

## RESEARCH ARTICLE

# The Ubiquitous Revolution: Diving into the World of Plastics

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The term “plastic” was derived, during early 1500s, from the Greek word *plastikos* which indicated “to mold” or “form” and was used in while sculpting figures made of wax or clay, reflecting the material’s property to be shaped. Another theory mentions that this word comes from Latin word *plasticus* (meaning: capable of moulding). It has been reported that the ancient Meso Americans (Olmec & Mayan civilizations, 1500 BCE) used to mix sap from the rubber tree with juice of morning glory vine to make containers and clothes water-resistant.

Only about a century ago, the word “plastics” became a common term for man-made or synthetic organic, high molecular weight, polymer materials that are moldable at high temperatures and solidify upon being cooled.

Every aspect of our human life is interwoven with the occurrence of some or other kind of plastic material. These highly versatile materials have predominantly restructured our very existence and living style by offering an inexpensive, safe, sanitary, convenient, durable product whose enchanting myriad of applications were nearly unthinkable, till a few decades ago. The advent of plastics, with their endless applications and opportunities, gave the philosophers a utopian vision of the future with abundant material wealth owing to man’s capability to shape almost anything and everything as per their whim and fancy.

Even then, this radically innovative material casts an appalling eclipse, posing serious environmental and health concerns. This article is an attempt to dive into the fascinating world of plastics—right from their serendipitous invention to their unescapable existence and the complex trap they have created. This story tries to explore the intricacies of the *toxic love story* between material marvel named ‘plastics’ and hyperconsumerism.

## The genesis: From imitation to innovation

The story of plastics commenced not with any short- or long-term planned research activity, instead, with a pressing need and a dash of ingenuity. In the mid-19th century, a New York based firm by the name Phelan & Collender offered a US \$10,000 reward for anyone who could offer a substitute for ivory, the then material of choice for production of billiard balls. Since, the availability of ivory was becoming sparse and highly expensive, due to the rampant slaughter of elephants, therefore, this challenge sparked the curiosity of John Wesley Hyatt, an American printer and inventor. In 1869, Hyatt, experimenting with cellulose nitrate (which was derived from cotton fibers treated with nitric acid), camphor, and alcohol, created a semi-synthetic material which he called “celluloid”. While not initially successful for billiard balls (as the early versions sometimes exploded upon impact!), celluloid soon found its niche in

Source: Internet



other applications, like photographic films, detachable collars, dentures etc. thereby, marking dawn of the ‘*plastic era*’.

However, celluloid was flammable and its properties were fairly limited. The true revolution came in 1907, with the invention of Bakelite by Leo Baekeland, a Belgian-born American chemist. Baekeland had been trying hard to create a non-flammable electrical insulator. By reacting phenol and formaldehyde, under controlled heat and pressure, he produced the first fully synthetic plastic which he termed “Bakelite”. Bakelite was found to be moldable, heat-resistant, and an exceptional electrical insulator. The arrival of Bakelite leapfrogged mankind into a new and fabulous era of human creativity where man could design and produce materials with custom-made properties. Bakelite rapidly pierced the consumer market due to its extensive applications in diverse sectors and products—right from jewellery to electrical parts and radio casings to kitchenware thereby demonstrating the colossal potential of this synthetic polymer.

This pioneering work ushered mankind into the new world of polymer chemistry, and even before the start of World War-II (around 1930’s), several new versatile products like Polyvinyl Chloride (PVC), Polystyrene (PS), Polyethylene (PE) and Nylon were available on the shelf. These new plastics offered a diverse range of properties—right from flexibility and transparency to strength and chemical resistance, thereby, paving way for their amalgamation into innumerable aspects of everyday life.

## The revolution: Reshaping our lives

The discovery of this marvel product—plastics—was revolutionary in every possible sense, and truly so because for the very first time, human manufacturing was not constrained by the limits of nature. The era after World War-II witnessed a disruptive increase in the production, regular use and exploring diverse applications of plastics. The grandeur success of US military may be significantly owed to their country’s booming plastic industry. For example, Nylon, invented by Wallace Carothers in 1935, was widely used for making parachutes, ropes, armours, helmet liners etc. Similarly, Plexiglas, a shatter resistant plastic, invented in Germany by Otto Röhm, provided an alternative to glass for aircraft windows.

