A Brief History of Plastic's Conquest of the World

The May 29, 2011 issue of Scientific American includes this excerpt from "Plastic: A Toxic Love Story" by Susan Freinkel, charting changes in the economy, society and the environment as inexpensive synthetic plastics replaced ivory, tortoise shell and other limited natural materials, and led to manufacture of a new generation of consumer goods.

Keywords

Transcript
A Brief History of Plastic's Conquest of the World
Cheap plastic has unleashed a flood of consumer goods
By Susan Freinkel  May 29, 2011
Editor's Note: The following is an excerpt from Susan Freinkel's book, Plastic: A Toxic Love Story.
Combs are one of our oldest tools, used by humans across cultures and ages for decoration, detangling, and delousing. They derive from the most fundamental human tool of all—the hand. And from the time that humans began using combs instead of their fingers, comb design has scarcely changed, prompting the satirical paper the Onion to publish a piece titled "Comb Technology: Why Is It So Far Behind the Razor and Toothbrush Fields?" The Stone Age craftsman who made the oldest known comb—a small four-toothed number carved from animal bone some eight thousand years ago—would have no trouble knowing what to do with the bright blue plastic version sitting on my bathroom counter.
For most of history, combs were made of almost any material humans had at hand, including bone, tortoiseshell, ivory, rubber, iron, tin, gold, silver, lead, reeds, wood, glass, porcelain, papier-mâché. But in the late nineteenth century, that panoply of possibilities began to fall away with the arrival of a totally new kind of material—celluloid, the first man-made plastic. Combs were among the first and most popular
objects made of celluloid. And having crossed that material Rubicon, comb makers never went back. Ever since, combs generally have been made of one kind of plastic or another.
The story of the humble comb's makeover is part of the much larger story of how we ourselves have been transformed by plastics. Plastics freed us from the confines of the natural world, from the material constraints and limited supplies that had long bounded human activity. That new elasticity unfixed social boundaries as well. The arrival of these malleable and versatile materials gave producers the ability to create a treasure trove of new products while expanding opportunities for people of modest means to become consumers. Plastics held out the promise of a new material and cultural democracy. The comb, that most ancient of personal accessories, enabled anyone to keep that promise close.

What is plastic, this substance that has reached so deeply into our lives? The word comes from the Greek verb plassein, which means "to mold or shape." Plastics have that capacity to be shaped thanks to their structure, those long, flexing chains of atoms or small molecules bonded in a repeating pattern into one gloriously gigantic molecule. "Have you ever seen a polypropylene molecule?" a plastics enthusiast once asked me. "It's one of the most beautiful things you've ever seen. It's like looking at a cathedral that goes on and on for miles."

In the post–World War II world, where lab-synthesized plastics have virtually defined a way of life, we've come to think of plastics as unnatural, yet nature has been knitting polymers since the beginning of life. Every living organism contains these molecular daisy chains. The cellulose that makes up the cell walls in plants is a polymer. So are the proteins that make up our muscles and our skin and the long spiraling ladders that hold our genetic destiny, DNA. Whether a polymer is natural or synthetic, chances are its backbone is composed of carbon, a strong, stable, glad-handing atom that is ideally suited to forming molecular bonds. Other elements—typically oxygen, nitrogen, and hydrogen—frequently join that carbon spine, and the choice and arrangement of those atoms produces specific varieties of polymers. Bring chlorine into that molecular conga line, and you can get polyvinyl chloride, otherwise known as vinyl; tag on fluorine, and you can wind up with that slick nonstick material Teflon.

Plant cellulose was the raw material for the earliest plastics, and with peak oil looming, it is being looked at again as a base for a new generation of "green" plastics. But most of today's plastics are made of hydrocarbon molecules—packets of carbon and hydrogen—derived from the refining of oil and natural gas. Consider ethylene, a gas released in the processing of both substances. It's a sociable molecule consisting of four hydrogen atoms and two carbon atoms linked in the chemical equivalent of a double handshake. With a little chemical nudging those carbon atoms release one bond, allowing each to reach out and grab the carbon in another ethylene molecule. Repeat the process thousands of times and voilà!, you've got a new giant molecule, polyethylene, one of the most common and versatile plastics. Depending on how it's processed, the plastic can be used to wrap a sandwich or tether an astronaut during a walk in deep space.

