From Wood To Paper

By Virginia Hughes

The world's increasing hunger for paper is fed by a process invented some 2,000 years ago

A MODERN PAPER MILL is a flurry of movement, noise, heat and steam. On cement-floor highways, forklift drivers navigate through wooden crates and steaming stainless steel pipes, sweating in temperatures that can reach 130 degrees Fahrenheit (about 54 degree Celsius). At the bottom of 10,000-gallon bubbling vats, sharp rotor blades stir chunky, fibrous paste. In a windowed control room, lined with button panels and computer screens, technicians watch the paste as it moves down the line—as fast as one mile per minute—getting thinner and drier and smoother until it emerges, 60 minutes later, in long, uniform rolls.

The world paper industry now produces more than 350 million tons of paper each year, a five-fold increase since the 1960s, for use as copy paper, newspaper, tissue and, less obviously, as filler material inside stereo speakers, electric plugs, even shoe inserts.

Pulp wood, above, is transported by train to a paper mill in Northern Ontario, Canada.

Paper has its beginnings in the forest, and more than half of all forestland is found in Russia, Brazil, Canada, the United States and China. Not surprisingly, these are also the countries that produce the most paper. The United States makes the most paper in the world, by far: 81.4 million tons in 2005, according to the latest data from the Food and Agriculture Organization of the United Nations. In comparison, second-place China made 53.5 million tons. (See sidebar: "Papermaking by the Numbers," page 15.)

Experts predict that in the coming decades, the world's major paper markets will shift. North America's paper production peaked in about 1991, says Joseph Genco, a professor of pulp and paper science and engineering at the University of Maine. "But in the last 10 or 12 years, the capital investment in the industry has been contracting very slowly." He adds that this lack of interest from investors, despite the continued improvements in paper machine technology, "is a fundamental problem. I think we're [the U.S.] becoming less globally competitive."

At the same time, the Eastern markets are on an upswing. "Even though paper was invented in China, the paper industry in that part of the world is relatively young," explains Timo Merikallio, senior vice president of technology at Botnia, a large pulp company in Finland.

Newly booming middle classes in China and Russia, especially, mean that international paper companies are starting to invest heavily in those regions. Experts predict their paper output will surpass North America's by 2015. "As their standard of living increases," Merikallio says, "so will their local consumption of paper."

Papermaking

Though the ancient Egyptians scripted hieroglyphics on thick sheets made from papyrus, historians credit paper's spread and standardization to the Chinese servant Cai Lun, who worked for the Chinese emperors in the early second century A.D. In the years before Cai Lun, the Chinese wrote on silk, bone and bamboo scrolls. But silk was prohibitively expensive, and bone and bamboo were heavy and difficult to transport.

In 105 A.D., Cai Lun presented his process to Emperor He: Mulberry bark, hemp, linen and water are mashed to a pulp. The pulp is poured onto a wood-framed fabric screen that's floating on water. The screen is then lifted so that the water can drain through the fabric, leaving just the long plant fibers on the surface. These fibers, once dried in the sun, could be peeled off the fabric as one extremely thin, ready-to-use sheet of paper.

With the invention of the printing press around 1450, demand for paper skyrocketed and mills appeared all over Europe. More than 200 years later, in 1690, the first mill opened in the New World, in Philadelphia, Pa. And in 1799, a French inventor developed the Fourdrinier machine, which thinned and smoothed the pulp on continuously moving assembly-line belts. A version of the Fourdrinier model is still used in most paper mills today.

Trees

More than 90 percent of the world's paper comes from trees of two types: hardwoods, like maple and oak, and softwoods, like pine and spruce. "The fibers in softwoods are longer and make a stronger sheet of paper," explains Gary Scott, chair of the Paper and Bioprocess Engineering Department at State University of New York, "but most paper has a mixture of the two."

Both types have the same basic anatomy: cellulose fibers glued together with a substance called lignin.

The crux of making paper is extracting the cellulose fibers from the wood and lining them up in the same direction. "The same technology is used globally," Merikallio says. "If you take a Chinese modern paper mill and compare it to a Finnish one, you probably wouldn't be able to tell the difference."

It all begins with harvested tree trunks, which are cut into 4- to 8-foot logs and then run through a debarking machine. Whirling blades in a chipping machine then cut the naked logs into 1-inch chips, which are either pumped through pipes or shipped to a nearby pulp mill.

