use of Batching	-	Contaminated Product
	- Oil (JBO)	-	Odor
BLEACHING	- Use of Chemicals	-	Contaminated Effluents/Water
AIR POLLUTION	- Particulars/Fiber Dust	-	Workers Health (Bisniosis)

Source : IIT Delhi Report on "Packaging of Bulk Commodities - 2000"

PLASTICS Vs METALS/GLASS

Complexities are evident in comparing of polymers with other materials such as metals and glass. Metal smelting affect the atmosphere for hundreds of miles down stream. Similarly, land damage and disposal of tailings from mining and refining operations are serious problems. Moreover, metal refinery and glass making require large amounts of energy. Thus from environmental point of view, comparisons of production processes may lead to a preference for using polymers rather than metal and glass. In additions, products fabricated from polymers often weigh less than those made from competing materials. Energy savings favour plastics for bottles over glass when energy requirements for production, transportation and recycling are considered. Substitution of polymers or polymer based composites for metals in aircraft and in automobiles results in weight reductions that translate to fuel efficiencies over the life of vehicles. In years to come, the advent of high performance polymer based composites, the integral and critical parts in automobiles such as wheels, brakes, springs, differentials and transmission shaft, will be substituted by plastics and composites. For aircrafts, the composite will be used for most of the secondary parts and large portion of primary portions of primary parts such as body and wings. It is expected that the R&D activities world over will be directed to the development of light weight polymeric composites having improved rigidity, toughness and processability[7](see figure below).



Energy Saving by weight reduction of Aircraft

PLASTICS Vs NATURAL MATERIALS

Natural materials are not always better than synthetic materials from an environmental point of view. The comparison of fibre production as instructure[1]. Natural fibre such as cotton and jute make heavy demands on agricultural resources including land use, fertilizers from petroleum and fuel for transportation. Maintenance of clothing made from synthetic fibres requires less hot water. Even though the trade off is complicated, synthetic fibres offer many advantages. Comparisons made on life cycle analysis of PP-HDPE woven sacks vis-a-vis Jute/ Paper sacks in terms of Environmental considerations (study carried out at IIT Delhi) is revealing.

CONSERVATION & PRESERVATION OF NATURAL PRODUCE

PLASTIC in Packaging of Fresh Fruits and Vegetables

40% of polymers in India are being used in packaging, industrial goods, house hold commodities, food and agricultural products. Plastics are the most recently developed materials to be used for packaging and one based on high technology processes. About 10 basic polymers are used but the variation on these and the range of possible combination of two or more makes the number of permutation almost infinitely large. The rigid, semirigid, flexible packaging can be made of processed plastics i.e. Plastics films and laminates of barrier properties. At IIT, Kharagpur, such laminates have been developed and by using them for modified atmosphere packaging of films, it has been shown that life span can be increased 1.5-2.4 times that of the self life in ambient atmosphere.

With the annual production of over 32 million tonnes of fruits (1994-95), India has emerged as the largest producer of fruits in the world (Chadha 1995). However, the estimated post-harvest losses due to improper handling, packaging and storage of fruits go as high as 30%. It amounts to losing about Rs. 30,000 millions annually. Recognizing both, the need to minimize post- harvest losses as well as the high export potential of horticultural produce, the Government of India has laid emphasis on quality and productivity of horticultural crops with a major thrust on the development of packaging and storage technologies. Fresh fruits are considered an integral part of any dietary system, since they are rich sources of minerals, vitamins and dietary fibres. Hence,- fresh fruits always enjoy good market demand. However, fruits, in general, have short shelf-life. They begin to lose their orchard-freshness, shortly after they are plucked from the tree. Mere protection from mechanical damage and microbial infection keeps the fruit in sound condition only for its normal season. It does not increase the major catabolic process, which brings about natural ripening and, subsequently, the deterioration of fruit in its normal course of time. In the process of respiration from the surrounding atmosphere by the fruit, CO_2 evolved by the fruit is given out to the surrounding atmosphere with concurrent release of some energy often as heat. Respiration involves oxidative breaking down of respiratory substrates (viz., carbohydrates, organic acids and other reserves) to CO_2 and water through a series of reactions, where each reaction is catalyzed by a specific enzyme. In this series of oxidation-reduction reactions, molecular O_2 acts as the final electron acceptor and is reduced to water. Hence, restricting the availability of the fruit retards oxidation. Its reduction of the substrates generally results in increased shelf-life of fruits Lowering of fruit temperature also reduces respiration significantly by diminishing enzymatic activities, whereas exposing the fruits to high CO_2 levels inhibits respiration, though, to a small extent. Thus, temperature and composition of storage air, particularly, the concentration levels of O_2 and CO_2 are the major storage factors, which can be manoeuvred to keep the fruit in pristine condition as far beyond its normal season as practical. However, there are critical levels of O_2 and CO_2 concentrations. Modification in storage air composition beyond these critical levels induces physiological and microbial disorders. Devoiding storage atmosphere completely of O_2, induces anaerobic respiration, which produces ethanol. It imparts off-flavour to the fruit, and thus reduces its consumers' acceptability. Likewise, CO_2 levels higher than the critical levels injure the fruit, rendering it unfit for prolonged storage. These critical levels need to be determined specifically, since they vary with the type of fruit, the cultivar and the geographical region.

Fresh fruits retain orchard-freshness longer, when stored in **Modified Atmosphere**, where the recommended levels of O_2 and CO_2 humidity and temperature are maintained. In Controlled Atmosphere (CA) storages, besides temperature, the concentrations of O_2 and CO_2 in storage air are also controlled to maintain the recommended levels. The developments in packaging materials, particularly; the advent of **permselective plastics films** have widened the scope for developing Modified Atmosphere (MA) packaging system for storage of fresh fruits.

In this system, fruits are sealed in retail size permselective plastics film packages called Modified Atmosphere Packages (MAP). In a properly designed MA package, as a result of respiration of the packaged fruit and restricted gas permeation through the packaging film, the composition of package air gets modified automatically. Thus, unlike CA storage, the recommended air composition is self-established in MAP. It obviates all those equipment, which are otherwise required for maintaining recommended air composition. This, apart from reducing storage cost, makes MAP technology applicable to the entire chain of fruit distribution right from orchard to ultimate consumer.

However, for accomplishing self-establishment of recommended air composition in MAP within a stipulated time, optimization of various package parameters as well as tailoring of film laminate are essential. Dynamics of Gaseous Exchange in MAP MA package is considered as a dynamic system, where respiration and gas permeation continue to take place simultaneously. During respiration, packaged fruits take O_2 from package atmosphere and give away CO_2 to the package atmosphere. Due to respiration of the packaged fruit, O_2 starts depleting and , starts accumulating within the package. Consequently, respiration begins to decrease, while O_2 and CO_2 concentration gradients between package atmosphere and the atmosphere surrounding the package, begin to develop. As a result, O_2 starts permeating into the package and CO_2 out of the package. However, the rate of gas permeation depends upon permeability coefficient of the film, its surface area and the gas concentration gradient across the film (Nemphos et al., 1976). In MAP, with the increase in concentration gradient, gas permeation increases and respiration of the package fruit decreases. The increase in gas permeation as well as the decrease in respiration continue till an equilibrium is reached, where O_2 consumption and CO_2 evolution of the packaged fruit become equal to the O_2 ingress and CO_2 egress of the package respectively. The package is then said to be in dynamic equilibrium with the surrounding atmosphere. Once established, the equilibrium gas concentrations remain nearly constant throughout the stipulated period of storage. However, in MAP, it is possible that the dynamic equilibrium may arrive at such levels of O_2 and CO_2 concentrations which are deleterious to the fruit or the equilibrium may not arrive for considerably long periods of time.

Hence, it is important that the MA package be designed properly and that the design facilitates production of package equilibrium conditions as precisely as possible.

For MAP packaging, film laminates based on Linear Low Density Polyethylene (LLDPE) have been developed with the objective of bringing GTR of the laminates as close to the gas transmission requirements of MAP as practical. The attainment of dynamic equilibrium at predetermined conditions is possible, provided the GTR of packaging film match with the gas transmission values required for MAP.

Various aspects of MA packaging of apples, tomatoes and bananas have been investigated in authors' laboratories. In a case study, the required TR value of a packaging film for MA packaging of Red Delicious apples was found to be around 7.The TR values of available films were found to be much lower than 7. In case of [high barrier films [i.e., Saranex -), the 15 (100 μ); Barex (60 μ) ; PET (100 pi)]/ the TR values were found to vary between 2.5 and 4, though, their OTR values were close to the OTR requirement of MAP. In low barrier films [i.e.,;" plasticized PVC (25 and 30μ) ; c" BOPP (30 and 40μ); LDPE (25 μ)], the maximum TR value was found to be around, 5 while their OTR values were much higher than the required ones. The laminates of low and high barrier films were also found to have GTC different from those required for MAP. To overcome this problem, a novel method of tailoring the film laminates was developed. In this method, two or more films, preferably, low and high barrier films are combined to form the laminate. Before combining, the effective surface area of one of the two films as well as that of the laminated portion is optimized. The films are then tailored to make their optimal surface areas effective, when combined to form the laminate by adhesive lamination process.

Conclusions and Recommendations

1. The life cycle analysis establishes the supremacy of polymeric materials in comparison with paper, metals glass and natural materials.
2. Generally plastics are produced by environmentally benign synthetic techniques. At no stage of manufacture or processing do they pose any burden on the environment.
3. There is a need for further research and development and awareness that plastics can conserve energy, water and forests resources. It has been exemplified on novel uses of plastics in agriculture.
4. Traditional materials like Glass, Paper, Jute and metals consume higher energy and water than plastics, thereby imparting more burden on the environment.
5. Plastics can be used in increasing the shelf life of fruits and vegetables, thus, reducing the 30% waste of fruits and vegetables caused during the transport and storage in our country. Many such novel applications of plastics can be found pertaining to conservation of resources.
6. Polymers such as polymeric flocculants are capable of purifying the undesirable industrial effluents and recycling such water for irrigation and domestic use.

References

1. R.S. Stein et al, Polymer Science and Engineers: The shifting Research Frontiers, Natural Academy Press Washington, D.C. pp. 22 (1994).
2. N. Yoda, Technology Management and Globalisation in the New Materials Age: Academia and Industry Collaboration in Polymer Research, Prog. Polym. Sci. 19, 974 (1994).

3. K. Udipi and A.M. Zoltor, Polymer and the Environment - The next Decade, J. Polym. Sci. Polym. Symp. 75, 109(1993)
4. A Technical Framework for Life-cycle Assessment, A Workshop Report SET AC Pub! tea lion 1101,14* Street N.W.Suite 1100, Washington,D.C. 20005, January 1991.
5. E.S.Stevens Green Plastics: An Introduction to the New Science of Biodegradable Plastics, Princeton University Press, Princeton and oxford.
6. Samuel I. Stupp et. Al. Interdisciplinary Macromolecular Science and Engineering, NSF Headquarters Arlington, University of Illinois Printing Services (1998).
7. U.Y.Kim, Research and Development Activities on Polymer for the 21st Century In Korea. Macromol. Symp. 98,1261 (1995).
8. W. Rathje and C. Murphy, Rubbish, Harper Collins (1992)
9. J. Leidner, Plastics Waste, Recovery of Economic Value, Marcel and Dekker, New York (1981)
10. A.C. Albertsson and S. Karlsson, Acta Polymer, 46, 114 (1995)
11. Anon, Plastic Maker Recycle for New Growth, R. chemical Week, 28 (Dec. 18-25,1991).
12. E.M. Kirschner, Recycling's Rough Adolescence, C & EN, 19 (Nov. 4,1996).
13. J.M. Henshaw, W. Han and A.D. Owens, Thermoplastic Composite Materials, 9, 4 (1996).
14. Advances in Materials Technology Monitor, 2, Number 4 (1995).
15. Ramani Narayan and J. Snook, The Role of Biodegradable Materials in Solid Waste Management in Waste Management and Recycling International, 1994, M.A. Johnson and Y. Samiullah eds, Sterling Publications Ltd., London, 2 (1993).
16. A.C. Albertsson and S. Karlsson, Controlled Degradation by Artificial and Biological Processes, In Macomolecular Design of Polymeric Materials, K. Hatada, T. Kitayama and O. Vogi Marcel Dekker in New York, pp. 793 (1997)
1 7. Advances in Materials Technology: Monitor, Advanced Polymers for Environment, Issue No. 34 (Dec. 1993).
18. T. Hayashi, Prog. Polym. Sci. 19, 663 (1994).
19. 1-1. Roper and H. Koch, Starch/Starke, 42,123 (1990).
20. A.C. Albertsson and S. Karlsson, Acta Polymer, 14, 114 (1995).
21. CL. Swanson, R.L. Shogren, C.F. Fanta and S.M. Iman, J. Envir. Polym. Deg. 1,155 (1993).
22. G.M. Chapman, Stale of Technology and Applications of Degradable Products, In Polymer From Agriculture Coproducts, ACS, p.29 (1994).
23. H. Verhoogt, B.A. Ramsay and B.D. Favis, Polymer 35, 5155 (1-44).
24. A.K. Mohanty, M. Mishra, G. Hinrichson," Bio-degradable Polymers & Bio composites: An overview, Macroniol.Mater. Eng., 276-277: 1 (2000).
25. Ramani Narayan, "Eco-efficient, Sustainable Biodegradable Plastics and Worldwide Standards" Proceedings Annual General Meeting of SBAOI and BEDPSI and National Conference on Tissues Replacement Materials & Devices and Biodegradable Polymers & Composites for the Millennium ahead, Dec. 6-8, 2000.IIT Kharagpur, India

Chapter 8

Recycling of Plastics and Integrated Waste Management

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RECYCLING OF PLASTICS AND INTEGRATED WASTE MANAGEMENT

The significant increase in plastic consumption has effected a similar growth in the plastic industry. Today, plastic is an industry - greater than steel and aluminum combined. The annual growth rate of the petrochemical industry is about 12 -15% compared to the general growth rate of industry, which is about 6-8%,

India's per capita consumption of plastics is of the order of 4 kg, against the world average of 18 kgs. The consumption of plastics is expected to grow at a healthy rate of 15 percent per annum compounded during this decade and is expected to reach a per capita consumption level of 8.5 kg by 2010 A.D. The Indian plastic industry, which has investments of the order of US $ 1.7 billion, is poised to become a US $ 5 billion industry in terms of investment in the next few years.