This New York Times dispatch is more than a hundred and fifty years old, and yet it sounds surprisingly modern: elephants, the paper warned in 1867, were in grave danger of being "numbered with extinct species" because of humans' insatiable demand for the ivory in their tusks. Ivory, at the time, was used for all manner of things, from buttonhooks to boxes, piano keys to combs. But one of the biggest uses was for
billiard balls. Billiards had come to captivate upper-crust society in the United States as well as in Europe. Every estate, every mansion had a billiards table, and by the mid-1800s, there was growing concern that there would soon be no more elephants left to keep the game tables stocked with balls. The situation was most dire in Ceylon, source of the ivory that made the best billiard balls. There, in the northern part of the island, the Times reported, "upon the reward of a few shillings per head being offered by the authorities, 3,500 pachyderms were dispatched in less than three years by the natives." All told, at least one million pounds of ivory were consumed each year, sparking fears of an ivory shortage. "Long before the elephants are no more and the mammoths used up," the Times hoped, "an adequate substitute may [be] found." Ivory wasn't the only item in nature's vast larder that was starting to run low. The hawksbill turtle, that unhappy supplier of the shell used to fashion combs, was becoming scarcer. Even cattle horn, another natural plastic that had been used by American comb makers since before the Revolutionary War, was becoming less available as ranchers stopped dehorning their cattle.

In 1863, so the story goes, a New York billiards supplier ran a newspaper ad offering "a handsome fortune," ten thousand dollars in gold, to anyone who could come up with a suitable alternative for ivory. John Wesley Hyatt, a young journeyman printer in Upstate New York, read the ad and decided he could do it. Hyatt had no formal training in chemistry, but he did have a knack for invention—at the age of twenty-three, he'd patented a knife sharpener. Setting up in a shack behind his home, he began experimenting with various combinations of solvents and a doughy mixture made of nitric acid and cotton. (That nitric acid–cotton combination, called guncotton, was daunting to work with because it was highly flammable, even explosive. For a while it was used as a substitute for gunpowder until producers of it got tired of having their factories blow up.)

As he worked in his homemade lab, Hyatt was building on decades of invention and innovation that had been spurred not only by the limited quantities of natural materials but also by their physical limitations. The Victorian era was fascinated with natural plastics such as rubber and shellac. As historian Robert Friedel pointed out, they saw in these substances the first hints of ways to transcend the vexing limits of wood and iron and glass. Here were materials that were malleable but also amenable to being hardened into a final manufactured form. In an era already being rapidly transformed by industrialization, that was an alluring combination of qualities—one hearkening to both the solid past and the tantalizingly fluid future. Nineteenth-century patent books are filled with inventions involving combinations of cork, sawdust, rubbers, and gums, even blood and milk protein, all designed to yield materials that had some of the qualities we now ascribe to plastic. These plastic prototypes found their way into a few decorative items, such as daguerreotype cases, but they were really only intimations of things to come. The noun plastic had not yet been coined—and wouldn't be until the early twentieth century—but we were already dreaming in plastic.

Hyatt's breakthrough came in 1869. After years of trial and error, Hyatt ran an experiment that yielded a whitish material that had "the consistency of shoe leather" but the capacity to do much more than sole a pair of shoes. This was a malleable substance that could be made as hard as horn. It shrugged off water and oils. It could be molded into a shape or pressed paper-thin and then cut or sawed into usable forms. It was created from a natural polymer—the cellulose in the cotton—but had a versatility none of the known
natural plastics possessed. Hyatt's brother Isaiah, a born marketer, dubbed the new material celluloid, meaning "like cellulose."

While celluloid would prove a wonderful substitute for ivory, Hyatt apparently never collected the ten-thousand-dollar prize. Perhaps that's because celluloid didn't make very good billiard balls—at least not at first. It lacked the bounce and resilience of ivory, and it was highly volatile. The first balls Hyatt made produced a loud crack, like a shotgun blast, when they knocked into each other. One Colorado saloonkeeper wrote Hyatt that "he didn't mind, but every time the balls collided, every man in the room pulled a gun."

However, it was an ideal material for combs. As Hyatt noted in one of his early patents, celluloid transcended the deficiencies that plagued many traditional comb materials. When it got wet, it didn't get slimy, like wood, or corrode, like metal. It didn't turn brittle, like rubber, or become cracked and discolored, like natural ivory. "Obviously none of the other materials . . . would produce a comb possessing the many excellent qualities and inherent superiorities of a comb made of celluloid," Hyatt wrote in one of his patent applications. And while it was sturdier and steadier than most natural materials, it could, with effort, be made to look like many of them.