Wood into Pulp

The purpose of pulping is to free the cellulose fibers from the rest of the wood. Wood is pulped using a highly efficient mechanical technique, a chemical technique, or a combination of the two.

About one-quarter of all pulping worldwide is done with a mechanical process, in which the wood is put into a "refiner" that grinds it between a rotating steel disk and fixed plate. Though this

How Much Paper Comes from One Tree?

The short answer is, it depends—on the tree size, wood density, what process you're using for pulping, and what kind of paper you're making.

In 1992, Tom Soder, a graduate student in the Pulp and Paper Technology program at the University of Maine, calculated that if you wanted to make a ton of printing paper by putting a mixture of hardwoods and softwoods, all 40 feet tall and about 7 inches in diameter, through the kraft pulping process, then you'd need 24 trees.

The Conservatree nonprofit extrapolates from Soder's method some other interesting figures:

- 1 ton of 100 percent virgin (non-recycled) newsprint uses 12 trees.
- 1 ton of coated, higher-end virgin magazine paper (used for magazines like *National Geographic* and many others) uses a little more than 15 trees.
- One tree makes 16.67 reams of copy paper or 8,333.3 sheets.

Paper giant Boise Cascade does its own calculating on its Web site. It states that one cord—a 128-cubic-foot pile of wood—makes 89,870 sheets of letterhead bond paper, or 2,700 copies of a 35-page newspaper.

The paper-making process begins when tree trunks are debarked and then fed into a chipping machine. The resulting wood chips, below, are then transported to a nearby pulp mill.

Wood chips are transformed into pulp, which is then mixed with water in pulpers that hold thousands of gallons (above). If pulp needs to be transported to a distant paper mill, it is dried and cut into rectangular sheets (below).

method ensures high yields—Scott estimates that 80 to 95 percent of the chips that go into the grinder turns into pulp—it doesn't get rid of much lignin, making the final product turn yellow or brown in the sun. Mechanical pulping is used mostly for newsprint or packaging papers.

Much more common is chemical pulping. In the chemical "kraft" process, wood chips are dumped in a vat of sulfuric acid and sodium chemicals, called a digester, and then pressure-cooked to remove about 90 to 95 percent of the lignin. The cooked pulp is then rinsed to remove the excess lignin and chemicals. At this stage, the remaining 5 or 10 percent of lignin in the pulp makes it brown. Chlorine dioxide, lye and ozone, among other chemicals, are added to bleach it into a bright white.

Chemical processes are much less fruitful than mechanical ones, says the University of Maine's Genco. "In a chemical process, you end up dissolving about half the wood solids away," he says. As a consequence, Genco says a lot of research is focused on increasing the yield and on producing other products—like ethanol—from the material that's not made into pulp.

At an integrated paper mill—that is, one that creates both pulp and paper—the bleached pulp feeds directly into a paper machine. At a simple pulp mill, the dried pulp is cut into rectangular sheets, which are stacked and shipped off to a paper mill.