The Indian plastic processing industry is characterized by a predominance of units in the small scale sector. There are about 20,000 primary processing units, converting more than four million tonnes per annum of raw materials. With the present volume of about 4 million tonne of Plastics, and likely to grow to more than 12 million by 2010, there is definitely going to be generation of some waste. Effective management of this waste is both a challenge and an opportunity.

Today, resource conservation is one of the burning issues related to the survival of Life on Earth. Being mostly non-biodegradable, plastics have always been the punching bag for environmentalists. Plastic is a material that can be a boon to mankind depending on how wisely it is used and re-used. There is no doubt that plastics' versatility allows it to be used in almost everything which help make life easier and better.

Plastic has unique characteristics. Its durability, formability and light weight enable usage of less raw material and energy throughout the product's life cycle from its development to its use, reuse and disposal. Thus, plastic materials help to conserve more resources when compared to other materials.

Plastics can play a significant role in energy conservation. Taking an example from everyday needs itself, grocery bags made of plastic require less total energy to produce than paper bags. They also conserve fuel in shipping. To give you figures - It takes five trucks to carry the same number of paper bags as fits in one truckload of plastic bags.

Comparison of Physical and Chemical Characteristics of Waste (in % of total weight)

	India *	Developed Countries
Paper **	3.0-7.0	20-50
Plastics **	0.5-0.9	1-3.0
Metals **	0.4-1.0	4-14.0
Glass **	0.3-0.8	3-10.0
Ash and Fine Earth **	30-50	3-10.0
Total Compostable Matter **	30-50	10-20.0
Moisture Content **	20-30	15-30
Organic Matter ***	20-30	15-30

* Mean value of data from 33 Indian cities, ** On wet weight basis, *** on dry weight basis
Source : *Research Report on Informal Economy of Solid Waste Disposal, Kolkatta*

Plastic Waste and the Indian Dimension

Item	World	India
Per capita consumption	18 kg	4 kg
Recycling (Machine, Industrial & Consumer waste)	15-20%	60%
Plastics in solid state	7%	0.5-2%

From at the above table it is found that India is amongst the lowest in generation of waste. India is amongst the lowest per capita consumption of plastics also and, consequently, the plastic waste generation is very low as can be seen in the following table.

The above tables show that India has a very low presence of plastics in solid waste. However, the recycling of plastics is amongst the highest in the world.

Waste Management

Waste management practices were initially developed for proper disposal or collection of solid wastes to avoid the adverse effects on public health. In dealing with waste, there are two fundamental requirements: generating less waste and an effective system for managing the waste produced.

Integrated waste management (IWM)

Aim of an Integrated Waste Management (IWM) system is to manage all the waste in an environmentally and economically sustainable way. It is a viable option in-lieu of traditional methods of landfill. IWM includes value addition to the waste, energy produced from the waste, variable rate charging to consumers, public education and shared responsibility. The participants are producers, consumers and local government. The results include increased recycling and energy recovery.

There are generally four different techniques involved for effective waste management

- **Reduce** : **Source reduction**
- **Reuse** : **Multiple use of products**
- **Recycle** : **Mechanical recycling**
- **Recover** : **Feedstock & Energy**

1. Reduce: source reduction

The first and perhaps best way of handling any kind of waste is to not create it in the first place or, in other words, to minimize waste by reducing it at the source. Plastic film, due, in part, to its high strength to weight ratio, has contributed significantly to waste minimization/source reduction efforts.

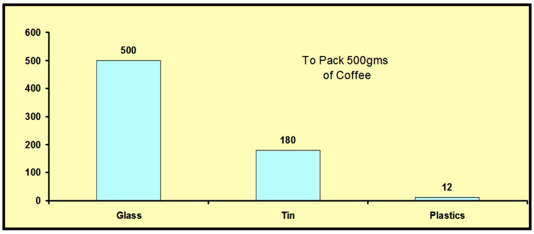
There are several other ways, however, that film has helped to reduce waste. One way is through the process known as thin-walling or down-gauging, where the walls of a package are made thinner while retaining the same performance characteristics. Using this technique, plastic grocery sacks are now 70 percent thinner than they used to be. In 1976, the average sack was 2.3 mil thick, but by 1989 it was only 0.7 mils thick. That means that today it takes substantially less plastic to make the same number of plastic grocery sacks, which is one example of waste minimization/source reduction.

The improved properties of film have also resulted in waste minimization. For example, the gas barrier properties of plastic films, like those used to protect some meats at the supermarket, have been improved to such an extent that product manufacturers now can use 25 percent less film without any loss in protection.

Source reduction in plastic packaging

Plastics Packaging	Original Weight / Thickness	Current Weight / Thickness	% Reduction
PET soda bottle (2 L)	68 gms	51 gms	25
HDPE drum (200 L)	20 - 22 kgs (MS drum)	8.5-9.2 kgs	58
Yogurt cup	12 gms	5 gms	58
1.5 lit. bottle	66 gms	42 gms	36

Another way in which waste minimization/source reduction has been achieved is by substituting other materials with plastic films or containers. Plastic film, when used in combination with other materials, also can result in waste minimization. For example, coffee used to be packaged strictly in steel cans but now is also packaged in plastic/aluminum laminate brick packs. Using equivalents to make the point, it would require 17 pounds of steel to hold 65 pounds of coffee, whereas it would require only 3 pounds of plastic/aluminum laminate to hold the same amount of coffee (which equates to a significant reduction in the amount of packaging needed to deliver the product and hence, the amount created and thrown away). And, even though the 17 pounds of steel can be recycled, it would have to be recycled at an 83 percent rate before the steel would be as resource efficient as the plastic/aluminum brick pack (Source: The Procter & Gamble Company, USA). In 1995, steel was only being recycled at a rate of about 65 percent.

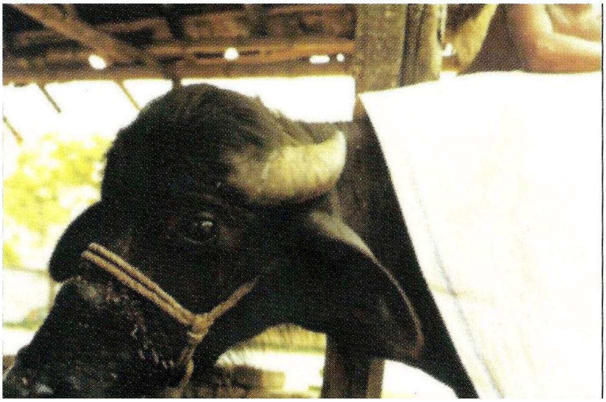


While waste minimization is a good thing in itself, it also has many other environmental benefits. For example, downgauged or thin walled products can reduce transportation costs by lightening the package and allowing more units to be loaded per truck for shipping; both of these things, in turn, help reduce the number of shipments necessary to deliver a product to market, resulting in lower fuel usage and less stress on roads. Source reduction, because it creates less waste in the first place, also reduces the need to manage waste at the end of the stream through such mechanisms as recycling or landfilling. And, if a product's functionality or lifespan in increased by using film, it helps reduce the need to make replacement shipments and may extend the time it takes for a product and/or package to reach the disposal stage. Thus, the use of plastic film not only reduces the amount of waste created, it also helps conserve natural resources and reduces our reliance on other waste management options.

2. Reuse: Multiple use of products

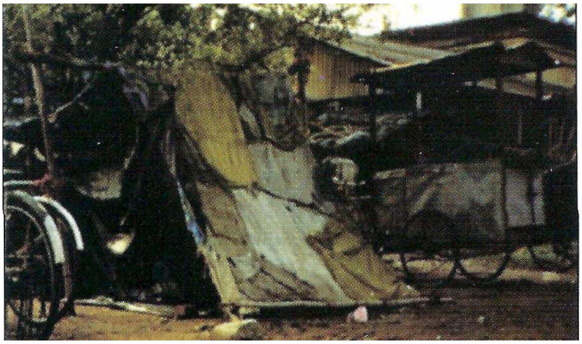
By multiple usage of particular plastic container/films/bags, one can reduce the scope for new plastics products. The following table has shown the additional usage of plastic products.

Indians are known for their ingenerity and tendency to reuse much of the plastics products used in day to day life and the pictures below show some of the many ways plastic woven sacks are reused in the country. No wonder, plastics recycling rates in India are amongst the highest in the world. This has significantly helped to reduce the impact of plastics on the environment.

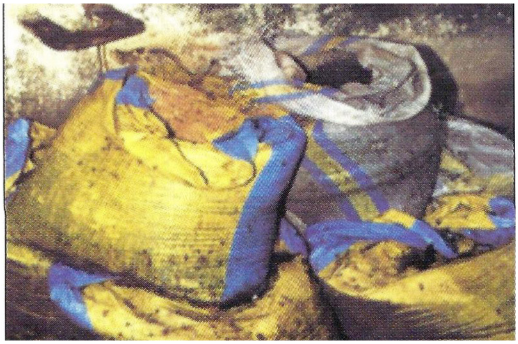


Animal covers

Carry bags



Covers of Jhuggis



Reused as sacks

Re-use of Plastics

Plastic Articles	Primary Use	Reuse (secondary use)
Blow moulded containers	• Edible oil packaging • Lube oil packaging • Chemical packaging	• Water storage / conveyance • Kerosene storage/conveyance
Blow moulded bottles	• Mineral water packaging • Soft drink packaging	• Cooling water in fridge • Water storage & conveyance
Woven sacks	• Cement packaging • Fertilizer packaging • Polymer packaging • Chemical packaging	• Large bags after stitching • Tarpaulin after stitching • Packaging of lime, marble chips • Hutment covers • Packaging of reprocessed plastic granules
Jars	• Packaging of creams • Packaging of adhesives	• Storing small miscellaneous items in house holds

3. Recycling: Mechanical Recycling

Recycling extends disposal capacity, saves money in disposal costs, conserves natural resources, creates jobs, and provides a reliable, cost-effective feed stock to industry. Although, at present, recycling is one of the best alternatives for the management of plastic wastes in addition to landfilling, its potential has not been fully tapped. In fact, India is still unaware of the actual benefits of recycling. Unfortunately, in India, waste is littered instead of being disposed, to facilitate collection. This report is a step towards dispelling myths about plastics and spreading awareness about Plastics Recycling.

Recycling of Plastics

World Resources foundation recommends the Mechanical recycling is the best option for the developed world. Plastics being one of the most interesting developments of the last century, recycling helps in creating new raw materials through mechanical feedstock and energy recovery. Besides, this mechanical recycling option for India results in :

- Clean Environment - no emission of gases or effluents
- Employment opportunities
- Business opportunities
- Economical Utility Products
- Low Cost Supply Chain
-

Plastics Recycling Technologies

Plastics recycling technologies are generally placed into four categories.

- Primary
- Secondary
- Tertiary
- Quaternary

Primary—The manufacturing of new plastic products with material and chemical properties equivalent to those of the discarded plastics items. Although much of clean thermoplastic manufacturing waste is recycled in a primary sense, remelted and reformed, primary recycling by these methods is not, at present, a viable economic option for the vast majority of post-consumer plastics or manufacturing wastes that are contaminated. Removing contaminants and separating similar plastic resins has been difficult and costly.

Secondary—The manufacturing of products with material properties inferior to the original products.

Tertiary—Processes that utilize waste plastics by altering a polymer's chemical structure to manufacture monomers, basic chemicals, or fuels.

Tertiary recycling is a range of technological approaches applicable to a wide range of plastic wastes, producing a variety of products that may be substituted for different materials. Tertiary recycling can be divided into three basic categories:

- **Depolymerization processes** that require clean, single-resin plastic wastes and produce monomers or other basic inputs that can be used in the production of new and stainless kind resins.

- **Tertiary processes that are applicable to mixed and contaminated plastics** waste streams and utilize waste plastics as a substitute for crude oil in refinery operations and as substitutes for basic chemicals in refinery recycling and pyrolysis.

- **Dissolution processes** that can be applied to mixed and contaminated waste streams to selectively remove individual resins or classes of resins for further processing and recycling.

With the exception of dissolution, tertiary recycling achieves closed loop recycling. Most of these technologies are in the developmental stage, and, with economic viability, they will substantially advance recycling efforts. Some tertiary technologies allow recovery of nearly pure polymers or their constituents from a waste mixture, and the reaction conditions destroy contaminants, allowing the recovered material to be used in food- packaging applications.

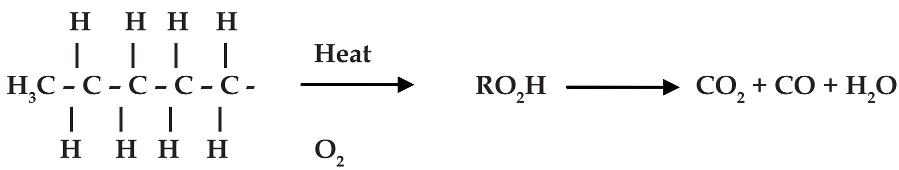
Quaternary—Incineration of plastics with heat recovery, either as part of the municipal waste stream or as a segregated waste.

Thermal Degradation of Plastics during Recycling

During mechanical recycling of plastics, it goes through several heating processes. Different plastics have different behavior to thermal processes. Polymers get degraded in presence of heat. Presence of Oxygen with heat further accelerates the degradation process. But, during recycling, there is neither emission of any toxic gas nor any chemicals are produced. Thermal degradation of some common plastics like, PE, PP, PVC and PS are discussed below.

Polyethylene (PE)

Thermal degradation of Polyethylene produces mainly carbon dioxide and carbon monoxide. In the presence of atmospheric O_2 and heat, Hydroperoxides are produced initially which ultimately generate CO_2 and H_2O.