Being lightweight, durable, adaptable, multi-purpose and most importantly the low production cost made plastics an ideal replacement for traditionally used items such as metal, glass and wood. This proliferation of plastics prompted a gigantic alteration in our lifestyle, offering unprecedented convenience, accessibility and seminal change in consumerism.

**Healthcare:** The advent of disposable syringes, blood bags, catheters, and other medical devices transformed the healthcare sector. These single-use and durable plastics shrunk the risk of infections contributing to improved patient safety and hygiene standards at fairly manageable costs. Even the advanced medical equipment, prosthetics, and implants, needed for enhancing the quality of life of the masses, became highly dependent on plastics. Silicone, an advanced type of plastic (made of molecular chains of

silicon and oxygen), is used in breast implants and silicone hydrogels are used for making optical lenses.

**Farm equipment:** Agriculture, too, has encapsulated plastics for applications like greenhouse films, irrigation pipes, mulch films, and storage containers. These applications have helped improve crop yields, conserve water, and reduce post-harvest and post-production losses, contributing to food security and availability.

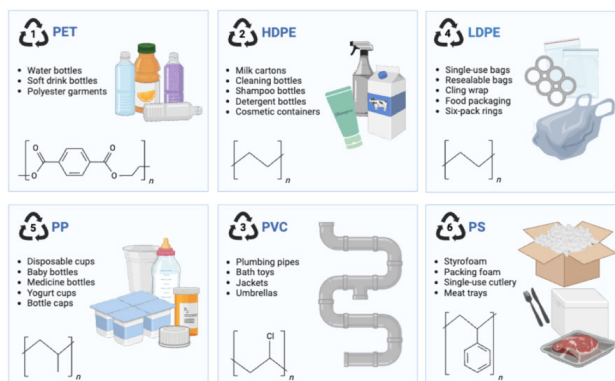
**Devices:** Electronics became more affordable and accessible due to the use of plastics in casings, insulation, and components. The lustrous and diverse designs of our smartphones, laptops, and televisions have been possible due to the moldability and insulating properties of various polymers. Use of highly cost-effective and durable plastic components in electronic devices has led to their rapid market acceptability.

**Packaging:** Plastics revolutionized how products were stored, transported and sold. The aspects related to food preservation, transportation of fragile items, shelf life, spoilage & wastage and transportation costs all became exceedingly, both, producer and consumer-friendly, thereby, making a wider variety of products accessible to a larger population. The ubiquitous plastic bag, while now a symbol of environmental concern, initially represented a convenient and hygienic substitute to cloth or paper made bags.

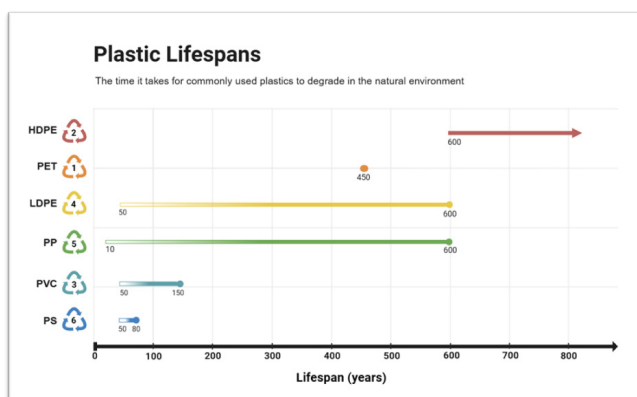
**Transportation:** The automotive and aerospace industries benefited immensely from the lightweight nature of plastics. Replacing heavier metal components with plastic parts led to improved fuel efficiency in vehicles and reduced weight in aircraft, contributing to energy savings and better performance. From dashboards and bumpers to interiors and structural elements in some advanced applications, plastics have become imperative to modern transportation.