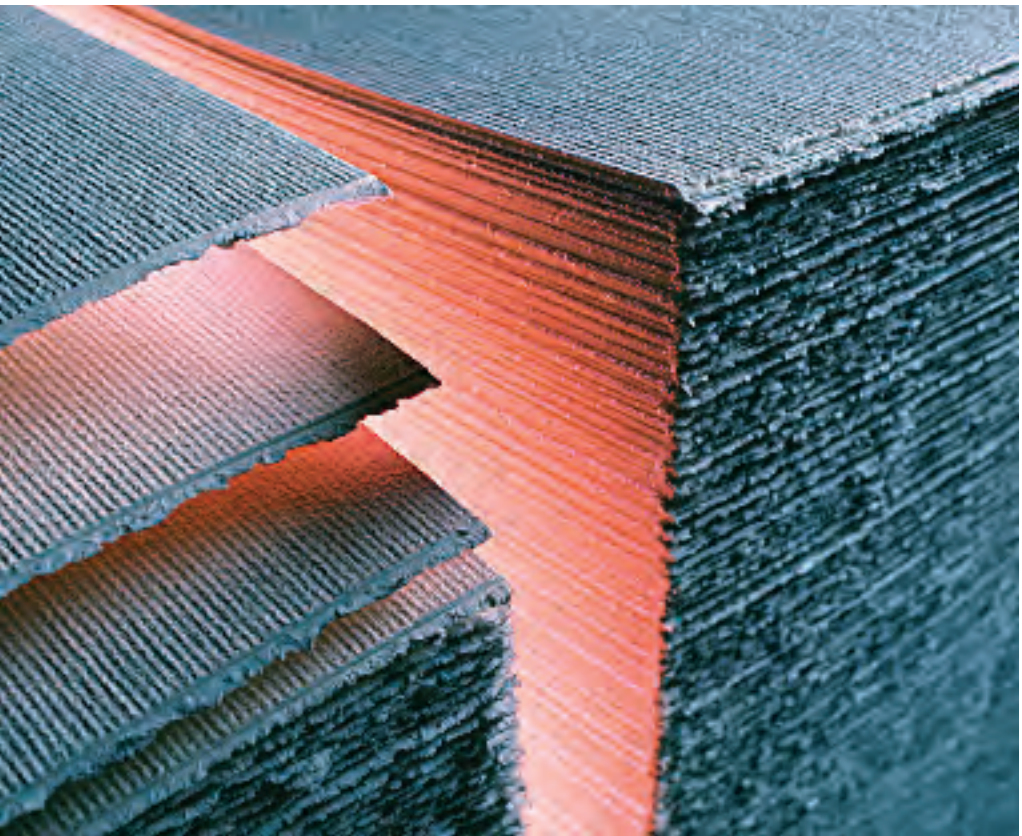
Pulp into Paper

Once delivered to the paper mill, pulp is first broken down in "pulpers" that hold thousands of gallons. These large vessels mix the pulp with up to 100 times its weight in water and then agitate the mixture with steel rotor blades. The slurry is then piped to 1,500-gallon holding tanks where, depending on the type of paper desired, various chemicals may be added. Clay and chalk, for instance, are commonly used to adjust the paper's final opacity. Starches are added to seal some papers, leaving the distinct stench of instant mashed potatoes.

The next stop is the paper machine. Once the pulp enters the machine, it doesn't stop moving until it's rolled up as a finished paper product. The belts move at a jogging pace, from about 575 feet per minute for an average-grade paper to more than 5,000 feet per minute on the fastest machines.

Machines come in all different sizes and work at varying speeds, but their fundamental mechanics are always the same. First, the pulp is watered down even more and pumped into what's called a "head-box." The head-box pushes the 1 to 1,000 pulp-to-water mix out through a horizontal slit and onto a moving belt of wire mesh. Water falls through the holes in the mesh, leaving the fibers aligned in a thin, wet sheet atop the wire.

The wet sheet then gets fed through a series of presses and then through heated iron cylinders for drying. The final paper product, made up of about 5 percent water, is rolled into 12,000-pound,

