RUBBER:

WHITE BLOOD OF THE FOREST

By Sue De Pasquale

"Rubber is a servant that follows us, literally, from the cradle to the grave. We are ushered into the world by the rubber-covered hands of a doctor in surroundings made sterile and quiet by this ubiquitous substance, and we make our exit in a rubber-gasketed coffin hauled by a rubber-tired hearse."

—The late Ralph Wolf, chemist and author, in an article in the October 1964 edition of Rubber World

It's impossible to imagine a world without rubber.

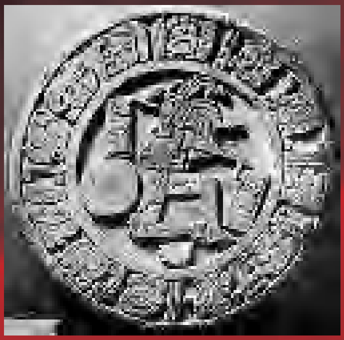
Each day, from the moment we rise to slip on our rubber-soled slippers and reach to turn off our rubber-insulated clock radio, we rely on this ubiquitous substance for work, play—and everything in between. While tires consume a majority of the rubber produced each year (accounting for 68 percent of annual worldwide rubber production), there are countless other uses for this durable substance, from the weather-stripping that keeps our houses warm to the surgical implants that can keep us alive. Rubber is used for the asphalt roadways we drive on, the athletic shoes that we run on, and the outdoor gym equipment our children play on.

Lest you think the importance of rubber is overstated, consider this: Many experts contend that rubber is the world's fourth most critical resource: after air, water and oil.

Today, the vast majority of the world's natural rubber supply—90 percent—comes from Southeast Asia. Thailand is the largest producer, followed by Indonesia. But natural rubber accounts for less than half the rubber produced in the world. The majority (about 60 percent in 2005, according to the International Rubber Study Group) is artificially produced, synthesized in factories around the world by mixing synthetic polymers with oil and other substances in "recipes" as varied as rubber's myriad uses.

While the innovations that made synthetic rubber commercially viable came fairly recently, with the advent of World War II, the first use and discovery of natural rubber dates back thousands of years. The story of how this milky substance, the "white blood of the forest," evolved from being a curious plaything to becoming a bulwark of our civilization is a fascinating tale—one of intrigue and atrocity, grandeur … and serendipity.

The story begins in 1600 B.C. in the jungles of ancient Mesoamerica, the area extending from today's central Mexico to Honduras and Nicaragua, where pre-Colombian civilizations flourished. It was here that the indigenous Olmec (which means "Rubber People" in the Aztec language) extracted a milk from the *Castilla elastica*, a type of rubber tree in the area. When



the sap-like extract—today known as latex—was dropped into boiling water, it would harden and could then be shaped into spheres … that bounced!

By the 1500s, the Aztecs were using latex extracted from the para rubber tree (*Hevea Brasiliensis*) to form 5-pound balls to play tlachtli, a game that required players to use their feet to get the ball down the field and through an elevated hoop. Teams were comprised of prisoners of war and the stakes were high: The losers were beheaded.

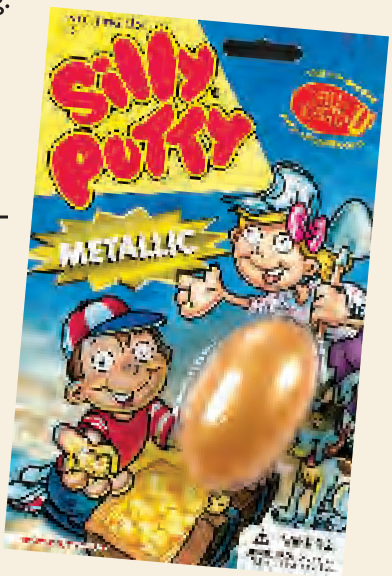
Though the Aztecs couldn't have known it at the time, the stretchiness of this new material was due to the scientific property of entropy—a system's inclination to move from a state of order to a state of disorder. Normally, rubber molecules, in the form of polymer chains, sit in a disordered tangled mess, like a plate of spaghetti. When stretched, the long polymer chains become aligned in one direction—reaching a state of order. But let go, and those chains return to a tangled mess. Thanks to entropy, the rubber snaps back to its original size and shape.