Beyond these major segments, plastics have permeated almost every facet of our lives, from clothing and furniture to toys and construction materials. Their affordability and adaptability has drastically improved the quality of life for communities. Globally, affordable plastic household items have become conventional, nearly replacing the more expensive and less durable alternatives.

## Common Plastic Types



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## A kaleidoscope of polymers: The diverse world of plastic types and their uses

The term ‘plastics’ embraces a vast family of synthetic or semi-synthetic materials with a diverse chemical structures and physical properties. Some of the common types include:

- **Polyethylene (PE):** These are the most widely produced plastics, available in numerous densities (HDPE, LDPE, LLDPE) and used in diverse range of products, right from packaging films and grocery bags (LDPE) to bottles and containers (HDPE) and flexible tubing (LLDPE). PE is extensively used in agriculture for irrigation and mulching purposes.
- **Polypropylene (PP):** Known for its strength, durability, hardness and heat resistance, PP is used in reusable food containers, car parts and medical devices. Packaging and automobile sectors have greatly benefited from the diverse applications of PP.
- **Polyvinyl Chloride (PVC):** Versatile and significantly low cost, PVC can be made either rigid (for example in pipes, window frames) or flexible (when used in films, cables, synthetic leather), depending on the additives used during their production process. PVC pipes are common in construction and agriculture, while flexible PVC is an integral part of almost all consumer goods.
- **Polystyrene (PS):** These may either be rigid and brittle (cutlery, electronics casings) or foamed (Styrofoam for packaging and insulation). The uniqueness of PS lies in their being lightweight and insulating thereby, making its properties make it popular for protective packaging and disposable containers.
- **Polyethylene Terephthalate (PET):** The application of PET is mostly in beverage bottles and food containers due to strength, transparency, insulation, wide temperature use range (from  $-60^{\circ}\text{C}$  to  $130^{\circ}\text{C}$ ) and impermeability properties. PET is also used for making light weight, tear resistant textiles and in electrical and electronic industry.

The immense adaptability, customization and personalization properties are the main factors for widespread acceptance of plastics. Research has been ongoing to develop new polymers and refine the existing ones so that even more applications of plastics may be explored.

## The manufacturing mosaic: From fossil fuels to finished products

The expedition of every plastic item commences with raw materials, primarily derived from fossil fuels such as crude oil and natural gas. These hydrocarbons (or complex mixtures of organic compounds made entirely of carbon and hydrogen atoms) are processed through refining to produce different kinds of monomers (simple, low molecular weight hydrocarbons), which are the building blocks of polymers. Some of the fairly well-known monomers include ethylene (for polyethylene), propylene (for polypropylene), and vinyl chloride (for PVC). By using the polymerization process, monomers are linked together into long chains, forming the plastic polymer resin. Different catalysts and reaction conditions are used to control the length and structure of the polymer chains, thereby determining the properties of the resulting plastic.

The polymer resins are most often produced in the form of pellets or powders, which is converted into finished products using a variety of techniques, such as injection molding, blow molding, extrusion and thermoforming. Additives, like colorants, stabilizers, plasticizers and flame retardants, are often incorporated into the plastic resins during processing to enhance their properties, appearance, or processability.

## The dark side of durability: Environmental and health hazards

The very properties that make plastics so useful—their durability and resistance to degradation—are also the root of their most significant environmental problems. Unlike natural materials that decompose over time, most conventional plastics persist in the environment for thousands of years.

**Plastic pollution:** Vast quantities of plastic waste end up in landfills, where they not only occupy space but also leach harmful chemicals into the soil and groundwater. These leachates and other plastic wastes enter our water



Source: Internet



Source/Credit: <https://www.savehandloom.org/>

bodies ultimately millions of tonnes finally invade the ocean each year, thereby polluting and threatening the coastal ecosystems.

**Impact on wildlife:** Plastic pollution poses a direct threat to wildlife. Marine animals become entangled in plastic debris like discarded fishing nets and plastic bags, leading to injury, suffocation, and drowning. They often mistake plastic items as food, leading to choking, internal injuries and starvation due to the digestive systems getting blocked.