Celluloid could be rendered with the rich creamy hues and striations of the finest tusks from Ceylon, a faux material marketed as French Ivory. It could be mottled in browns and ambers to emulate tortoiseshell; traced with veining to look like marble; infused with the bright colors of coral, lapis lazuli, or carnelian to resemble those and other semiprecious stones; or blackened to look like ebony or jet. Celluloid made it possible to produce counterfeits so exact that they deceived "even the eye of the expert," as Hyatt's company boasted in one pamphlet. "As petroleum came to the relief of the whale," the pamphlet stated, so "has celluloid given the elephant, the tortoise, and the coral insect a respite in their native haunts; and it will no longer be necessary to ransack the earth in pursuit of substances which are constantly growing scarcer."

Celluloid appeared at a time when the country was changing from an agrarian economy to an industrial one. Where once people had grown and prepared their own food and made their own clothes, increasingly they were eating, drinking, wearing, and using things that came from factories. We were fast on our way to becoming a country of consumers. Celluloid was the first of the new materials that would level the playing field for consumption, as historian Jeffrey Meikle pointed out in his insightful cultural history American Plastic. "By replacing materials that were hard to find or expensive to process, celluloid democratized a host of goods for an expanding consumption-oriented middle class." Ample supplies of celluloid allowed manufacturers to keep up with rapidly rising demand while also keeping costs down. Like other plastics that would follow, celluloid offered a means for Americans to buy their way into new stations in life.

Perhaps celluloid's greatest impact was serving as the base for photographic film. Here celluloid's gift for facsimile achieved its ultimate expression, the complete transmutation of reality into illusion, as three-dimensional flesh-and-blood beings were transformed into two-dimensional ghosts shimmering on a screen. Here, too, celluloid had a powerful leveling effect in several ways. Film offered a new kind of entertainment, available to and shared by the masses. A dime bought anyone an afternoon of drama,
romance, action, escape. Audiences from Seattle to New York roared at the antics of Buster Keaton and thrilled to hear Al Jolson speak the first words in a talkie: "Wait a minute, wait a minute, you ain't heard nothin' yet." The mass culture of film reeled across class, ethnic, racial, and regional lines, drawing one and all into shared stories and imbuing us with the sense that reality itself is as changeable and ephemeral as the names on the movie marquee. With film, an old elite was dethroned; the glamour once associated with class and social standing was now possible for anyone with good cheekbones, some talent, and a bit of luck.

Ironically, the world opened by celluloid film nearly killed the celluloid-comb industry. In 1914, Irene Castle, a ballroom dancer turned movie star, decided to cut her long hair into a short bob, prompting female fans across the country to take scissors to their own hair. Nowhere did those shorn locks fall harder than in Leominster, Massachusetts, which had been the country's comb capital since before the Revolutionary War and which was now the cradle of the celluloid industry, much of it devoted to combs. Nearly overnight, half of the comb companies in town were forced to shut down, throwing thousands of comb makers out of work. Sam Foster, owner of Foster Grant, one of the town's leading celluloid-comb companies, told his workers not to worry. "We'll make something else," he assured them. He hit on the idea of making sunglasses, creating an entirely new mass market. "Who's that behind those Foster Grants?" the company later teased in ads that featured photographs of celebrities such as Peter Sellers, Mia Farrow, and Raquel Welch hidden behind dark lenses. With a quick trip to the local drugstore, anyone could acquire the same glamorous mystique.

For all its significance, celluloid had a fairly modest place in the material world of the early twentieth century, limited mainly to novelties and small decorative and utilitarian items, like the comb. Making things from celluloid was a labor-intensive process; combs were molded in small batches and still had to be sawed and polished by hand. And because the material was so volatile, the factories were like tinderboxes. Workers often labored under a constant spray of water, but fires were still common. It wasn't until the development of more cooperative polymers that plastics truly began to transform the look, feel, and quality of our lives. By the 1940s, we had both the plastics and the machines to mass-produce plastic products. Injection-molding machines—now standard equipment in plastics manufacturing—turned raw plastic powders or pellets into a molded, finished product in a one-shot process. A single machine equipped with a mold containing multiple cavities could pop out ten fully formed combs in less than a minute.