Whatever the cause for rubber's strange behavior, Spanish and Portuguese conquerors of the period were amazed by it. They believed the Aztecs' rubber balls to be enchanted by evil spirits, and they admired the Indians' ingenuity in using dried rubber to waterproof shoes and cloth.

Unfortunately, notes Wade Davis, an explorer-in-residence for *National Geographic* who specializes in ethnobotany, the study of plant lore and agricultural customs of populations, "All of these [early] products had a critical flaw. In hot weather a rubber cape would become a sticky

Did You Know?

- Though the para rubber tree (*Hevea Brasiliensis*) is the source of most natural latex for commercial rubber, the milk-like sap can be found in a wide variety of other plants and trees, including the dandelion and the fig.



- Silly Putty, that childhood favorite that makes its home in an egg-shaped container, was discovered by two scientists working independently to find an artificial alternative to natural rubber during World War II. By dropping boric acid into silicone oil, both James Wright of General Electric and Earl Warrick of Dow Corning happened upon the bouncing putty. Since 1950, more than 300 million eggs of silicone Silly Putty have been sold.

- Communities across the country—including areas of Santa Monica, Calif., New Rochelle, N.Y., and Washington, D.C.—have begun to install rubber sidewalks, an alternative to concrete, that bends (rather than buckles) as tree roots grow beneath—sparing root damage and protecting municipalities from injury lawsuits. Other benefits: easier snow removal, fewer injuries for runners and a smoother ride for those in wheelchairs.

Rubber is tapped (far left) by slicing away a thin sliver of bark from trees; the Aztec people used rubber to make 5-pound balls for the game tlachtli, depicted in stone carvings (left); vulcanization made pneumatic bicycle, carriage and, eventually, car tires possible. Henry Ford (right) set out to establish his own rubber plantation in Brazil in an ill-fated attempt to bolster the rubber supply.

shroud. In cold weather, a pair of rubber shoes would crack like porcelain."

Indeed, it was this "critical flaw" that prevented rubber from being used as much more than a novelty item over the next several centuries. (One particular novelty use gave the material its name, however; the 1770 discovery by Britain's Joseph Priestley that dried latex could be used for erasing or "rubbing out" pencil marks.) When early entrepreneurs tried to harvest and ship natural rubber, they found that it quickly rotted into a sticky, crumbly, smelly mess, due to the breakdown of its proteins (like milk curdling), and oxidation caused by its exposure to air.

Though scientists had some modest success at stabilization by adding such curatives as ammonia, the big breakthrough didn't come until 1839. "It was only the accidental discovery of vulcanization by Charles Goodyear that transformed rubber from a curiosity into a fundamental component of the industrial age," says Davis, a rubber expert tapped by the History Channel for its 2001 documentary, "Modern Marvels: Rubber."

In his experiments, Goodyear added sulfur to latex—and accidentally spilled some of the mixture on a stovetop. The combination of the sulfur and the heat succeeded in "curing" the rubber through a chemical process that cross-linked the material's individual polymer strands. The vulcanization process transformed rubber into a durable material, resistant to chemical action, heat and electricity. "The consequences," says Davis, "were profound." (For more information about Charles Goodyear and his invention, see page 16.)

In factories, manufacturers now had an effective material with which to seal machines—an important breakthrough with the arrival of the Industrial Age. The first pneumatic tires on bicycles and carriages became possible, foretelling the birth of the automobile. Entrepreneurs saw the potential rubber held and scrambled to make their fortunes. In an attempt to disrupt Brazil's rubber harvesting monopoly, England's Sir Henry Wickham in 1876 smuggled thousands of rubber tree seeds out of that country, planted them in London's Royal Botanical Gardens, then shipped the seedlings to Singapore and Indonesia, where huge rubber plantations soon flourished.