**Emission of Greenhouse Gases (GHGs):** The entire lifecycle of plastics, right from the extraction of fossil fuels to their production, transportation, and disposal (particularly of through the incineration route), contributes significantly to emission of GHGs, thereby exacerbating climate change. While plastics are often touted as lightweight alternatives that can reduce transportation emissions, the sheer volume of plastic produced and its miserable end-of-life management contribute significantly to their overall carbon footprint. As per 2019 estimates, plastics are responsible for around 3.3% of global GHG emissions (*Hannah Ritchie, Our World in Data, October 2023*).

**Toxicity:** Several chemicals used during the production of plastics like phthalates, bisphenol A (BPA), nonylphenols

(NPs), dioxins, furans, heavy metals and flame retardants, have high potential to leach out of plastic products and spread into food, water and environment. These chemicals are notorious endocrine disruptors, thereby having the potential to play havoc with the body's hormonal system, leading to a range of adverse health effects. Microplastics and the leachates from chemical additives are known causative agents for developmental arrests, neurotoxicity, reproductive issues and even several types of cancers. Research has already proven that leachates from plastics are causative agents for increased mortality in marine organisms, induce cell damage (cytotoxicity), inhibit photosynthesis & bioluminescence and cause oxidative stress.

**Micro- & Nano-Plastics (MNPs):** Gradually as the plastic products break down due to sunlight, wind, and wave action, they fragment into smaller and still smaller pieces called microplastics (less than 5 mm in size). These persistent MNPs are omnipresent and found in the air we inhale, the water we quench our thirst with, and soil that grows our food. They are ingested by marine organisms, from plankton to fish and seabirds, leading to physical harm, bioaccumulation of toxins and disruption of the food chain. Studies have also shown the presence of microplastics in human tissues and organs, raising concerns about serious health impacts.

The prestigious journal *Nature Medicine* reported in their April 2025 issue about the increasing MNP bioaccumulation overtime (from autopsy specimen samples of 2016 and 2024, collected retrospectively) in human brain, kidney and liver tissues. These researchers have also reported notable deposition of micro- and nano-plastics in cerebrovascular walls and immune cells (*Nat Med 31, 1114-1119 (2025)*). Another study conducted by Hu C. *et al.*, which was published in the *Journal of Toxicological Sciences*, reported the presence of microplastics in male reproductive system (testis) of canines and humans and ascertained that the total microplastics were nearly 3 times greater in human testes than in canine tissues, predominated by Polyethylene (PE). Other studies have established that microplastics translocate across the blood-brain barrier and have been detected in human blood.

## The Indian scenario: A unique set of challenges and innovations

India faces a unique set of challenges in managing plastic waste due to its large population, rapid urbanization, and complex unorganized, frail informal waste management sector. Our Nation generates colossal quantities of plastic waste, and while recycling rates are relatively high compared to some developed nations, a substantial portion still ends up uncollected and utterly mismanaged, contributing to environmental hazards and degradation.

The informal sector, mostly ragpickers (waste pickers), play the imperative role in collecting and sorting recyclable plastics in India. This labour-intensive system, while providing



Source: Internet

livelihoods for millions, often operates under perilous conditions and lacks adequate infrastructure and social safety nets. However, there are growing efforts to integrate the informal sector into formal waste management systems and improve their working conditions.

Indian government has implemented various regulations and initiatives to address the plastic waste problem, including ban on single-use plastics in several states, as well as Plastic Waste Management Rules (2016 and the amendments thereafter) that mandate producers' responsibility for the collection and processing of plastic waste (Extended Producer Responsibility or EPR). The effectiveness of these measures might have been limited with significant challenges still lingering in their effective implementation and enforcement.

The solitary silver lining that remains in such grim conditions is that our Nation is investing heavily on finding innovative R&D solutions to tackle the menace created by plastics, and these efforts are equally complemented through expansive grassroots level initiatives. Public and Private sector organizations, hand-in-hand with progressive mindset individuals and philanthropists, alike, are bidding hard to evolve alternative materials, promoting waste segregation, reduction and reuse practices, and finding creative ways to upcycle (refine, deploy, reuse) plastic waste into useful products, such as furniture, handicrafts, construction materials and laying of bituminous roads.