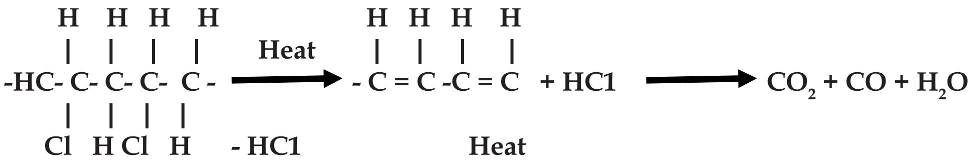
Polypropylene (PP)

Polypropylene is more prone to thermal degradation compared to Polyethylene but the degradation process and the end products are similar to PE. Mainly due to thermal degradation in the presence of O_2, alkyl peroxides and Hydroperoxides are produced which ultimately produce CO_2.

It can be said that by recycling Polyolefin waste, we get the gases like CO_2 CO which are very similar to products of burning of candles.

Polyvinyl Chloride (PVC)

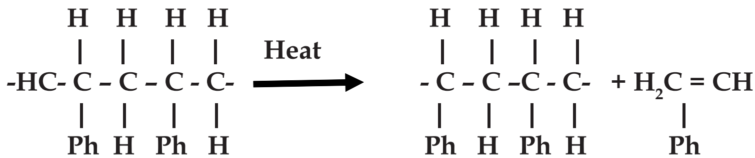
PVC is adequately stabilized to undergo significant thermal degradation during recycling. In the thermal degradation process of PVC during recycling or incineration, mainly Hydrochloric (HC1) gas is evolved which is not toxic. ITC1 elimination occurs in a series of allyl-activated steps (ZIP reaction) finally producing some conjugated Polyenes of various length



There is no evidence of cyclisation during processing or recycling of PVC and no chance of formation of Dioxin or any other chemicals.

Polystyrene (PS)

The thermal degradation of Polystyrene proceeds by a free radical chain mechanism. In the absence of O_2 'mainly disintegration of polymer chains occurs, which lead to oligomer or monomer . But the amount of monomer emission at temp. <300°C is very negligible.



(Ref: Grassie, developments in Polymer Degradation, Vol. 2 p 187 and Vol. 3, pl0l)

Sources of Plastic Waste for Recycling :

Sources of plastic waste can be inhouse, industrial products and/or consumer waste.

Source of plastic waste

Machine Waste	Industrial Waste	Consumer Waste
• Runners	• Barrels	• Milk Pouch
• Flashes	• Crates	• Carry bags
• Defective articles	• Films	• Cups / glasses
• Purging	• Jerry cans	• Buckets / mugs
• Sweepings	• Rotomoulded tanks	• Pens
	• Cement bags	• Mats
	• Tarpaulins	• Luggage
		• TV cabinets
		• Footwear

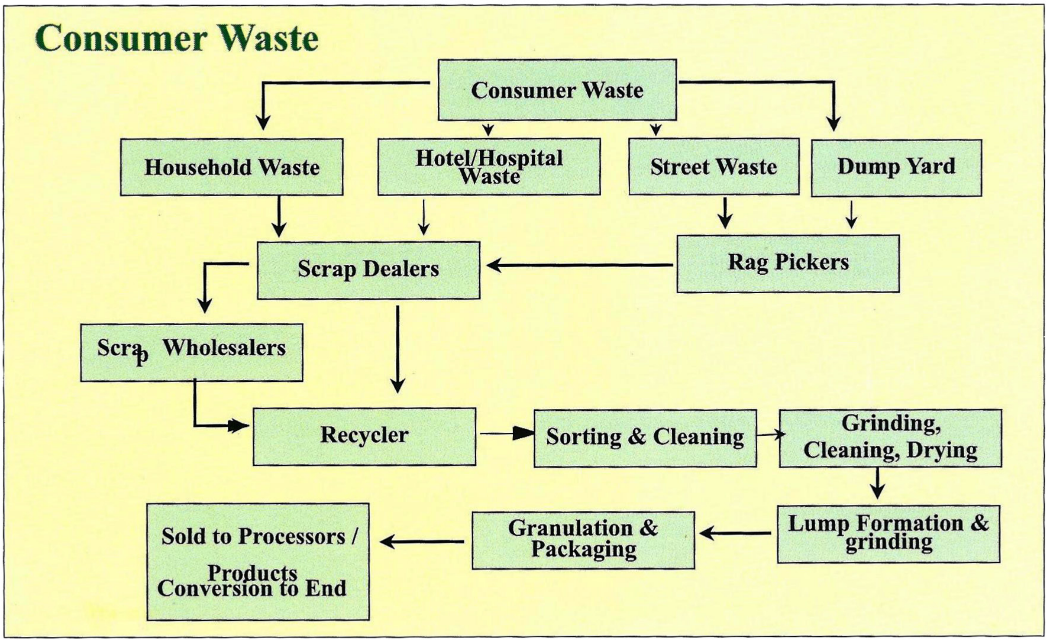
Indian Plastic Recycling Industry

The Indian Recycling Industry has helped in an effective waste disposal problem. Almost 2300 recycling units are spread over the length and breadth of the country involving 3 lakh people (Table).

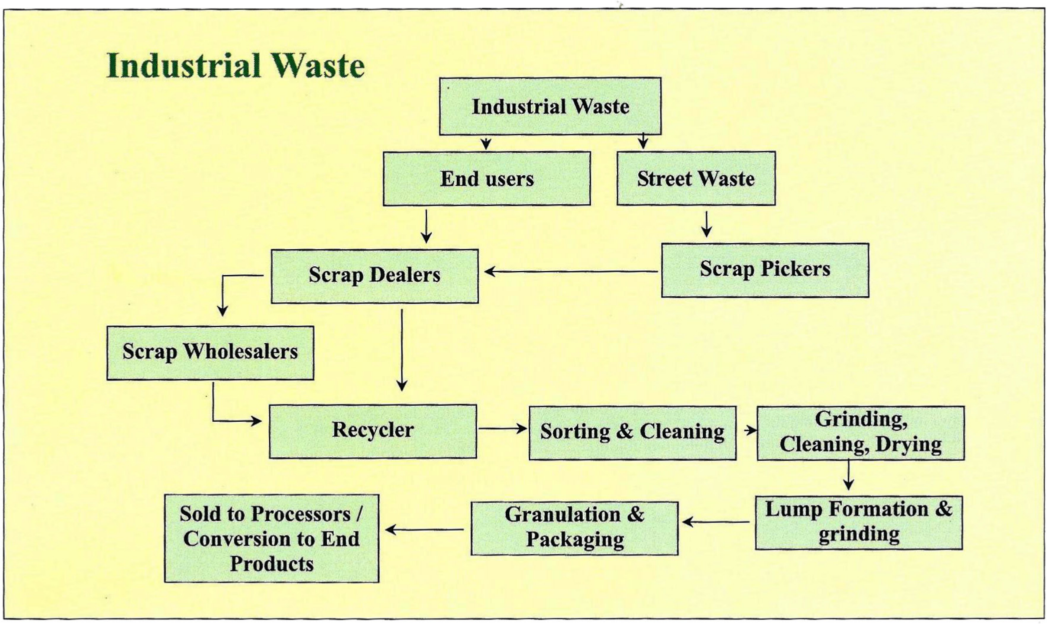
Indian recycling scenario-a overview

Volume Recycled	1.2 MMT
No. of units	2300
Palletizers	3200
Turnover (Rs. Cr)	5000
Value Add (Rs. Cr)	1600
Ragpickers Employed	1.3 lakh
Employment	3.2 lakh

Recycling Centers Spread throughout the country



Flow diagram : Processing of consumer plastic waste



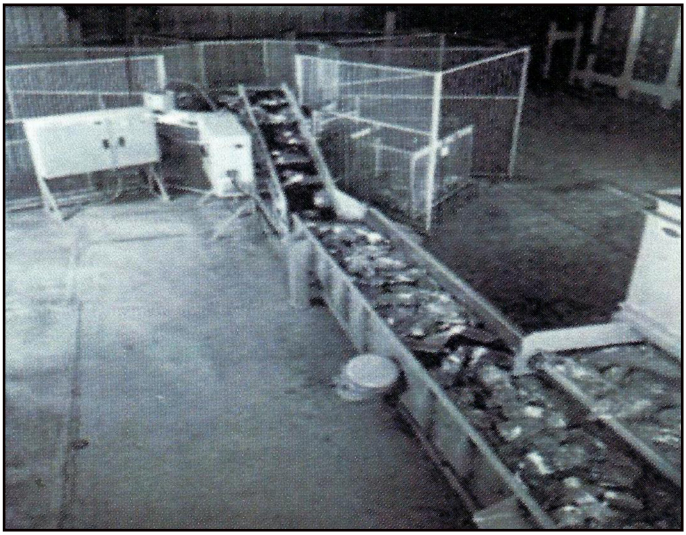
Flow diagram Processing Industrial plastic waste

Steps that plastic goods undergo during the process of Mechanical Recycling:

- **Collection-** Plastics arc first recovered from the waste stream. Plastic wastes are either brought to a centralized collection point or are picked up by a hauler from designated waste containers. These are also collected by bag pickers from municipality dustbins from where they are taken to handlers.

- **Handling-** Then, the handlers sort the plastics from the waste, code them and then density them.

- **Sorting-** Plastics are separated from other materials like steel, aluminium, rubber wastes etc. They are also sorted by resin types for eg. PET and HDPE plastic materials are separated before they are processed further. This is done manually in India while in advanced countries by using an automatic separator that uses infrared identification or X-ray to identify plastic waste by resin type or color. Labels, caps and rings too are separated from plastic bottles.



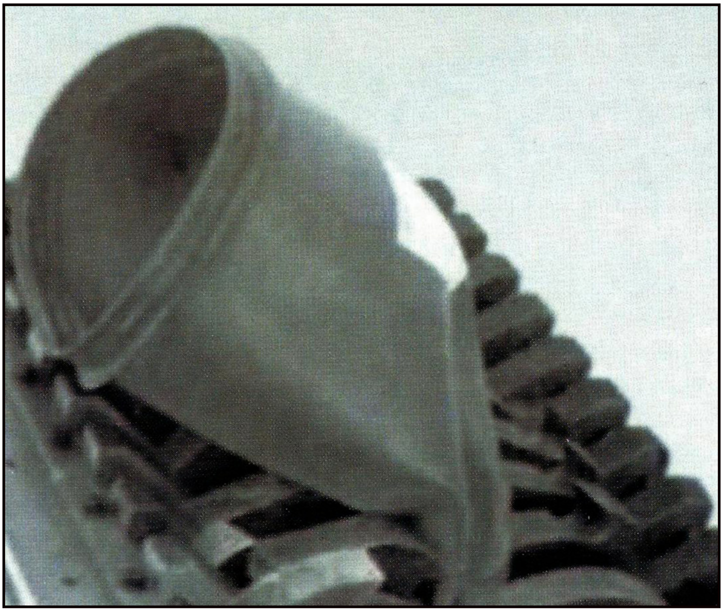
(Overview of the processing line of the NIR based plastic bottles sorting system)

- **Coding-** To combat the recycling problem posed by the need to separate different plastics, many manufacturers have adopted a coding system. Containers are stamped with a code indicating the type of plastic from which they are made. Coding makes it possible to sort containers in the recycling process if they are made of a single type of plastic.

- **Densification-**It takes a small quantity of plastic to produce large volume items. To avoid the high shipment costs arising from the high Volume to Weight ratio of plastic products, the handlers densify the plastics. This is generally done using Baling and, at times, by granulating or grinding the plastics depending upon the market specification.

- **Reclamation-**This is when the sorted and densified plastic is converted to flakes or pellets that can be used to manufacture new items. The process of flaking involves granulating it to convert it into small uniform sized chips of material. However, for obtaining clearer material, these flakes are washed, dried and then pelletized. The process of pelletizing involves melting the plastic, extruding it into thin strands and then chopping them into small uniform pieces.

- **End-Use -**The pelletized or flaked plastic can then be sold to the manufacturers of recycled



(Courtesy : Sydel Ensemblier Industriel, France Ref: Polymer Recycling by Scheirs)

products. From bottles and containers, clothing, automotive accessories, bags, bins, carpet, plastic lumber, film and sheet to hospital supplies, housewares, packaging, shipping supplies, toys, recycled

Although the above process may seem very simple and straightforward, it poses unique recycling challenges. Recycling plastics is difficult because the plastic waste that comes through is a mix of plastics having different properties. Separating plastics poses problems for the recycling industry. Multi layer packaging also makes it difficult to isolate plastics of one kind as it involves layers of different plastics fused into one container.

India has many success stories of use of recycled plastics for commercial uses conversion of automobile battery cases to inexperience moulded Luggage, milk film to Barsati film (hamlet covers), plastic woven sacks (PWS) to **Niwar Patti** are just a couple of the numerous application of in a country famous for maximum plastics recycling in the world.

Uses of Recycled Plastics - International Status

The "commercial" sector that spans outlets that distribute and/or sell products or services to consumers represents a significant potential source of plastic for recycling. Items like **Packaging films, trays, soda and milk crates, food pails, industrial drums and stretch film** have been recovered.

The electronics and information technology industries also have a lot of scope to implement plastic recovery programs for durable goods, such as computers, automobiles, appliances, building and construction products. Durable goods have a successful history of being recycled and reused. Many success stories in India like conversion of automobile battery into inexpensive luggage, milk film into Barsati film (for hamlet covers), plastic woven sacks into Niwar Patti to quote a few.