The quest for profits may have hit its low point with the "Rubber Barons" of the Amazon. At the height of their power, in the Brazilian city of Manaus, theirs was a frightening display of wealth. The ruling rich were said to quench the thirst of their horses with the finest champagne, according to the *National Geographic's* Davis. Such extravagance came at the expense of the local indigenous people, for harvesting rubber required a huge work force. The "Rubber Barons" ruled by terror—through enslavement, rape, starvation, torture and decapitation.

"The atrocities unleashed at the height of the rubber boom are simply too dreadful and formidable to even speak about," Davis says. And the horror was not confined to South America. In Africa, Belgium's King Leopold rang up enormous profits—and caused an abominable loss of life—through his "rape of the Congo." Leopold's soldiers would take settlements by storm, looting and forcing the women and children into imprisonment—ransomed against an arbitrarily decided weight of rubber the men must go off and "tap." During their absence, many of the imprisoned women were raped and died of starvation and disease. If a village's men refused to endure this forced labor, the entire settlement was wiped out, the soldiers cutting off hands (and sometimes heads) from the dead as trophies.

"There seems to be no reason to doubt that 10 to 15 million natives 'vanished' in the Congo during Leopold's rubber-grabbing years," notes United Kingdom analytical chemist and rubber historian John Loadman. Not all of these deaths "can be laid at the door of rubber or, indeed, at the door of Leopold himself," concedes Loadman, since during this time Africa was swept by a devastating plague of sleeping sickness. But the historian concludes, "If we take a not-unrealistic weight of rubber to come out of the Congo as 75,000 tons [68 million kilograms] and the rubber-related loss of native life as 7.5 million, we have the value of a Congolese native life—10 kilograms of rubber!"

Not all who aimed to profit from

Synthetic rubber formed into bales is prepared for packaging.

rubber were so unscrupulous. American automobile pioneer Henry Ford saw the strain that was put on the world's rubber supply during World War I, and in the 1920s set out to establish his own rubber plantation in Brazil—a sprawling 2.5 million-acre site known as "Fordlandia." The ambitious undertaking was ultimately ill-fated: Ford's entire plantation was wiped out by leaf blight, an insidious fungus that causes the young leaves of the rubber tree to die and continues to plague rubber growers in South America to this day.

A little more than a decade later, the winds of war would begin to blow again. And this time, the impact on rubber supplies would be nothing short of devastating.

By 1939, rubber had become the single largest commodity imported into the United States. Americans were consuming 592,000 tons of crude natural rubber a year—80 percent of it for automobile tires, according to chemist and historian James J. Bohning.

Perhaps most tellingly, "98 percent [of U.S. rubber imports] came from Asia," writes Bohning in "Styrene at Dow" (*Chemical Heritage Magazine*, Fall 2004).

Japan saw its chance and moved to put a stranglehold on the Allied rubber supply. "By the end of 1941," writes Bohning, "the Japanese had completely obstructed rubber supplies from the Far East; further, entry of the United States into the war demanded unprecedented supplies for military uses—estimated in 1942 to be 842,000 tons."

Consider: A single Sherman tank required half a ton of rubber and every warship required at least 20,000 rubber parts. Though the U.S. government mounted the biggest recycling campaign in the history of the world, encouraging Americans young and old to come forward to well-publicized scrap drives with their tires and wagon wheels, such patriotic efforts could only help in the very short term.

The United States needed a way to produce vast quantities of artificial rubber—and needed it fast.

What followed next was an unprecedented collaboration between government, industry and research scientists. Earlier study by the Goodyear and Goodrich companies had shown that butadiene (a gas that is a byproduct of petroleum refining) to be a promising ingredient for synthesized rubber; after considering some 200 other materials to co-polymerize with it, the U.S. Rubber Reserve and industry representatives ultimately decided to go with styrene, says Bohning. Beyond the two small molecules, or monomers, says Bohning, the "recipe" was fairly simple: soap, water, catalysts and a modifier. "There were three major hurdles to overcome: manufacturing large quantities of the two monomers, co-polymerizing them; and learning how to actually use the synthetic material instead of the natural one."