DuPont, which bought one of the original celluloid companies in Leominster, released photos in the mid-1930s showing the daily output of a father-and-son pair of comb makers. In the photos, the father is standing next to a tidy stack of three hundred and fifty celluloid combs, while ten thousand injection-molded combs surround the son. And although a single celluloid comb cost one dollar in 1930, by the end of the decade one could buy a machine-molded comb of cellulose acetate for anywhere from a dime to fifty cents. With the rise of mass-production plastics, the fanciful decorative combs and faux ivory dresser sets so popular in the celluloid era gradually disappeared. Combs were now stripped down to the most essential elements—teeth and handle—in service of their most basic function. Bakelite, the first truly synthetic plastic, a polymer forged entirely in the lab, paved the way for successes
like that of DuPont's injection-mold-comb-making son. As with celluloid, Bakelite was invented to replace a scarce natural substance: shellac, a product of the sticky excretions of the female lac beetle. Demand for shellac began shooting up in the early twentieth century because it was an excellent electrical insulator. Yet it took fifteen thousand beetles six months to make enough of the amber-colored resin needed to produce a pound of shellac. To keep up with the rapid expansion of the electrical industry, something new was needed.

As it turned out, the plastic Leo Baekeland invented by combining formaldehyde with phenol, a waste product of coal, and subjecting the mixture to heat and pressure was infinitely more versatile than shellac. Though it could, with effort, be made to mimic natural materials, it didn't have celluloid's knack for imitation. Instead, it had a powerful identity of its own, which helped encourage the development of a distinctively plastic look. Bakelite was a dark-colored, rugged material with a sleek, machinelike beauty, "as stripped down as a Hemingway sentence," in writer Stephen Fenichell's words. Unlike celluloid, Bakelite could be precisely molded and machined into nearly anything, from tubular industrial bushings the size of mustard seeds to full-size coffins. Contemporaries hailed its "protean adaptability" and marveled at how Baekeland had transformed something as foul-smelling and nasty as coal tar—long a discard in the coking process—into this wondrous new substance.

Families gathered around Bakelite radios (to listen to programs sponsored by the Bakelite Corporation), drove Bakelite-accessorized cars, kept in touch with Bakelite phones, washed clothes in machines with Bakelite blades, pressed out wrinkles with Bakelite-encased irons—and, of course, styled their hair with Bakelite combs. "From the time that a man brushes his teeth in the morning with a Bakelite-handled brush until the moment when he removes his last cigarette from a Bakelite holder, extinguishes it in a Bakelite ashtray and falls back upon a Bakelite bed, all that he touches, sees, uses will be made of this material of a thousand purposes," Time magazine enthused in 1924 in an issue that sported Baekeland on the cover. The creation of Bakelite marked a shift in the development of new plastics. From then on, scientists stopped looking for materials that could emulate nature; rather, they sought "to rearrange nature in new and imaginative ways." The 1920s and '30s saw an outpouring of new materials from labs around the world. One was cellulose acetate, a semisynthetic product (plant cellulose was one of its base ingredients) that had the easy adaptability of celluloid but wasn't flammable. Another was polystyrene, a hard, shiny plastic that could take on bright colors, remain crystalline clear, or be puffed up with air to become the foamy polymer DuPont later trademarked as Styrofoam. DuPont also introduced nylon, its answer to the centuries-long search for an artificial silk. When the first nylon stockings were introduced, after a campaign that promoted the material as being as "lustrous as silk" and as "strong as steel," women went wild. Stores sold out of their stock in hours, and in some cities, the scarce supplies led to nylon riots, full-scale brawls among shoppers. Across the ocean, British chemists discovered polyethylene, the strong, moisture-proof polymer that would become the sine qua non of packaging. Eventually, we'd get plastics with features nature had never dreamed of: surfaces to which nothing would stick (Teflon), fabrics that could stop a bullet (Kevlar).

Though fully synthetic like Bakelite, many of these new materials differed in one significant way. Bakelite is a thermoset plastic, meaning that its polymer chains are hooked together through the heat and
pressure applied when it is molded. The molecules set the way batter sets in a waffle iron. And once those molecules are linked into a daisy chain, they can't be unlinked. You can break a piece of Bakelite, but you can't melt it down to make it into something else. Thermoset plastics are immutable molecules—the Hulks of the polymer world—which is why you'll still find vintage Bakelite phones, pens, bangles, and even combs that look nearly brand-new.

Polymers such as polystyrene and nylon and polyethylene are thermoplastics; their polymer chains are formed in chemical reactions that take place before the plastic ever gets near a mold. The bonds holding these daisy chains together are looser than those in Bakelite, and as a result these plastics readily respond to heat and cold. They melt at high temperatures (how high depends on the plastic), solidify when cooled, and if made cold enough can even freeze. All of which means that, unlike Bakelite, they can be molded and melted and remolded over and over again. Their shape-shifting versatility is one reason thermoplastics quickly eclipsed the thermosets and today constitute about 90 percent of all the plastics produced.