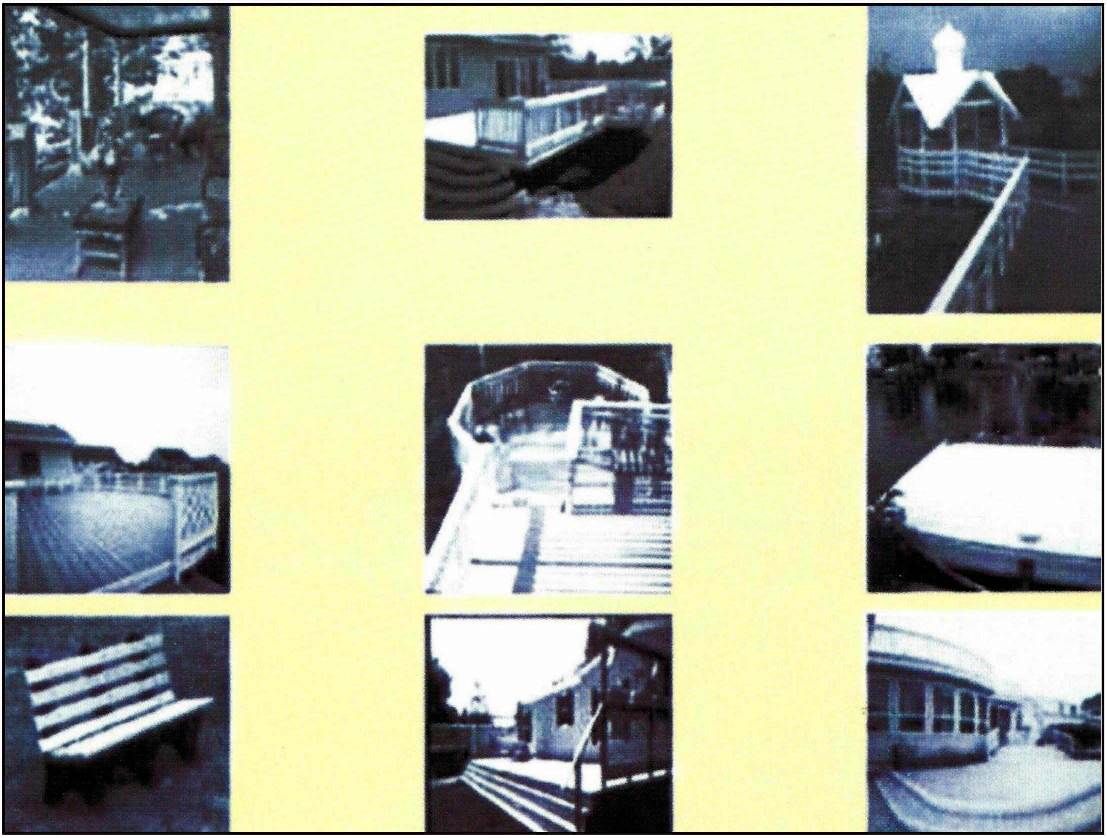
Commercial Uses of Recycled Plastics

Name of plastic	Some uses of virgin plastic	Some uses of recycled plastic
PET bres,	soft drink and mineral water bottles	multi-layer soft drink bottles, carpet fi- fleecy jackets
HDPE	milk crates, bottles for shampoo and cleaners, milk and cream bottles,	waste bins, detergent bottles, crates, agricultural pipes, kerbside recycling crates. Plastic lumber, Plant pots, Traffic cones, Toys, Outdoor furniture.
Rigid PVC	clear cordial and juice bottles, plumbing pipes and fittings.	detergent bottles, tiles, plumbing pipe fittings.
Flexible PVC	garden hose, shoe soles, blood bags and tubing.	hose inner core, industrial flooring.
LDPE	garbage bags, garbage bins, black plastic sheet.	packaging and plant nurseries, bags.
PP	drinking straws, ice cream containers, hinged lunch boxes	composite bins, crates.
PS	yoghurt containers, plastic cutlery.	coat hangers, office accessories, rulers, video/CD boxes.

Plastic Lumber made by Recycled Plastics

Plastic lumber made by using Recycled Plastics is a very attractive, ecofriendly and cheap application. This fabrication process is becoming very popular day by day. Plastic lumber based different products of various lucrative design and looks like, Fencing, Furniture, pellets, staircase, railing etc. are available in the market. Mostly recycled HDPE are used for making these types of lumbers. The plastic lumbers are not only environmental friendly (saving wood) but also viable alternative to traditional hardwood lumber.

Other than this, plastic lumbers are virtually maintenance fee, strain resistant, water proof, graffiti proof, UV resistant, impervious to insects, termite proof, long lasting (> 50 years,

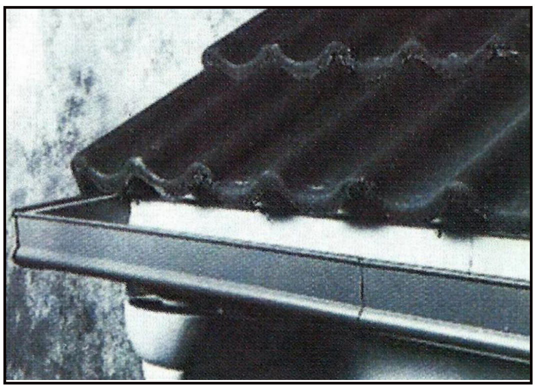


depending upon applications) and overall aesthetically pleasing (wood grained finish). Processing and other fabrication processes are very easy for plastic lumber. Plastic lumber can hold nails approx. 90% better than wood and screws 50% better than wood.

Recycled Vinyl can be put to varied uses -Industrial Practices

- **Vinyl Siding to Mobile Home Skirting and extruded products:** Vinyl Regrind from vinyl windows and siding profiles can be used to manufacture strong and durable UV-stabilized walls and partitions that can withstand strikes from 1,360 kgs of dop hammer. Vinyl Siding Scrap can be ground up, sold and converted into extruded products such as gutters and pipes.

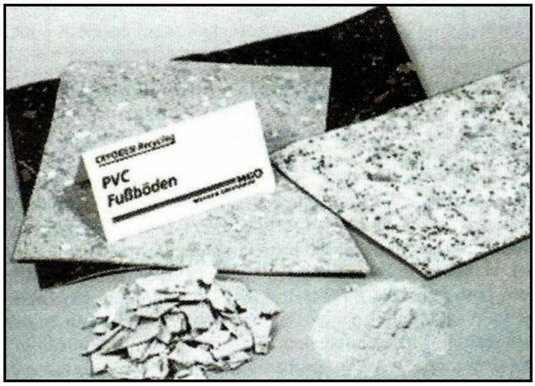
- **Bottles to Fashionable Knitwear:** You can even wear Vinyl Mineral Bottles! Old reclaimed bottles can be converted into



Rain Water Guttering and Roofing

fibres that can then be transformed to yarn for making new clothing. This technology has been developed by a French clothing manufacturer- Rhovyl, in association with French additives company-Elf Atochem. They have successfully created stylish sweaters, socks and scarves from recycled PVC yarn and wool in a 70:30 ratio blend. Approximately 27 bottles are needed to produce one sweater. France uses about four billion vinyl bottles annually of which almost half are being recycled.

- **Intravenous Fluid (IV) Bags to Floor Tiles:** Disposables used in the medical market present a recycling challenge, and most plastic used in this market is incinerated, although much of it is not hazardous and could be recycled, such as IV solution bags. Baxter Healthcare Corporation of Round Lake, Illinois, tested the feasibility of recycling IV bags by establishing a pilot collection program with a network of hospitals, enabling them to extract these items from the waste stream for recycling into a number of industrial and commercial products, including floor tiles. The manufacturer of these tiles, Turtle Plastics, Cleveland, Ohio, characterizes this application as the ultimate closed-loop application, since hospitals are one of the places where such tiles are used.



PVC Floor Coverings (Messer Griesheirum GmbH, Krefeld,, Germany)

- **Wires and cable scrap:** can be converted to sound-deafening panels for use in cars, truck mud flaps and floor mats.

- **Computers to Highways:** The discarded machines can be and are being successfully recycled into roads. Recycled computers and discarded plastic electronic housings are used to form new and proven filler for highway underlayerments and pothole filler mix.

- **Monitors to Keyboards:** IBM In the United Kingdom, IBM has successfully achieved closed loop recycling of PVC monitor housings into PVC computer keyboard backs at 100% recycled content. Since 1993, IBM has used more than 500,000 pounds of recycled PVC, resulting in a 22% cost savings. The electronics market is a particularly promising area for recycling, given the high value of the finished product. Vinyl is expanding in these applications because of its favorable cost and fire retardant properties, and is proving to be a valuable material in the very competitive business equipment industry

- **Automotive and Appliance Shredder Residue:** Plastics recovered from Automotive and Appliance Shredder Residue (ASR) can be put to use in many areas, as a concrete additive, fuel reductant for steel mill blast furnace, in pyrolysis and gasification and energy recovery through co-combustion with municipal solid waste.

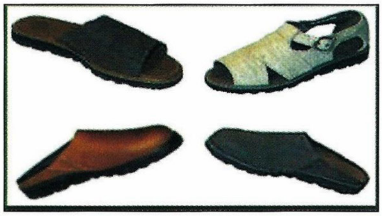
Indian Experience in Recycling

.....Converting to value added end products

Huge Value addition

Plastic Waste

Box strapping



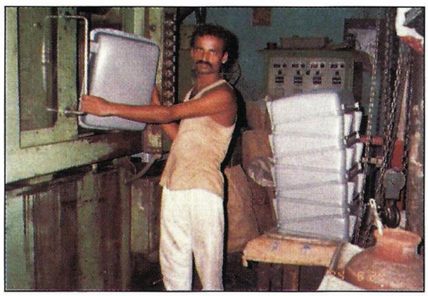
Plastic footwear

Huge Value addition

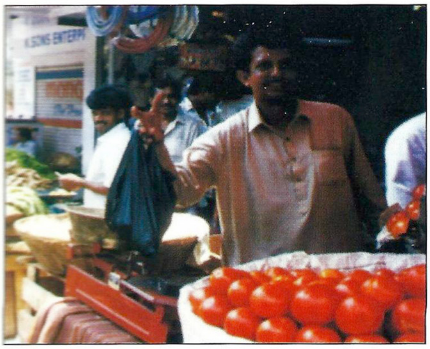
Milk pouches

Barsati film

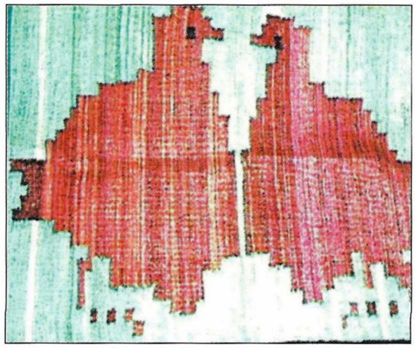
Battery Cases



Luggage



Plastic Carry Bag



Mats

PET recycled to useful products

India, one of the major technological centres on PET recycling. CSIR/NCL, Pune under the poineering role of Dr. R.A. Mashelkar

4. Recover: Energy and Feedstock Recovery Through Recycling

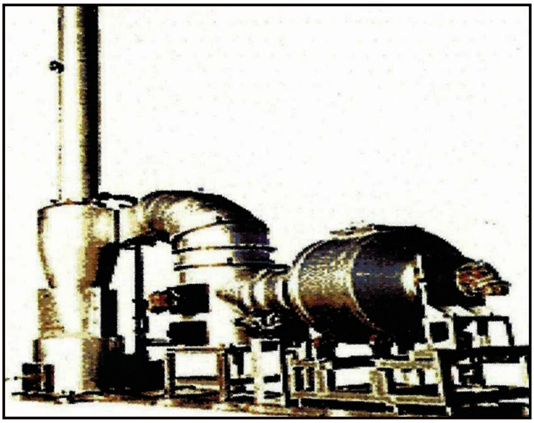
Energy recovery offers an interesting techno-economic alternative to Municipal solid waste recycling. It reduces overt dependency on mechanical recycling using rag picker chain.

- Abundant availability of feedstock at nil cost (MSW) in large metros
- Plastics in MSW help to increase calorific value
- Source of low cost energy for city/community needs

Incineration of plastic waste with energy recovery

Waste plastic contain significant reserves of energy that can be recovered through combustion processes. In most cases the calorific value of waste plastics is comparable to or higher than coal.

In fact, in most cases, the calorific value of waste plastics is comparable to, or higher than, coal (29 MJ/Kg). The energy recoverable by combustion of different packaging materials is shown below :



Energy Recovery by Incineration

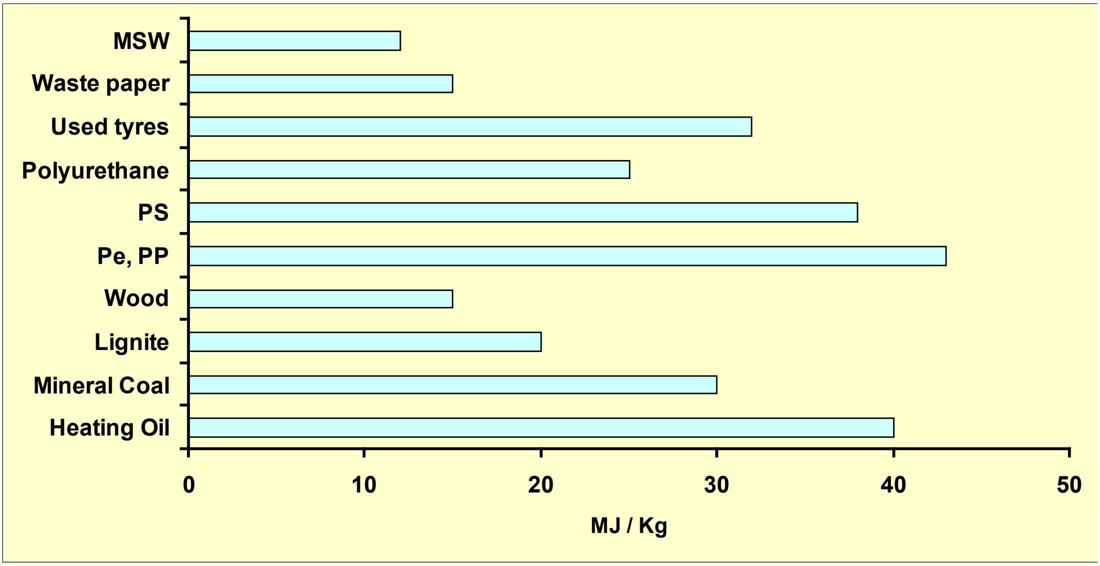
Heat content of different Plastics

Polymers	Lower Heat Value (Mj/kg)
PE	46
PP	44
PA	32
PET	22
Cellulose acetate	16

The plastic waste can be burned on its own or can form a part of mixed combustible fraction for use in solid fuel fired boilers and plants. Incineration of plastic waste allows steam for heating or for electricity generation as well as heat recovery from fire gases.