Thanks to the unflagging efforts of scientists at Dow Chemical, Union Carbide and other industry labs, these challenges were overcome in a remarkably short period of time, and within less than two years, U.S. industry was producing massive amounts of GR-S (Government Rubber-Styrene) synthetic rubber. In 1943, some 230,000 tons of synthetic rubber hit the market. "By the end of the war," notes Bohning, "production had reached the 1 million-ton milestone."

Since World War II, scientists have made great strides in polymer science, but the basic process for producing most synthetic rubber remains fairly straightforward. Synthetic polymers are mixed in the presence of soapsuds in a reactor, creating liquid latex. "The dry rubber in this milky liquid is then coagulated into crumbs, washed, dried and baled ready for shipment," notes the Rubber Manufacturers Association. Of course, this explanation is highly simplified.

In reality, there are thousands of different "recipes" for producing synthesized rubber, depending upon what it's needed for. DuPont's Neoprene, for

From Tree to Tire: The Manufacturing Process of Natural Rubber

Tapping: Plantation rubber trees must grow for about six years before they are ready to be "tapped." Tappers slice away a thin sliver of bark so the latex can flow down a sloping panel (think of blood oozing from a scrape on the skin) and then to a metal spike that sticks out of the tree and allows the latex to drip into the collecting cup (shown on cover). After several hours, the wound heals and the flow stops. (Repeated tapping actually stimulates more production of latex.) The gathered latex (about one fluid ounce) is then filtered, treated with acid to coagulate the colloidal particles, pressed into thin crepe sheets, then air- or smoke-dried for shipment and processing.

Mastication: The raw rubber is then put through a mechanical grinding process—known as mastication—to make it soft, plastic and sticky and easier to mix with compounding agents. Until 1920, masticators were rubber mills: steel rollers that rotated at different rates in a trough to shear and knead the rubber. The rollers were hollow, allowing cold water or steam to be circulated to control the temperature of the kneading process. In more modern times, the mill has been replaced by the Gordon plasticator, which operates like a household food chopper. The churning process heats the rubber to more than 360 degrees Fahrenheit, breaking it down.

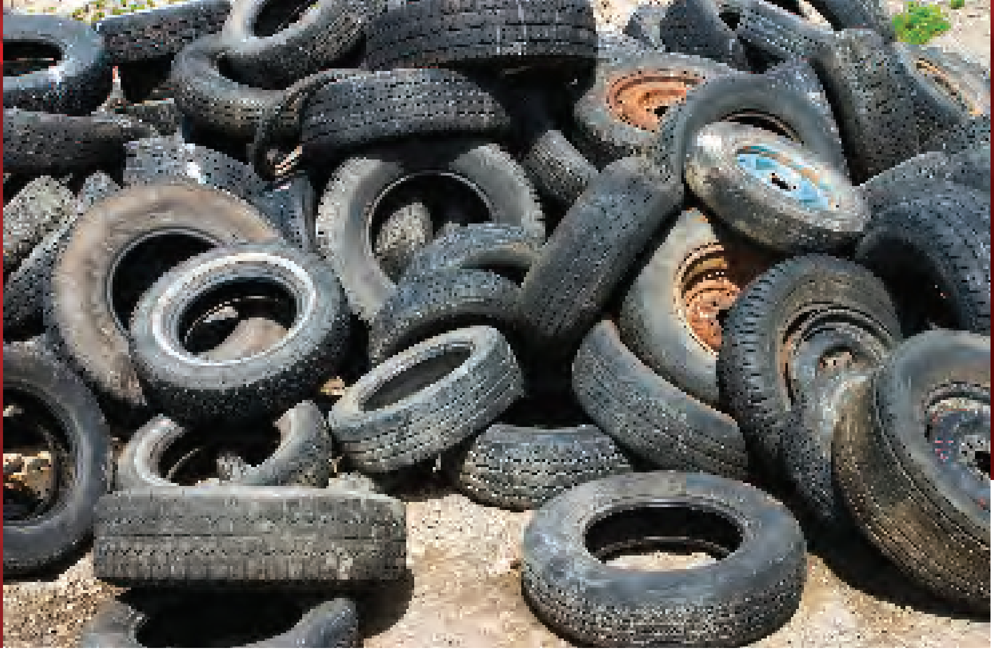
Mixing: The masticated rubber is next mixed with compounding ingredients, using rollers rotating in opposite directions. The ingredients include fillers (calcium carbonate or barium sulfate) that stiffen the mixture but don't materially strengthen it, and fillers that do add strength (carbon black, zinc oxide, magnesium carbonate and various clays). Pigments also are added, including zinc oxide, lithopone and organic dyes. Softeners (petroleum products such as oils or waxes, pine tar or fatty acids) help the various ingredients better meld. Ground sulfur (necessary later for hot vulcanization) is also usually added at this point.