Many of the new thermoplastics at one time or another found their way into combs, which, thanks to injection molding and other new fabrication technologies, could be made faster and in far greater quantities than ever before—thousands of combs in a single day. This was a small feat in and of itself, but multiplied across all the necessities and luxuries that could then be inexpensively mass-produced, it's understandable why many at the time saw plastics as the harbinger of a new era of abundance. Plastics, so cheaply and easily produced, offered salvation from the haphazard and uneven distribution of natural resources that had made some nations wealthy, left others impoverished, and triggered countless devastating wars. Plastics promised a material utopia, available to all.

At least, that was the hopeful vision of a pair of British chemists writing on the eve of World War II. "Let us try to imagine a dweller in the 'Plastic Age,'" Victor Yarsley and Edward Couzens wrote. "This 'Plastic Man' will come into a world of colour and bright shining surfaces...a world in which man, like a magician, makes what he wants for almost every need." They envisioned him growing up and growing old surrounded by unbreakable toys, rounded corners, unscuffable walls, warpless windows, dirt-proof fabrics, and lightweight cars and planes and boats. The indignities of old age would be lessened with plastic glasses and dentures until death carried the plastic man away, at which point he would be buried "hygienically enclosed in a plastic coffin."

That world was delayed in coming. Most of the new plastics discovered in the 1930s were monopolized by the military over the course of World War II. Eager to conserve precious rubber, for instance, in 1941 the U.S. Army put out an order that all combs issued to servicemen be made of plastic instead of hard rubber. So every member of the armed forces, from private to general, in white units and black, got a five-inch black plastic pocket comb in his "hygiene kit." Of course, plastics were also pressed into far more significant service, used for mortar fuses, parachutes, aircraft components, antenna housing, bazooka barrels, enclosures for gun turrets, helmet liners, and countless other applications. Plastics were even essential to the building of the atomic bomb: Manhattan Project scientists relied on Teflon's supreme resistance to corrosion to make containers for the volatile gases they used. Production of plastics leaped during the war, nearly quadrupling from 213 million pounds in 1939 to 818 million pounds in 1945.
Come V-J Day, however, all that production potential had to go somewhere, and plastics exploded into consumer markets. (Indeed, as early as 1943, DuPont had a whole division at work preparing prototypes of housewares that could be made of the plastics then commandeered for the war.) Just months after the war's end, thousands of people lined up to get into the first National Plastics Exposition in New York, a showcase of the new products made possible by the plastics that had proven themselves in the war. For a public weary of two decades of scarcity, the show offered an exciting and glittering preview of the promise of polymers. There were window screens in every color of the rainbow that would never need to be painted. Suitcases light enough to lift with a finger, but strong enough to carry a load of bricks. Clothing that could be wiped clean with a damp cloth. Fishing line as strong as steel. Clear packaging materials that would allow a shopper to see if the food inside was fresh. Flowers that looked like they'd been carved from glass. An artificial hand that looked and moved like the real thing. Here was the era of plenty that the hopeful British chemists had envisioned. "Nothing can stop plastics," the chairman of the exposition crowed.

All those ex-GIs with their standard-issue combs were coming home to a world of not only material abundance but also rich opportunities created by the GI Bill, housing subsidies, favorable demographics, and an economic boom that left Americans with an unprecedented level of disposable income. Plastics production expanded explosively after the war, with a growth curve that was steeper than even the fast-rising GNP's. Thanks to plastics, newly flush Americans had a never-ending smorgasbord of affordable goods to choose from. The flow of new products and applications was so constant it was soon the norm. Tupperware had surely always existed, alongside Formica counters, Naugahyde chairs, red acrylic taillights, Saran wrap, vinyl siding, squeeze bottles, push buttons, Barbie dolls, Lycra bras, Wiffle balls, sneakers, sippy cups, and countless more things.

That proliferation of goods helped engender the rapid social mobility that took place after the war. We were a nation of consumers now, a society increasingly democratized by our shared ability to enjoy the conveniences and comforts of modern life. Not just a chicken in every pot, but a TV and stereo in every living room, a car in every driveway. Through the plastics industry, we had an ever-growing ability to synthesize what we wanted or needed, which made reality itself seem infinitely more open to possibility, profoundly more malleable, as historian Meikle observed. Now full-fledged residents of Plasticville, we began to believe that we too were plastic. As House Beautiful assured readers in 1953: "You will have a greater chance to be yourself than any people in the history of civilization."