Energy recovery from plastic waste can take a number of forms including :

- energy recovery as a part of incineration of municipal solid waste (MSW)
- energy recovery through monocombustion with traditional fossil fuels.
- the use of plastic waste as a fuel in cement kilns (utilized as a partial substitute for coal and coke)



Heat content of various plastics in MJ/kg
Source: APME documents 'A fuel for the future; energy from plastics waste'

Energy recovery also offers a positive recycling route for any plastics that cannot be sensibly recycled by mechanical means due to excessive contamination, separation difficulties, polymer property deterioration etc.

Plastic waste as a part of MSW (Municipal solid waste) due to its high calorific value, has a positive effect of MSW incineration. Plastics are also considered a benefit in MSW incineration as a fuel that is low in ash and moisture.

The fuel characteristics of plastics in MSW can be described by their heat content, moisture content, ash content and heavy metal contents. Their rate of combustion in MSW is determined by dynamic parameters such as bulk density, surface to volume ratio, ignition point etc. Plastic combustion produces volatiles, which can ignite very easily. The flammability parameter (ratio of heat of combustion divided by heat required to produce volatiles) is sometimes used for company solid fuels using this parameters. PP and PS have comparable combustion performance to wood.

Combustion data for components of municipal solid waste.*

Material	Heat energy (Mt/kg)	Ash (wt. %)	Moisture (wt %)
Paper/cardboard	11-17	8-9	6-15
Compositibles	4-6.3	15-30	60-70
Fines	3-4	15-30	40
Textiles	13-16	2-5	22.5
Plastics	33-39	2-4.3	10

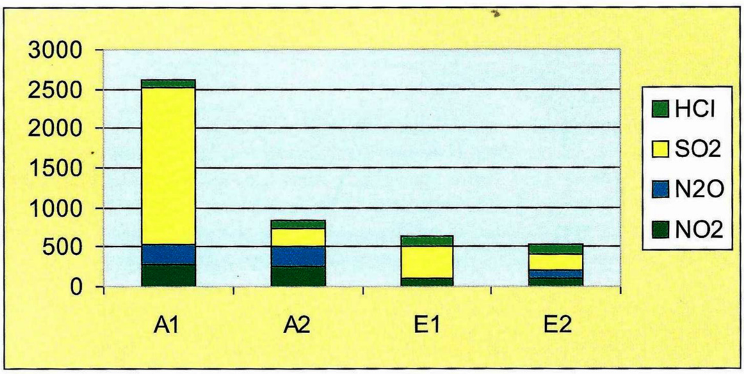
**(Adapted from Mark FE, PWMI Technical Paper. The role of plastics in municipal solid waste combustion)*

While the energy content of the plastic waste can be recovered in today's municipal solid waste combusters, the heat value of plastics is considerably higher than that of the general MSW stream (35 GJ/t to 11 GJ/t). Hence, some plant modification (retrofitting) is necessary to cope with the higher heat values for higher plastic inputs. A state of the art MSW incineration facility for handling plastics waste would require the following features:

- A forward or reverse reciprocating grade made of several independent zones
- Good control for primary and secondary air

A flue gas treatment system comprising fly ash removal, multistage wet scrubbers for HC1, HF, SO removal active carbon treatment to remove volatile heavy metal such as mercury, selective catalytic reduction of No.

Advanced process for utilizing plastic derived fuel. The separately collected plastic material, with or without other combustible material like paper, can be prepared in a form suitable for fuel substitution by co-combustion in normal boiler plants or other industrial furnaces. Before plastic waste can be utilized as fuel, it must be converted to a prepared form that makes it suitable for transportation and storage and for metering into the energy conversion plant. There are a number of different commercial combustion techniques for incinerating plastics waste. Monocombustion involves the incineration of plastics waste on its own to produce steam, which can be utilized for electricity generation. For monocombustion to be efficient, it is necessary to process the plastic waste. Such plastic waste can be utilized in power plants and other solid fuel fired boilers.



Comparison of Flue gas emission for the combustion of coal and mixed plastics
Source: APME, Europe

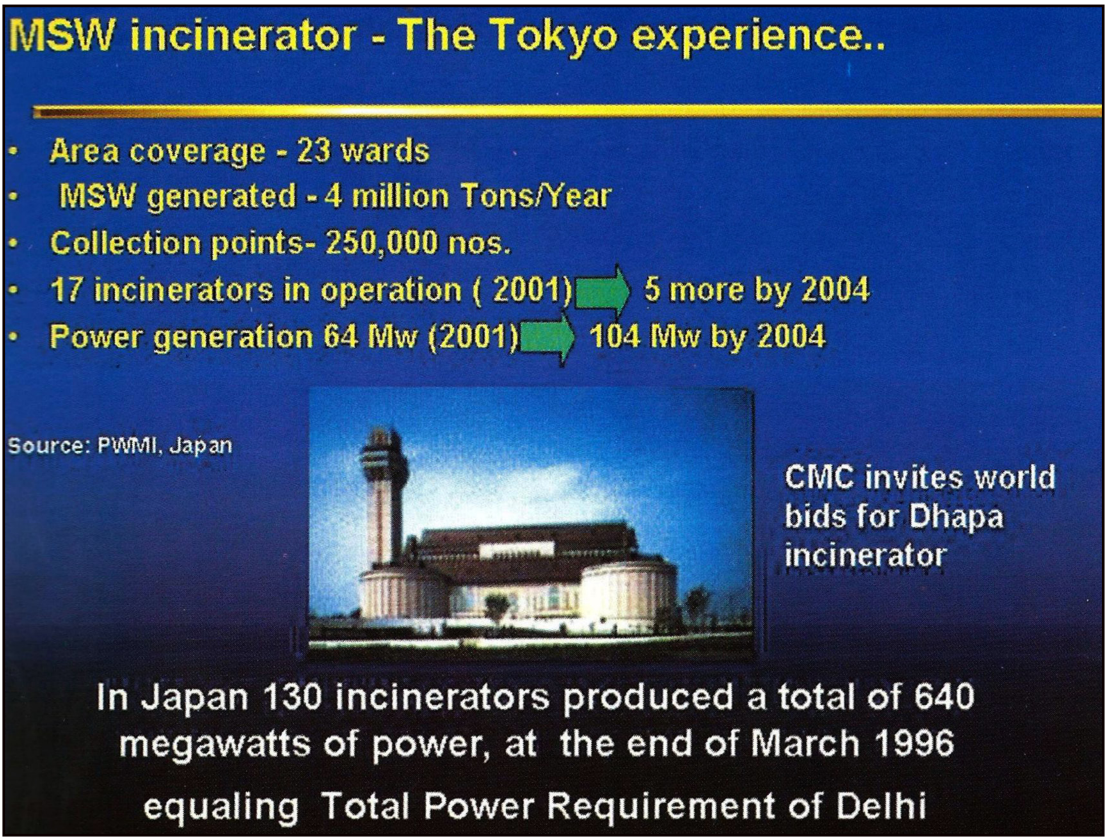
A1: coal without limestone
A2: coal with limestone
E1: Mixed Plastics without limestone
E2: Mixed Plastics with limestone

Mixed plastic waste, when burned, produces less sulphur dioxide and more HC1 than coal under same conditions.

Co-combustion is generally preferred to monocombustions. An important point of distinction between monocombustion and co-combustion is that monocombustion requires specially designed boilers while co-combustion can be performed in existing boilers. If the plastic waste is sorted, shredded and evenly mixed with a primary fuel (coal or peat), then the combustion is more efficient and no excessive gas cleaning is required. The cost of combustion of plastics waste offers the combustion process to be more homogenous and controlled. Waste plastics make excellent fuel for cement plants where they serve as a partial substitute for coal or coke.

Incinerator Experiences (Japan)

Almost 50% of the plastic waste generated is recycled in Japan while other portion is effectively used for energy recovery. To deal with this trend, the country is testing and developing a variety of recycling technologies for effective used of resources. On energy generation font Plastic waste has been effectively used as a fuel for high energy intensive units like cement plants. According to survey performed by Japan Cement Association the amount of recycled modified waste plastic has been steadily increasing from 29,000 Tons in 1998 to 1,02,000 Tons in 2000.



What is the significance of "Fuel and Material" here?

Industrial waste plastic, whose main components are hydrogen and carbon, has high-calorie properties. This makes to suitable as auxiliary fuel material, while the ash left behind after burning this fuel can also be recycled as a portion of cement raw material.
"Fuel and Material" therefore, refers to two key characteristics possessed by industrial waste plastic plays a role in both material and energy recovery

Plastics Recycling in Developed Countries - Challenges, Innovations & Advances

Plastics Recycling in USA

In USA, recycling of post consumer plastics began in earnest in the late 1980s. Plastic packaging makes up more than 70% of all the plastics recycled reflecting the emphasis of most municipal recycling efforts on packaging. Many municipal programmes have been launched as a result of state level mandates and recycling efforts, are therefore, concentrated in those regions facing a landfill shortage. There has been a rapid increase in recycling of plastics in USA in the last decade.

Plastics Recycling in Europe

Mechanical recycling i.e. the material reprocessing of waste plastics by physical means into new plastic products, is European plastics industry's preferred recovery technique. Assessing the potential for post-use plastics waste recycling, predicting recovery tends in 2001 and 2006, it was established that the quantity of plastic waste mechanically recycled across western Europe has the potential to more than double over the period 1995 - 2006.

Challenges of Recycling Plastic Films

Efficient diversion and consolidation of recovered materials: What does it take to get plastic films out of the waste stream? Identification of films in the waste stream, determination of their recyclability, implementation of steps to divert them, and once diverted from the waste stream, the ability to market them. The more film an individual business can recover, the better its chances of finding a recycler willing to take it.

Sorting of like materials: Plastic films are more difficult than plastic containers to identify by resin, as most films do not carry such identifiers, necessitating training for generators and recyclers on how to distinguish between film types. Sorting generally must occur early in the recovery process, near the initial point of generation, to be successful. Better sorted films have more recycling options. Mostly the sorting is done by hand, in fact hand sorting is the most efficient way to separate out different types of plastic wastes.

The ability to remove contaminants: Films Plastic are likely to pick-up and retain more surface contamination than container plastics on account of a greater amount of surface area relative to their weight. This common surface contamination, such as labels, dirt and food residue can pose a bigger challenge to plastic film reclaimers than other recycled material users, because of tight quality tolerances. In plastics reclamation, remaining surface contamination such as a single label must be mechanically screened from the melted resin before it can become a quality raw material for use in new plastic products.

Technology and Market Developments: Advancements in processing and manufacturing technologies arc creating improved opportunities for recycling films into mainstream plastic products by broadening the types of films that can be processed, and the product applications in which they can be used. Advancements in processing include

- **Technologies for contaminant removal,**
- **Film washing and drying, and**
- **Pelletization into market-grade resins.**

Advancements in manufacturing include improved ability to compound resins to form new blends and the ability to combine plastics with other materials, such as cellulose wood fiber, to create a new generation of composite products.

Technology developments, combined with increased awareness of recycling opportunities in the public and private sectors, have already begun to stimulate new plastic film recovery efforts. One major area of emerging end-use applications involves the **production of plastic lumber, and wood-plastic composites for building applications**. These products are experiencing tremendous market growth, and several have developed vertical integration strategies to actively participate in the development of new recovery channels for plastic films. They represent a large capacity consumption potential for polyethylene and other recovered plastics resins, including recovered film resins.

Advanced Recycling Techniques

The terms Chemical Recycling and Feedstock Recycling of plastics, sometimes collectively referred to as Advanced Recycling Technologies, describe a family of plastics recycling processes that convert solid plastic materials, though the use of heat, into smaller molecules (chemical intermediates).

These chemical intermediates, usually liquids or gases, but sometimes solids or waxes, are suitable for use as feedstocks for the plastics. Advanced Recycling complements conventional mechanical recycling. However, for technical and/or economic reasons, mechanical recycling of plastics is not always practical.

Chemical Recycling

The term chemical recycling is most often applied to the depolymerization of certain condensation or addition polymers back to monomers (the basic building blocks from which plastics are made). Examples of these types of plastics are polyesters (e.g., the PET used in soda bottles), polyamides (e.g., the nylon used in carpeting), and polyurethanes (e.g., the foam in automobile). Two nylons, nylon 6 and nylon 66, are used for carpet fiber and high performance molded applications while the principle source of polyurethanes to be depolymerized are preconsumer or post-consumer foams like automobile parts.

Long chain polymers can be treated chemically and/or thermally to break the chains into short segments. When the treatment is done to re-create the chemicals from which the polymers wee initially made, we call that feedstock or monomer creation. If the treatment breaks the polymers into an assortment of chemical species, it is up to the processor to decide whether to recover specific chemicals for feedstock use or to use the assortment of chemical species for fuel or to use some combination of both end products. The resulting synthesis chemicals can then be used to make new plastics that can be indistinguishable from the initial or virgin polymers.

Feedstock Recycling

The thermal depolymerization of polyolefins and substituted polyolefins into a variety of smaller hydrocarbon intermediates is termed as Feedstock Recycling. Synthesis Gas, a mixture of hydrogen and carbon monoxide, is an important by-product of a special class of feedstock recycling processes. It can all be used as chemical feedstocks for further upgradation to commercial products at oil refineries and chemical plants.

Developments to Watch: Recycling Plastics

Recycling the mountains of discarded computer cases, soda bottles, and other plastic waste makes ecological sense. But current recycling methods have serious flaws. Reusing a mix of different plastics typically involves a chemical glue, or "compatibilizer," to link otherwise incompatible polymers. Without good chemical bonds, the resulting material may be fragile. Yet compatibilizers "are expensive and don't always work," explains Viktor Williams, manager of global polymer recycling at DuPont in Geneva.