Latex is coagulated and then dried on a conveyor for use in the production of automobile and truck tires.

Calendering/Extrusion: The rubber is next either calendered or extruded, depending on what it will be used for. Calenders are machines with rolls of equal diameter that can be adjusted for clearance between the rolls and for operating at different speeds. Calendered rubber is used for sheeting, fractioning (squeezing it into the texture of fabrics or cords) or coating. With extrusion, presses force the rubber compound through dies to form flat, tubular strips that can be used for rubber tubing, hose and inner tubes, and as stripping for setting windows and sealing doors.

Vulcanization: Once fabrication is complete, the mixture is vulcanized under high temperature and pressure. Rubber is often vulcanized in molds that are placed under compression in hydraulic presses, or subjected to external or internal steam pressure during heating,

SOURCE: Adapted from The History Channel Online Encyclopedia
www.historychannel.com/encyclopedia



North America generates approximately 300 million waste tires annually. Until 1985, nearly all of them were sent to landfills or collected for stockpile. In 2003, four out of five scrap tires in the U.S. were consumed in end-use markets.

example, the trade name for a family of rubbers based on polychloroprene, is particularly well-suited for insulation—from wetsuits, to electrical insulation—and is a mainstay for gaskets, hoses and corrosion-resistant coatings. Butyl rubber is impermeable to air and useful for applications requiring airtight rubber—such as adhesives, caulks and sealants. First used for the inner tubes of tires, this application remains a mainstay for butyl rubber even today.

In the manufacturing of tires, styrene-butadiene is often used to improve traction. But that's just the outer layer. Today's high-performance tires are comprised of layer after layer and the rubber recipes differ for each. The properties of the treadblock are different from the inner liner, which are different from the sidewall. Manufacturers also add a variety of chemicals to the rubber compounds (antioxidants, wax, anti-ozone materials) to improve wear and durability. During the first 50 years of the tire industry, tires were expected to last just 5,000 to 10,000 miles. Today's dealers sell some tires that are guaranteed to last up to 80,000 miles.

The downside of tire durability, of course, is the disposal problems it represents. Remember the cross-linking of rubber's molecules that vulcanization made possible? It's this same principle that makes rubber so hard to recycle. Waste tires are the most visible manifestation of this disposal problem. According to some estimates, North America generates approximately 300 million waste tires annually.

Until 1985, most scrap tires were either sent to landfills for burial or collected for stockpile. Minnesota was the first state to enact legislation and regulations to change the way scrap tires were being managed and by 1990, all states but two (Alaska and Delaware) had followed suit. Since then, progress in recycling or finding an "end use" for used tires has been marked. In 2003, approximately four out of five scrap tires in the United States were consumed in end-use markets, according to the 2003 edition of *U.S. Scrap Tire Markets 2003 Edition*, put out by the Rubber Manufacturers Association (RMA).

A large percentage of scrap tires—nearly 45 percent—were used for "tire derived fuel," "offering a cleaner and more economical alternative to coal in cement kilns, pulp and paper mills, and industrial and utility boilers," according to the report. Nearly 20 percent were consumed by the civil engineering market (shredded tires improve drainage and help prevent erosion when used in road and landfill construction and septic tank leach fields); and nearly 10 percent were ground up and used for playground and sports surfacing and rubber-modified asphalt.