## Charting a sustainable course: The future of plastics

Addressing the crucial threats posed by plastics requires a multi-pronged approach involving extensive technological innovation, policy changes, consumer behavioural shifts, industry alliances, and trans-boundary collaborations.

**Reducing consumption and promoting reuse:** Though easier said than done, the prime and most efficient way to curb plastic pollution shall be to reduce our dependence on single-use plastics and instead embark upon and promote reusable alternatives. For example, encouraging and incentivizing the use of reusable bags, glass bottles, containers and cutlery shall significantly shrink the amount of plastic waste generated. In India, traditional practices of carrying reusable containers and net baskets (often made from cane or straw) for shopping and food need to be revived, socially accepted and promoted.

**Developing & enhancing waste management and recycling infrastructure:** There is a prudent need to invest profoundly in robust and dependable waste collection system, comprehensive sorting techniques (including semi-automation), and greener recovery-cum-recycling processes. Our government and private sector need to work hand-in-hand towards enormously enhancing the present meagre capacity and efficiency of the recycling facilities (including their decentralization), and developing innovative

eco-friendly recycling processes & technologies that have the potential to handle diverse categories of plastic wastes. Formalizing, encouraging, incentivizing and capacity building of the informal waste management sector shall certainly create greener footprints by improving recycling rates.

**Developing biodegradable and compostable alternatives:**

There is a pressing need and clarion call to substantially commit our resources (funds, focus, time and innovation) into development and deployment of environmentally acceptable, biodegradable and compostable plastics, and its alternatives, which should be originate and be derived from renewable resources. Exploring and promoting the development and use of such alternatives is the ultimate call of the hour.

**Harnessing greener chemical recycling processes:**

Chemical recycling, which breaks down plastics into their its building blocks that can then be used to produce either fresh usable plastics or associated chemicals, holds a promising potential for dealing with plastic waste that is otherwise difficult to recycle through mechanical routes. S&T and engineering advancements in filling the knowledge-gaps related to this field might offer promising ways to effectively close the loop on plastic production and subside our dependence on the non-renewable fossil fuels.

**Strengthening regulations and enforcement:** Our esteemed Parliament and the pillars of our democracy, in unison, need to work towards development of stringent norms and policies to implement and enforce stricter legal frameworks and regulations on the production, use and disposal of plastics. Proper and expansive implementation of the Extended Producer Responsibility (EPR) schemes that hold producers accountable for the end-of-life management of their products are equally decisive in the achieving long term sustainable and replicable success stories. Synchronizing all-inclusive agreements, cooperation and collaborations at local, regional and international levels shall be equally mandatory to address the menace of plastic pollution.

**Raising social awareness, public participation and fostering behavioural transformation:** Educating the public about the environmental and health impacts of plastic pollution and promoting sustainable consumption habits are of utmost essence. Empowering individuals and involving local communities for capacity building shall certainly facilitate the public in making informed choices. Raising social awareness amongst the masses and enabling them to showcase participative decision-making roles shall surely inculcate transformative responsible behaviour patterns, thereby enabling reduction of single-use plastic consumption and proper waste disposal thereby embossing a noteworthy difference.

## Conclusion: Navigating the plastic paradox

Without an iota of doubt, it can be stated that plastics revolutionized our lives, bringing unprecedented convenience and innovation across a multitude of sectors. However, their persistent nature, sheer scale of production, and more importantly, the irrational, imprudent and impulsive consumption have created significant

environmental and health catastrophe. Addressing this challenge requires a phenomenal shift in how the society produces, uses, and disposes of plastics. By embracing a circular economy model, investing in sustainable, eco-friendly alternatives, robust greener waste management systems, fostering responsible consumer behaviour, and implementing effective policies, the world can navigate the plastic paradox and work towards a future where the benefits of these versatile materials are realized without compromising the health of our planet and ourselves.

The journey from the accidental invention of celluloid to the ubiquitous presence of plastics is a testament to human ingenuity. Now, we must apply that same ingenuity to create a more sustainable relationship with this material marvel. ♦

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