A new process—in essence, an industrial-scale Cuisinart—may solve these problems. Developed by Bernard Dubrulle d'Orhcel, chief technology officer of New York-based startup New Generation Plastic, the idea is to feed used plastics into a chamber with whirring blades. As the blades chop up the waste, the mechanical stress seems to beak existing chemical bonds, paving the way for new ones to form, says Francesco Paolo La Manila of Italy's University of Palermo, who has studied the process. In fact, tests show that the resulting material can have better properties than any of the original ingredients

Depolymerization for Monomer Feedstocks

Several commercial processes exist to recover synthesis monomers or feedstock chemicals from plastics by depolymerization. Other processes are under development. The depolymerization processes for monomer feedstock must be very efficient with very high yields of monomers and little waste. Several plastics ac, by their chemical nature, advantageous for such treatment. Polyethylene terephthalate (PET), certain polyamides (nylon 6 and nylon 66) and polyurethanes can be efficiently depolymerized. The resulting synthesis chemicals can then be used to make new plastics that can be indistinguishable from the initial or virgin polymers.

- **Nylon Depolymerization**
  Nylons are also polymers that can be depolymerized efficiently to recover monomer feedstocks. Two nylons, nylon 6 and nylon 66, are used for carpet fiber and high performance molded applications.

Nylon 6 is made by reacting caprolactam to form polymers. Caprolactam is a ringed chemical of seven atoms (six carbons and one nitrogen). During the polymerization the ringed molecule is opened up to form a monomer chain. The monomer chains are then link together to form a polymer.

- **Polyurethane Depolymerization**
  Polyurethanes can also be depolymerized to form useful monomers. Polyurethanes are typically formed by reacting diisocyanate with a glycol, such as EG. Polyurethanes can be theoretically depolymerized by hydrolysis or glycolysis like polyesters or by ammonolysis, like nylons. The principle source of polyurethanes to be depolymerized would be foams, either pre-consumer or post-consumer such as auto seat cushions.

Future Outlook

Advanced recycling of plastics represents a significant technological advancement that in the case of some polymers is already supplementing existing mechanical recycling processes. These processes signal a significant technical advancement in plastics recycling because the products, after purification, are identical to current feedstocks and monomers used to produce new plastics.

Innovations in Technologies

To provide an adequate life to the Post-Consumer Recyclate (PCR) plastics and to least prevent the degradation as far as possible, selected additives are incorporated during their reprocessing. The quality improvement of the recycled plastics though additives (stabilizers) does not mean only the physical improvement but also the mechanical, thermal, outdoor weathering and in other long-term properties of the product.

Polyethylene (PE)

Addition of 0.2% of Recyclostab 411 has been reported to almost double the thermal ageing resistance of PCR - HDPE products. It is also reported that by using a combination of 0.1% phenolic and 0.1% of phosphite it was possible to hold the level of properties of recycled HDPE containers equivalent to the original values.

Most of the PCR materials of low-density polyethylene find applications in extruded products. Most of this recycling is done without any additional stabilizers. The garbage bags, tarpaulins, carry bags and the electrical conduits are the main applications of these PCR materials. However use of 0.1 —0.3% of phenolic and phosphite additive mix has been found to increase the long-term stability of these products. Blending LDPE & HDPE at a ratio of 70 : 30 or 80 : 20 is found to improve overall properties of sewage and drainage pipes. Addition of virgin LLDPE into PCR-HDPE for blown film and cast film is reported to give improvement in dart impact strength, tear and optical properties. Using recyclate LDPE in extrusion was found to cause reduction in melt flow rate and leading to gels formation in films. Addition of 0.1-0.3% phenolic and phosphite additive mix was found to improve the processability in these cases also.

Polypropylene (PP)

Recycling of old PP battery case has always been considered as the major challenge to recycling industry as they are in contact with aggressive acid like HLS04. However, addition of 0.4% of phenolic & phosphite stabiliser blend were found drastically to improve the performance of PCR-PP battery case.

Polyvinyl Chloride (PVC)

Most of the PVC goes for applications in building, construction or in agricultural sector where the products have a life-time sometimes in the range of 20-50 years. It is possible to reprocess the waste generated from these sectors by compensating with additive package.

Unlike other polymer waste, much of the PVC waste is generated at the processor end - the processor of pipe, profile, flooring and roofing materials. The reprocessing of off-scrap from the profiles are ground into fine powder and processed into new profiles, electrical ducting or conduits, without any additional stabilizers. Similarly, the flooring and roofing waste can once again be used without any additional stabilizers. The PCR of PVC bottle scrap can be recycled into long-life pipes and fittings with additional heat stabilisation.

Cable Sheathing and Insulation is Recycled

In Italy, about 14000 tonnes of PVC is recovered from electric cables each year and used to make car mats and carpet underlay.

Flooring is Being Recovered

Recycling schemes in Australia and Germany are giving old PVC floor coverings a second life as backing layers for new floor coverings.

Pipes Achieve A Second Life

Since 1989, PVC pipes have been recycled n the Netherlands, Denmark, Austria and Germany. The material produced is used to make new pipes, closing the recycling loop.

Polystyrene (PS)

Expanded polystyrene (EPS) represents a major market of polystyrene consumption and the sizable portion of this goes in packaging. Restabilisation with 0.1 % of phenolic is found to effectively maintain the colour stability and the molecular weight of the recyclate as high as possible.

Engineering Plastics

Engineering Plastics such as polyamide, polyester, polycarbonate, etc. represent a small market sector. However, recycling of these PCR materials are important since they are relatively high value products. Addition of heat stabilizers, preferably a combination of hindered phenol and phosphite, was reported to improve the processing and the long-term properties of PCR polyamide scrap. This additive package was also found to be effective for PCR - ABS scrap. The addition of phosphite in the PET recyclate (bottles) improves the melt stability. Most recent investigations claim that the best stabilizer system for PET is the combination of phosphite with a small portion of phenolic antioxidant. The discolouration during the reuse of PC can be inhibited by the addition of phenolic stabilizer at an optimal level of 0.1%.

Mixed Plastics

Mixed Plastics waste are the residual materials that remain after the sorting and separation. The stabilization of such materials should be done taking into account their composition and also unusual temperatures that might be encountered during the processing of these recyclates.

Nickel Dithiocarbonate has been found to be successful in improving the long-term stability of mixed plastic waste containing PE, PP, PS, PET and even PVC. As regards the thermal stability while reprocessing of mixed plastics waste, stabilizer combination of phenolic with phosphite leads to aggressive results. For the outdoor application, in addition to all the stabilizers, the addition of light stabilizer is necessary. The restabilization of polymer with HALS compounds is reported to result in substantial extension in product life-time.

Gasification Technology - Solution to Plastic Waste in Japan

In the area of chemical recycling using pressurized gasification, the Plastic Waste Management Institute has been commissioned by NEDO of Japan (New Energy and Industrial Technology Development Organization) to turn waste plastic into raw materials for the chemical industry. Two companies are to participate in this program: Ebara Corporation and Ube Industries, Ltd. The internally circulating fluidized bed technology, gas smelting technology and pressurized dry feed system owned by Ebara Corporation will be used in conjunction with gas refining technology, owned by Ube Industries for many years, to demonstrate efforts in the field of resource recovery.

Construction on the demonstration plant commenced in Ube City. The site will comprise a raw materials acceptance and storage facility, raw materials supply facility, low temperature gasification furnace, high temperature gasification furnace/slag recovery facility and waste water treatment facility. The planned processing capacity for organic waste such as waste plastics in 30 tons a day, or about 10,000 tons annually.
The features of the gasification technology include the following:

1. No real generation of re-synthesis of dioxins because of the reducing atmosphere of gasification temperature between 1300 and 1500°C and partial oxidization of entire process, and because of momentary cooling to about 200°C.
2. Plastics containing chlorine can be used for gasified raw materials without prior sorting or processing.
3. Non-combustibles such metals and soil from waste plastics will be collected as un-oxidized metals or slag from the bottom section of the low and high temperature gasification furnaces. Chlorine will be collected as ammonium chloride (a fertilizer) from the circulating water.

If development of this technology progresses further, it will be possible to recycle waste plastics into raw materials for the chemical industry without generating dioxins. This will contribute to the reduction of carbon dioxide emissions, as well as reduce the consumption of finite fossil fuels.

Moreover, this technology is gaining attention as one of the key ways to turn “other plastics” into new products.

Recycling of Mixed Plastics

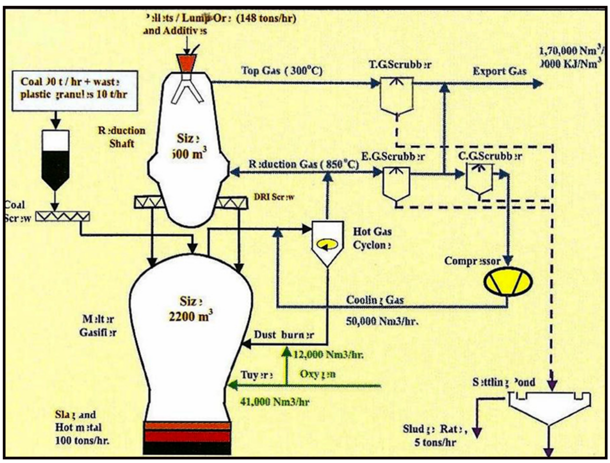
Mix plastics in the form of laminates essentially used for packaging of edible products have become very popular for their functional performance over the last few years. These laminates ensure excellent packaging, low weight and inexpensive. The plastics generally used are LDPE, LLDPE, HDPE, Polyester Film, BOPP etc. Since plastics are not compatible chemically with each other, there is an apparent doubt about recyclability of these laminates, however, technologies have been developed, these products have been effectively recycled into basic raw materials which in tern use for making end products. In India, Flex Industries are largest laminates manufacturer company has developed technology for laminates. Commingled laminates are compatibilised and processed and usual processing techniques and polymer granules have been used. Some of the useful products manufacture laminates included injection moulded components used for bicycle industries, flower pots, road dividers etc.

Corex Ironmaking Process-New Idea in Recycling

Corex Iron making process is one type of energy recovery process which is basically a new concept in Recycling. It is an alternative process to Blast Furnace iron making. This process is a coal based smelting reduction process to produce liquid iron for steel making. The iron ore pellets are charged into shaft reactor, which are reduced at 850"C to direct reduced iron (DRI) using Corex gas produced in another reactor called Melter Gasifier. In place of non-coking coal (10% substitution of coal) waste plastic (Mainly PE, PP, PS) granules of size 30-40 mm can be used for this process. All the PE, PP and PS are of high hydrocarbon chain length and source of high calorific value of about 10,000 Kcal/kg.

Advantages of the Corex Process

At present, the blast furnace is the principal route of liquid iron for Steel-making all over the World including India. Countries like Japan and Germany have established a technology of using waste plastics by injecting plastic granules (6-8 mm) through the tuyeres of the blast furnace. In blast furnaces, coke (and not non-coking coal) is used as a fuel and reductant due to requirement of high strength at room as well as high temperature and hence plastics granules can not be charged directly substituting partly coke but can only be injected through the tuyeres of blast furnace. However, in the Corex Process, where non-coking coal (and not coke) is used, plastics granules can be directly charged along with coal.



Flow diagram of the Corex process

This is a most competitive method of using waste plastics in an Ironmaking process. The main advantages of this process:

- Elimination/reduction of serious health hazard and economic unfriendly biodegradable material

- Elimination/reduction of a biodegradable material which is being partly recycled to produce unhygienic products
- Saving of foreign exchange used for import of expensive low ash coal (partly) being used in Corex Ironmaking process
- Reduction in emissions of greenhouse gases like CO, because of higher H content of plastics as compared to coal and lesser problem of slag generation due to zero ash content of plastics.

Corex Process: Indian Scenario

The plastic waste recycling in India is much higher (45%) as compared to World standard (15 - 20%). The suggested approach of using waste plastics in Corex Ironmaking process is most environment friendly, non-hazardous and economic route. An ecological study produced by renowned Universities and Institutions in 1996 proved that waste plastics utilization as a raw material in Ironmaking process (like blast furnace) is the most ecologically compatible plastics recycling process.

So far, Corex based Ironmaking capacity in the World is:

Country	Company	Capacity, MTA
India	Jindal Vijayanagar Steel Ltd.	1.6
South Korea	POSCO	0.8
South Africa	Saldanha	0.8

Today and tomorrow, plastics will make it possible to enhance quality of life and use resources wisely. Plastic are the material of choice because they make it possible to balance social needs with environmental concern. But to fully appreciate this we must take a life cycle approach - seeking conservation of resources in production and use, and, allowing the flexibility to use a range of recovery options to maximise environmental gain. The future will be a place where miniaturisation is the norm, as manufacturers seek to reduce the amount of natural resources they consume and the waste they produce. The increasing use of nanotechnology will place plastics centre-stage as man rises to the challenge of developing smaller, increasingly powerful products with environmental benefits built in.

Prevention of waste through education and new developments in reusable systems are playing an increasingly important part in resource conservation and waste management. Minimising the volume and weight of waste at the production stage is the first step to help solve the overall waste problem.

The plastics industry will continue to encourage reduction and re-use where contributions to resource conservation and prevention of waste can be balanced with fitness for purpose.

An integrated policy allows all these considerations to be balanced, ensuring the best waste management option for net environmental gain and economic sense.

Based on the above discussion it can be agreed that Plastic Waste Management has been effective internationally and at national level. Recycling of plastics has contributed immensely. Both Industry and Government have been proactive and lot of initiatives have been taken by the Industry which are highlighted as under.

INITIATIVES BY THE INDUSTRY IN PLASTICS WASTE MANAGEMENT

Plastic Industry has been a responsible care industry and many initiatives have been taken in the direction of Waste Management in general and Plastic Waste Management in particular some of these are highlighted as under:

Indian Centre for Plastics in the Environment (ICPE)

The Indian Centre for Plastics in the Environment (ICPE) set up on recommendation of a Task Force constituted by The Ministry of Environment and Forests (MOEF), is a body registered under Society Act on 27 January 1999.