The RMA also reported progress in reducing existing stockpiles of scrap tires. In 2003, some 275 million scrap tires remained in U.S. stockpiles, according to the RMA, a reduction of nearly 75 percent since 1990.

The Future of Rubber

What will the future hold for the "white blood of the jungle"?

While synthetic rubber is a multi-billion-dollar industry, countless applications demand the "real thing"—natural rubber. In the United States, in an effort to reduce dependency on foreign imports of natural rubber, particularly in the face of rising prices and uncertainty in the crude oil market, officials of the U.S. Department of Agriculture are looking for viable sources other than the rubber tree.

One candidate: the guayule (wa-YOO-leh), a small desert shrub resembling sagebrush that flourishes in the southwestern United States and Mexico. When the shrub is harvested and ground, the latex extracted has the same properties as natural rubber, with an additional benefit: It's hypoallergenic. In the medical industry, where rubber allergies are a serious problem for caregivers and patients alike, the guayule holds promise. To date, guayule has been used to produce hypoallergenic surgical gloves and catheters. Currently in production: guayule condoms.

In the years ahead, industry leaders will undoubtedly continue to explore natural rubber alternatives like the guayule, even as researchers forge ahead with innovations in polymer science, creating newer and better synthetic rubbers. Because one thing's for sure: The world's voracious consumption of the stretchy stuff will not be abating anytime soon.

Special thanks to Jeff Grau, senior hose development engineer, Parker - Industrial Hose Division, for his help with this article.

Rubber By the Numbers:

21 million tons: Amount of rubber consumed worldwide in 2005. Roughly half was consumed in Asia and islands of the Pacific.

90: Percent of worldwide natural rubber supply that comes from Southeast Asia. Thailand is the largest producer of natural rubber, Indonesia the second largest.

30 percent: Increase over the last decade in world production of rubber.

1960: Year that worldwide use of synthetic rubber surpassed natural rubber for first time.

8.8 million: Total number of tons of natural rubber produced worldwide in 2005.

12 million: Total number of tons of synthetic rubber produced worldwide in 2005.

1.3 billion: Number of tires manufactured annually around the world. (Tires account for 68 percent of worldwide rubber production.)

60: Percent used for tire manufacture of all rubber consumed in the U.S.

7: Number of gallons of oil needed to produce a single tire. (Five gallons serve as "feedstock," while the remaining two supply the energy necessary for manufacturing.)

290 million: Number of tires generated in the U.S. in 2003.

233 million: Number of tires in the U.S. that found an "end-use" in 2003 (for tire derived fuel, sports surfacing and rubber-modified asphalt, etc.); That's 80.3 percent of total tires generated.

45: Percent of total scrap tires generated in the U.S. in 2003 that were used for tire derived fuel

73 percent: Reduction of scrap tire stockpiles since 1990, in the U.S.

SOURCES: RUBBER MANUFACTURERS ASSOCIATION, U.S. SCRAP TIRE MARKETS 2003 EDITION, INTERNATIONAL INSTITUTE OF SYNTHETIC RUBBER PRODUCTS INC.

Where Does it All Come From?

Natural Rubber Production by Area

Rank	Region	2005 Production
1	Asia	8,320
2	Africa	403
3	Latin America	195

Thousands of Tons

Synthetic Rubber Production by Area

Rank	Region	2005 Production
1	Asia/Oceania	4,988
2	European Union	2,675
3	North America	2,430
4	Other European Nations	1,234
5	Latin America	653
6	Africa	78

Thousands of Tons

Where It Goes.

Rubber Consumption by Area

Rank	Region	2005 Consumption
1	Asia/Oceania	5,471
2	European Union	1,334
3	North America	1,316
4	Latin America	532
5	Other European Nations	227
6	Africa	120

Thousands of Tons

Synthetic Rubber Consumption by Area

Rank	Region	2005 Consumption
1	Asia/Oceania	5,308
2	European Union	2,565
3	North America	2,181
4	Other European Nations	976
5	Latin America	766
6	Africa	104

Thousands of Tons