It is a nodal agency recognized by the Government of India to handle all issues related to Plastics and Environment in the country. The creation of ICPE is in tune with the leading four International Organisations (Japan, USA, EEC, Canada) working on the issue related to plastic and environment including recycling and waste management.

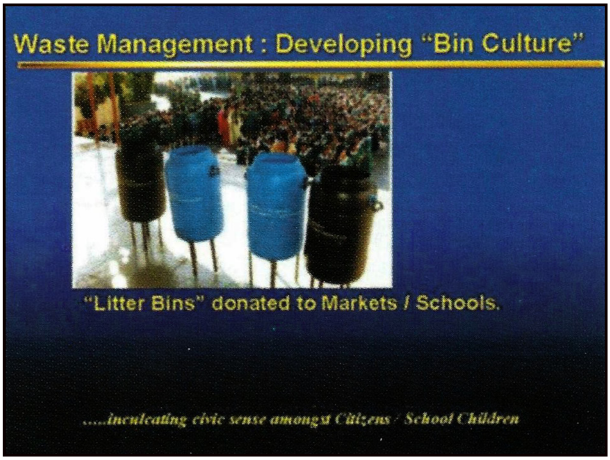
The Govt. of India, MOEF has launched the Environment Information System (ENVIS) program to disseminate information relating to environment. The ministry has identified ICPE as a node for capacity enhancement program relating to "Management of Plastics, Polymer Wastes and Bio-polymers and Impact of Plastic on Eco-system". ICPE has been selected as one of the 4 nodes in the country to work on this world bank funded project.

Waste Management: Pilot Projects

Waste Management pilot project have been started with various NGOs like ICPE-Nagar-BMC Project for "Clean Mumbai Foundation". This a pilot project for Municipal waste management. Similarly project with NGOS for integrated "Municipal Waste Management" have been started at other centres.

Compactor Project

ICPE has successfully installed a proto - type Compactor to manage the voluminous plastics waste (PET bottles) collected at the railway stations. ICPE is working together with the civic authorities and Western Railways in facilitating collection and recycling of plastic waste through technological inputs.



Project Developing "Bin Culture"

Plastic "Litter Bins" have been donated at markets places and schools to inculcate civic sense amongst citizens/school children. This initiative has received good response.

Commitment to Gazette Notification

Industry is committed to support the regulation on carry bags of thickness minimum 20 micron. A tripartite initiative by ICPE/BMC & NGO in implementing the Gazette notification.

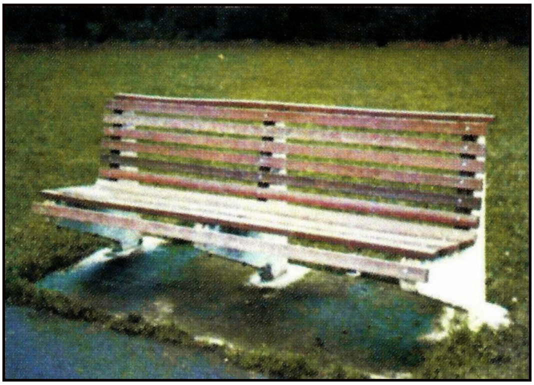
Communication

Plastic industry has been very active in communication to highlight the issues related to plastics and plastic waste management. Following communication activities are being carried out by ICPE on a regular basis.

- An advertising Campaign had been started against littering.
- Popularisation of Gazette notification on 20 micron thickness of carry bags.
- "Eco Echoes" a quarterly newsletter with wide circulation for general awareness among masses about plastics.
- Publishing information on plastics & environment in English, Hindi, & major regional languages.

Other Development Projects

Two prestigious projects sponsored by Plastic Industry have been successfully completed at University Department of Chemical Technology (UDCT) Mumbai.



Recycling of Plastics into Synthetic wood
Plastic waste has been used and regrouned by appropriate technology and converted into lumber which can be used as a wood substitute.

Cracking of Plastic into Industrial wax
Plastic waste from PE/PP can be converted into low molecular weight fractional products and used as industry wax.

Plastic Waste for Road Construction

Quality of Bitumen for Road Construction can be improved by incorporation of shredded/coalsced polyethylene carry bags. This projects was undertaken by centre for Transport Engineering-Bangalore University in collaboration with Karnataka PWD. Same has been repeated at University of Madras (Chennai). CRRI is also associated with the project of using plastic waste helping in Upgradation of Bitumen application in Road Construction.

Recently the Chennai Corporation has also agreed to carry out field tests on a similar project initiated by the Thiagarajar College of Engineering, Madurai and grant it official recognition. Since the mixing / melting of plastic waste (plastic cups, carry bags, etc.) to make this **"Plastic-Tar"** is carried out at a low temperature of about 170°C, there is no emission of gases such as during incineration.

Life Cycle Analysis
Life Cycle Analysis for plastics a scientific project with the IIT, Delhi released July 2002 Delhi to quantify the overall impact of various polymers on environment on the basis of the entire cycle of raw material, production, usage and waste.

Standards for Recycling of Plastics

There are prescribed standards and laid down specification on waste management and plastic recycling. Indian standards related to recycling, codification, guidelines for plastics packing and the code of practice followed in USA are given in subsequent sections.

Standards/Specifications for Recycling

The Indian plastic industry has helped formulate standards and specifications for plastics recycling in the country. There are two BIS standards introducing the coding system recycling practices and standards for the manufactures & usage of recycled plastics.

Recycled Plastics for the manufacturing of Products Designation IS: 14535

Scope
1. This standard is intended to be used for the identification of the recycled plastics material on the basis of its basic properties and applications.
2. This standard applies to recycled plastics material ready for normal use without any further modifications.
3. Though some modification and test methods have been provided in the standard any specific modification and the relevant test method which may be necessary in some specific applications shall have to be agreed upon between the purchaser and the supplier.

4. Though this designation system is only indicative of a broad classification of the recycled material, the absolute value of the low results may be provided which shall be agreed to between the purchaser and the supplier

Guidelines for Recycling of Plastics

This standard prescribes guidelines to the manufacturers of plastic products with regard to the marking to be used on the finished product in order to facilitate identification of the basic raw material. It will also help in identifying whether the material used on the end product is virgin recyclate or a blend of virgin and recyclate.

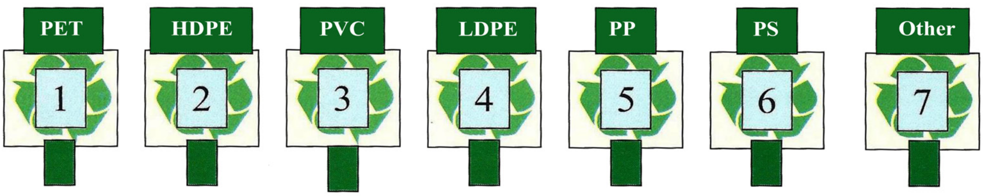
Terminology
End Products

Products made out of virgin, recycled/reprocessed plastics. Typical suggested and products along with use of appropriate types of plastics waste /scrap as per 4 are given in Annex A. A process by which plastics waste is collected, segregated , processed and returned for use.

Classification of Recycling

Plastics recycling technologies have been historically divided into four general types - primary, secondary, tertiary and quaternary.

IS:14534/14535-1998 Introducing Coding System/recycling practices
Packaging guidelines of MOEF
MOEF notification " Recycled Plastic Manufacturers & Usage rule " 1999



Regulatory & statutory norms

GUIDELINES FOR PLASTICS PACKAGING IN INDIA

The National Task Force on plastics has helped to form the guidelines for plastics packaging in India which in as per the EU guidelines. Some of the salient features of these guidelines are given below:

Definitions (Article 3)

Plastics Waste shall comprise firstly plastics that has served its intended life and is rejected in the form of broken objects and secondly those plastics which originate as waste from various plastics producing and processing steps. Since plastics degrade in time, they become an eye sore.

Waste Management shall mean management of plastics waste and shall include "collection", "segregation", "cleaning", "upgradation"., "reprocessing/recycling", "marketing", and "incineration", if required.

"Value addition" shall mean a positive return on reprocessing of plastics waste by way of improvement in properties of upgraded and recycled material.

Prevention (or minimisation/conservation) (Article 4)

The first time to think about recycling is not when waste product accumulates, but right at the start of the development process. The aim of product planning and development shall be waste prevention, if possible, and if not, minimisation of waste and ensuring that the product is recycling-friendly. A number of measures can be employed to achieve this aim.

Source reduction of material content in plastics products by using the appropriate grade of polymer. The onus of reducing material content in packaging lies not only with the packer but also with the resin manufacturer and processors who use both right as well as flexible packaging material. Change over from rigid to flexible packaging and further down gauging of the flexible into films. Material reduction may also be done through size reduction where smaller size of packaging is adequate. This also includes small volume build-up and low wall thickness in case of right packaging. These measures ensure easy recycling and minimum waste. These measures may also be applied to bulk packaging.

Policy shall be framed to encourage the use of recyclates in non-critical applications such as office furniture, dustbins, garbage collection drums, bags, etc. and make it mandatory. However, the performance of end product shall not be downgraded.

Reuse of Packaging (Article 5)

Manufacturers and users shall encourage reuse systems of packaging, which can be reused in an environmentally sound manner, in conformity with the objectives of this Guideline.

Recovery and Recycling (Article 6)

Recovery and recycling involves a complex process through which material that can be effectively and efficiently collected from businesses and residences, then be sold to manufacturers for processing and reuse in new generation of products. Technologies such as mechanical recycling, recovery of energy from waste-to-energy incineration, thermal recycling of plastics and composting of biodegradable plastics all contribute to the recovery and recycling of plastic packaging.

Some suggestions that will help in improving recovery and recycling of plastic packaging are :

- Avoiding the mixing of incompatible or difficult to separate materials whenever possible
- Using proper coding/wording for identification of the plastic resins, as per the relevant BIS standard, for waste in segregation and sorting.

Using a homogeneous macrostructure as far as possible. This is highly dependant on product design, eg PP Bottle and PP shrink film for labelling and packaging and helps to minimize the waste and ensues that the entire unit is recyclable and segregation is not required.

Manufacturers and consumers of plastics must recognise and meet the environmental considerations that are involved not only in producing basic plastics resins/manufacturing plastics products and using such products but also eventually disposing of the material or removing it. Source reduction practices shall be given priority and evolve new ways of producing/using plastics products.

Return, Collection and Recovery Systems (Article 7)

Most countries of the world are focussing a lot of attention on developing the infrastructure required to collect, recover and recycle waste plastics. Unlike most developed economics, where material recycling of plastics has often proved uneconomical, plastics recycling in India is a fast growing, lucrative industry through informal network of rag pickers, Kabariwalas and waste dealers. Its success can be traced to the main collection system - an army of over one million rag pickers who scavenge the country's waste dumps. It is therefore, an economic imperative for India that these rag pickers shall be encouraged by providing them with appropriate incentives and tools for making the job more lucrative/remunerative. In order to ensure that greater volumes of the total plastics waste generated in the country reaches the recycler, a more organised system of return, collection and recovery needs to be implemented.

Essential Requirements on the composition and the reusable and recoverable including Recyclable, nature of plastics packaging (Article 8)

1. *Requirements specific to the manufacturing and composition of packaging :*

- Packaging shall be so manufactured that the packaging volume and weight is limited to the minimised adequate amount to maintain the necessary safely, hygiene and acceptance for the packed product and for the consumer.
- Packaging shall be designed, produced and commercialised in such a way as to permit its reuse or recovery, including recycling, and to minimise its impact on the environment when packaging waste or residues from packaging waste management operations are disposed of.
- Packaging shall be so manufactured that the presence of noxious and other hazardous substances and materials as constituents of the packaging components is minimized with regard to their presence in emissions, ash or leachate when packaging or residues from management operations or packaging waste are incinerated or landfilled.

2. *Requirement specific to the reusable nature of packaging. The following requirements must be simultaneously satisfied*

- The physical properties and characteristics of the packaging shall enable a number of trips or rotations in normally predicable conditions of use.
- Possibility of processing the used packaging in order to meet health and safety requirements for the workforce.

- Fulfill the equipments specific to recoverable packaging when the packaging is no longer reused and thus become waste.

3. *Requirements specific to the recoverable nature of packaging :*

- Packaging recoverable in the form of material recycling: Packaging must be manufactured in such a way as to enable the recycling of a certain percentage by weight of the materials used into the manufacture of marketable products, in compliance with current standards to the Community. The establishment of this percentage may vary, depending on the type of material of which the packaging is composed.
- Packaging recoverable in the form of energy recovery: Packaging waste processed for the purpose of energy recovery shall have a minimum inferior calorific value to allow optimisation of energy recovery.
- Packaging recoverable in the form of composing: Packaging waste processed for the purpose of composting shall not hinder the separate collection and the composition process or activity into which it is introduced.
- Biodegradable packaging : Biodegradable packaging waste shall be of such a nature that is capable of undergoing physical, chemical, thermal or biological decomposition such that most of the finished compost ultimately decomposes into carbon dioxide biomass and water.

RECYCLED PLASTICS IN FOOD PACKAGING
FDA ACTIONS AND CONCERNS - U.S. VIEW

INTRODUCTION - Use of Recycled Plastic for specific end uses has been introduced in US as per FDA directives.

A variety of plastic materials are used for food packaging applications. The low molecular weight components such as monomers and additives in the form of antioxidants, stabilizers, plasticisers, etc. which are used during processing may migrate from the packaging material into the product packed inside and may cause contamination which could be dangerous.
Recycling of plastics may cause further problems of contamination. In view of the seriousness of the problem of solid waste, the FDA supports recycling as a solution to the solid waste problem which is consistent with its mandate to protect public health.
The legal considerations, recycling procedures, potential problems and the testing methods are highlighted here.

LEGAL CONSIDERATIONS FOR USE OF RECYCLED MATERIALS

- Food, Drug and Cosmetic Act
- Food Additive Regulations

POTENTIAL PROBLEMS WITH RECYCLED PLASTICS

- Permeability - contamination
- Variety of types/grades of plastics
- Variety of additives

PLASTICS WASTE MANAGEMENT

Concerned with the growth of generation of Urban Solid Waste, including plastics waste in tune with the diversification of packaging industry, the Government of India the Ministry of Environment and Forests have formulated **Municipal Solid Waste (Management and Handling) Rules 2000.** And it is obligatory on the part of all the local authorities in the country to fulfill the requirements laid down in these rules in respect of collection, segregation and disposal of waste. To achieve these objectives, Municipal Authorities all over India have geared their activities to organize and manage municipal solid waste and work out the management and disposal options as per the composition. Slates like Delhi, Himachal Pradesh, Haryana, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, U.P. and West Bengal have formulated plans of action to fulfill the requirement of the rules.

The disposable products used extensively in medical and healthcare field, are invariably based on plastics. According to the **Bio-medical Waste (Management and Handling) Rules 1998** (Ministry of Environment and Forests) these disposables form medical waste, which are not required to be recycled but disposed of through autoclaving and incineration. A number of private agencies have come up in India, which take responsibilities for disposal of bio-medical waste.

In India, collection and segregation of plastics waste as recyclables are value added products and it is a business for lakhs of rag pickers and waste dealers. The plastics waste gives higher value per kg. as against paper and cardboards. Amongst the technical disposal options for plastics waste, material recycling is the major one as practised all over India. The BIS has formulated a Guideline IS - 14534 giving details of various stages of recycling and the limitations.

In the collection and segregation of waste, **plastics litterbins** are normally used. Municipal authorities all over India have launched programmes for collection and segregation of waste at source through plastic bins to implement **Municipal Solid Waste (Management and Handling) Rules 2000.**

RECYCLING PROCEDURES

- Reuse of in-house plant trim
- Physical processing
  - Grinding and washing
  - Melting and reforming
- Chemical processing (Regeneration)
  - Polymer depolymerized
  - Regenerated reagents purified.

ISSUES

- Quality and control of feedstock
- Quality of recycling process
- Intended end use

SOURCES CONTROL

- Process considerations
  - Physical removal or avoidance of surfactants, inks, adhesives in wash water
  - Removal of contaminates

- Feedstock consideration
  - Polymer type
  - Additive levels
  - Cleanliness

- **TYPES OF USES**
- Substitute for virgin
- Use with barrier material
- Use with selected food types

CHEMICAL CONTAMINANTS

- Application of threshold of Regulation Policy
- 0.5 ppb dietary intake level+negligble risk

USES OF RECYCLED POLYMERS TO WHICH FDA HAS NO OBJECTION

- **Physical - General Collection**
  PE Grocery bags
  PS Egg cartons
  PET Fresh produce containers
  PET Food-contact articles (surrogate testing data)

- **Chemical**
  PET Food-contact articles, from monomers or oligomers (surrogate testing data)

- **Physical - Controlled Collection**
  PE Harvesting crates for fresh produce,
  & Shipping containers for meat, poultry,
  PP & seafood
  PS plates, cutlery, trays, cups, containers, lids, fruit and vegetables
  Containers, food-service clamshells, meat and poultry trays,
  Airline snack trays.

Source: Centre for Food Safety & Applied Nutrition, PDA: USA.
Modern Hood Packaging, Publication: Indian Institute of Packaging,
Mumbai 1998 - P 757-761.

Recommendations

- Implement the Municipal Solid Waste Rules (2000) effectively. State/Local Authorities to provide infrastructure for waste management

- Make Packaging Guidelines & BIS standards on recycling mandatory. Industry extends it's support & commitment
- Replicate Multipartite Waste Mgmt model (eg. Mumbai) on National Scale. Industry extends support
- Provide support/Infrastructure for Public communication/Education Programs (civic authorities)
- Adopt National Policy on induction of Incineration Technology for Waste Management. Industry will support Pilot Project.
- Evaluate/implement alternative technologies for recycling of Waste, e.g. Pilot Road Construction Project by industry
- Develop Recycling Park/Zones with concomitant fiscal incentives. Technology upgradation of small & tiny plastic recycling units.

References

1. Green challenge - C&EN - July 2002
2. Waste Disposal problems of the Petroleum Industry - Waste Control - The Atlantic Refining Company- Philadelphia, PA
3. A systems Approach to the Environmental Analysis of Pollution Minimization - Mr. Sven Erik Jorgeson.
4. Book- By Blackie Academic & Professional tilled " Clean Technology and the Environment
5. Indian Polymer Industry & Environmental Issues - presentation by Mr. K.G. Ramanathan - Sept 2002
6. Proceedings- International Conference on "Plastic Waste Management & Environment (15-16 March 2001)
7. National seminar on Economy & Ecology moving together with Plastics -May 2002, New Delhi - C1I & IPI.
8. Management of Municipal Solid Waste - Central Pollution Control Board.
9. A proposal for Up-gradation of the Plastic Recycling industry - Nov 2001 - ICPE.
10. Report of the Committee on Plastics Waste Disposal - by Central Pollution Control Board - Feb 2002
11. PWMI Newsletter - dtd 25.9.2002 - "Latest Trends in Post Use Plastic Recycling in Japan "
12. PWMI Newsletter - dtd 21.10.2000 - "Containers & Packaging - Recycling Law "
13. PWMI Newsletter - dtd 20.6.2000 - "Plastic Products, Plastic Waste & Resource Recovery (1998)
14. PWMI Newsletter - did. 19.10.1999
15. PWMI Newsletter- dtd. 18.7.1999 - "Plastic Products, Plastic Waste & Resource Recovery (1997)
16. PWMI Newsletter - dt. 17.4.1999 - "Development of Technology for full scale Enforcement of Containers & Packaging. Recycling law to turn into new products "
17. PWMI Newsletter — dtd. 15.4.1998 - "Liquefaction Technology"
18. PWMI Newsletter - dtd. 14.8.1997 - "Start of a new sage in Plastic Waste Recycling "
19. PWMI Newsletter - dtd 11.3.1996 - "Construction of the Niigata Plastic-to-Oil Conversion Centre "
20. PWMI Newsletter - dtd. 10.10.1995 - " Project started for the development of next-generation technology for the Liquefaction of Plastic wastes (Plastics Waste Management Institute-Japan) 1995
21. Brochure of " Ariake Incineration Plant - Tokyo met. Gov. "

22. Report on "The Ultimate Solid Waste Solution " by Interstate (IWT) Waste Technology
23. Report on "Law for promotion of sorted collection and Recycling of Containers & Packaging " 1995 - by Clean Japan Center
24. Report on "Chemistry of Dioxin Formation "- by Sandip Tyagi
25. Summary report by APME - "Weighing up the options - A comparative study of Recovery and Disposal routes" - March 1998
26. Summary report by APME - "New Insights into European Waste management Choices"
27. Report by APME on " Communique" - 1999
28. A report on "Recycling Center" by American Plastics Council - Aug 2002
29. Environmental issues on "Waste Management" by APME -Asso. For Plastics Manufacturers in Europe
30. Warmer Bulletin - Compost - Article on " Sustainable Management of Municipal Solid Waste "
31. Presentation to R. Misra Commission by ICPE
32. Presentation to R. Misra Commission by ICPE on Recycling - September 2001
33. Medical Plastics Data Services - Jan 2002 - Critical Considerations in Development of Blood bags and Platelet Storage Bags - Dr. CSB Nair
34. Medical Plastics data Services - May 2002 - Medical dfevice Industry - Mr. Sameer Tamhane -Industry Analyst,Frost and Sullivan - USA

Bibliography

General, Magazines, Plastics

1. Technical information of Metal Can packages - Indonesian Packaging Federation.
2. ICPE comments on the presentation on "Plastics & Environment" - Policy framework - by Smt. Sheela Rani - IAS - Chairperson - Tamil Nadu Pollution Control Board.
3. Down to Earth - Journal - World Summit on Sustainable Development - Sept 2002
4. ECVM - Industry charter for the production of VCM & PVC - European PVC Industry
5. PVC & Municipal Solid Waste Combustion Burden or Benefit - Netherlands Organisation for Applied Scientific Research - Dec 1998
6. European Council for Plasticisers & Intermediates - Aug 2001
7. A discussion of some of the Scientific issues concerning the use of PVC - CS1RO report -Molecular Science Australian National University -2001
8. Plastics - An analysis of Plastics consumption & Recovery in Western Europe - 1998 Association of Plastics Manufacturers in Europe (APME)
9. ET Polymers - Plastic woven sacks and its diversified applications September 1999 by Satyajeet Bhonsle - RIL
10. The Economic Times - Nov-Dec 2001 Polymers - PET
11. Magazine on the Power of Knowledge "Everything about Water" - April 2001
12. Magazine on Plastic Woven Sack news dated July 2000 -All India Flat tape Manufacturers Assn
13. Magazine on Plastics - A special supplement on E-Commerce in the Plastic industry - Summer 2000
14. Plastics Precis - Keeping Energy Efficiency top of Construction Agenda - Quarterly newsletter from the Association of Plastics Mfrs in Europe
15. Plasticisers in Europe - August 22, 2001
16. Plastics & Auto Industry
17. Plastics consumption in the Automobile Industry of Western Europe 1998 - German Association of Plastics Mfrs
18. Plastics Industry & The Environment - Strategic Issues & Initiatives - Aug 1998 - ICPE
19. Plastics & The Environment - Frequently Asked Questions - ICPE - Nov 2001 (FAQ)
20. Plastics & The Environment - Widespread Myths and Tactual Position - ICPE
21. Plastics & The Environment Point- Counterpoint - ICPE
22. ECO - Echoes - ICPE Newsletter - April - June 2002 - "Given Earth a Chance" - June 2002
23. ECO - Echoes - ICPE Newsletter - Jan - March 2002 - "Stay Cool with Plastics :
24. ECO - Echoes - ICPE Newsletter -Jan - March 2001 - "Plastics as Component of Municipal Solid Waste"
25. ECO - Echoes - ICPE Newsletter- April - June 2001 "Drinking Water - Bottled"
26. ECO - Echoes - ICPE Newsletter - Oct - Dec 2000 - "Encouraging Bin Culture"
27. ECO - Echoes - ICPE Newsletter - July - Sept 2000 - "The Environment Millennium - Time to Act"

28. PVC & Environment - compiled and issued by ICPE - Oct 2001
29. ICPE report on "Who is ICPE" ?
30. Report on "The role of PVC" by APME
31. Publication by "The Gazette of India" dtd 2.7.2002
32. Saving the Planet with Pesticides & Plastic by Dennis Avery - Hudson Institute
33. Perspective Plan for Indian Polymer Industry (2000-2010) - July 2001 - BAG Report

Energy, Life Cycle Analysis, Conservation

1. Environmental examples : Energy Recovery - Association of Plastics Manufacturers in Europe.
2. Environmental Consideration & Options in managing India's long -term energy strategy (ECO miles) -Tata Energy Research Institute-New Delhi
3. EPA - 600/7-76/034S - Environmental Consideration of selected Energy Conserving manufacturing process options - Pulp and Paper Industry report - Tata Energy Research Institute - New Delhi
4. Energy Audit Series - No 6 - The Aluminium Industry - Energy Consumption and Conservation in Aluminium Industry - issued jointly by Dept. of Energy and Dept. of Industry
5. Environmental Sources & Emissions handbook - Marshall Sittig - Noyes Data Corp -1970
6. Report no 9 - Industrial Energy Thrift Scheme - Energy used in Paper Industry - Dept of Industry.
7. Ministry of Environment & forests (MOEF) Notification - New Delhi - dated 25.9.2000
8. Project report on Life Cycle Assessment of Plastics in Packaging in terms of Cradle to Grave approach - Part I - Project report on Plastic Pouch v/s Glass Bottles for milk packaging - Sept 2002 - IIT Delhi
9. Project Report tin Life Cycle Assessment of Plastics in Packaging in terms of Cradle to Grave Approach - Part 11
10. Research Corner - Breathing Easier about Energy - Foundation for Clean Air Progress - 2002
11. Environmental Benefits - by APME - Balanced Material & Energy Recovery
12. Environmental Considerations of Selected Energy Conserving manufacture process Options - by Industrial Environmental Research Lab, Ohio
13. World Energy Consumption - The International Energy Outlook 2002

Bio-Degradability

1. Green Plastics - Plastics from Renewable Resources - Concept paper on Biodegradable Plastics by Dr. Y.B. Vasudeo & Dr. R. Rangaprasad, RIL
2. British Polythene Industries PLC - Biodegradable Plastic Friend or Foe? 1997
3. Biodegradability Plastics (1997) - Antonin SLEJSKA (www.vurv.cz)
4. Report on Biodegradable Polymers for the Environment" by Richard A. Gross & Bhanu Kalra

5. A Novel Biodegradable Copolyster for Films and Fibres - by Mike Baker , Bill Haille-Eastman Chemical Co.-Sept 2002

Recycling, Waste Management, Reuse

1. Green challenge - C&EN - July 2002
2. Waste Disposal problems of the Petroleum Industry - Waste Control - The Atlantic Refining Company - Philadelphia, PA
3. A systems Approach to the Environmental Analysis of Pollution Minimization - Mr. Sven Erik Jorgeson.
4. Book - By Blackie Academic & Professional titled " Clean Technology and the Environment
5. Indian Polymer Industry & Environmental Issues - presentation by Mr. K.G. Ramanathan-Sept 2002
6. Proceedings - International Conference on " Plastic Waste Management & Environment (15-16 March 2001)
7. National seminar on Economy & Ecology moving together with Plastics -May 2002, New Delhi-CU& IPI.
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32. Presentation to R. Misra Commission by ICPE on Recycling - September 2001
33. Medical Plastics Data Services - Jan 2002 - Critical Considerations in Development of Blood bags and Platelet Storage Bags - Dr. CSB Nair
34. Medical Plastics data Services - May 2002 - Medical device Industry - Mr. Sameer Tamhane-Industry Analyst, Frost and Sullivan - USA

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