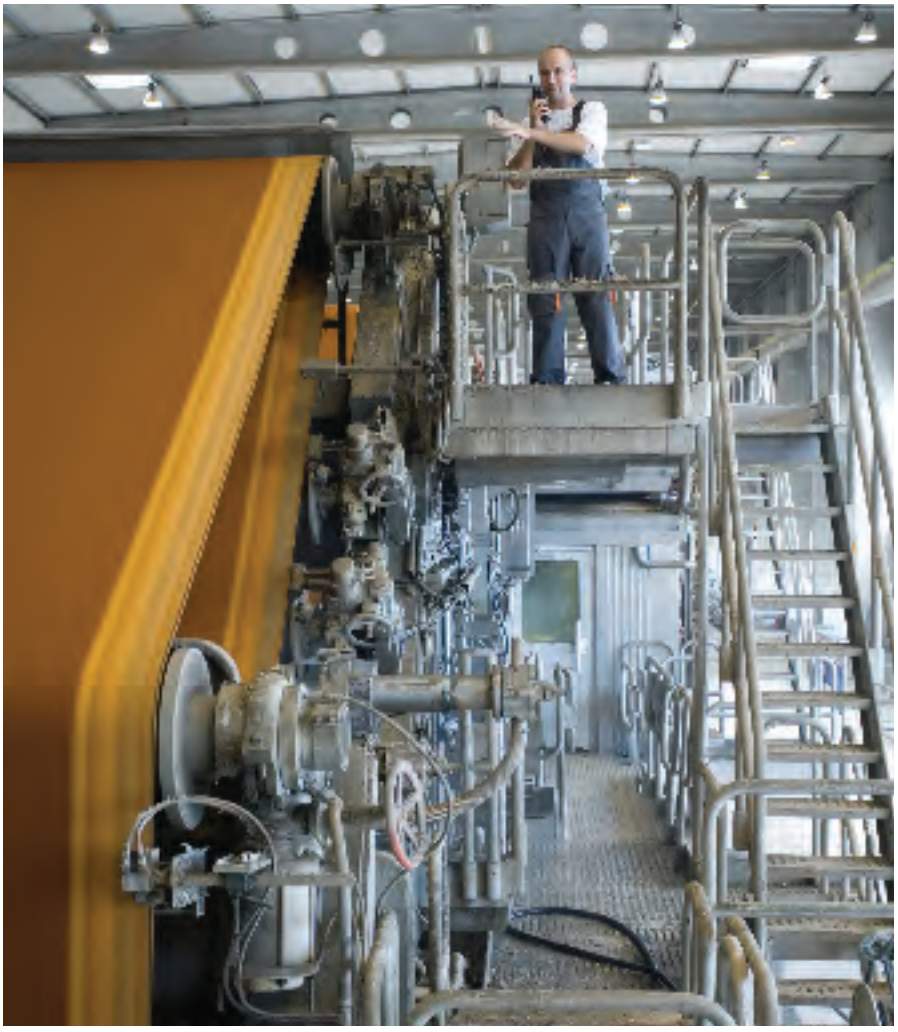


60-inch diameter reels that hold as much as 40,000 feet (12,192 meters) of paper. Most paper mills have machines on-site that cut the paper into rolls of various sizes or reams and then ship them off to their customers. This issue of *BOSS* magazine, for instance, used about 15,000 pounds of paper that arrived from the paper mill in 35-inch-wide rolls.

The fibers contained in new paper can be easily re-pulped and processed to make recycled paper. To recycle paper, the used paper must first be de-inked to remove contaminants such as inks, glues, even staples and paper clips. Once that's done, fiber can be dumped in the digester just as virgin wood chips are. The product, though, won't be exactly the same. The extra processing slightly damages the fibers; each fiber can be recycled three to six times before it loses all strength.

Papermaking's Environmental Footprint

The paper industry has come under fire in recent decades for its environmental footprint. Pulp and paper mills create



Pulp moves at high speed through a paper machine before it is rolled into huge reels ready to be cut and shipped (above).

Biopulping

The conventional chemical pulping process—in which chemicals break down wood to release cellulose fibers from the lignin "glue"—yields only 45 to 50 percent. Moreover, chemical pulping produces toxic byproducts that are released into air and water. Mechanical pulping doesn't use chemicals, but still consumes enormous amounts of energy.

But nature has its own wood decayers, and they're both efficient and clean: fungi. These moldy organisms are at the heart of a third kind of pulping process, called biopulping.

About 20 years ago, scientists looking to develop biopulping methods at the University of Wisconsin's Forest Products Lab screened hundreds of different fungi. "They were looking for one that preferentially attacked the lignin in the wood," says Gary Scott, who worked on the Wisconsin project a bit later and is now chair of the Paper and Bioprocess Engineering Department at State University of New York. The scientists identified one species, *Ceriporiopsis subvermispora*, that broke down both hardwoods and softwoods very well.

Just 5 grams of *C. subvermispora*, when fed the right nutrients, could break down a ton of wood chips. The only drawback: the biological breakdown takes about two weeks, compared to the chemical process that takes three hours.

The Wisconsin team took its bugs to a commercial mill and tested them successfully on 50 tons of woodchips. "But that's as far as it ever went," Scott says.

At that time, "the paper industry went into quite an economic slip," Scott explains, where little excess money was available for capital improvements. "Now we're just starting to come out of it."

But research continues at academic institutions, and now the technology has advanced to the point where biopulping could be scaled up for large mills. "The technology is there, and it's been demonstrated on a large scale," Scott says. "It's just a matter of a company making a capital investment."

As for when it will actually be implemented commercially, Scott estimates five to 10 years, depending mostly on rising energy costs. "As energy prices go up, it just becomes more and more advantageous to use it."

Finished paper is wound onto rolls at a Wisconsin paper mill, left; rolls of newsprint sit ready to be shipped to printing plants, right.

tons of air and water pollution, deplete the world's natural forests and use primarily fossil fuels. Yet, as the world's consumption for paper increases, so does consumer and corporate awareness about the environment—leading the world's top companies to make some smart changes to the process.

Virtually all paper mills use oxygenated chlorines for bleaching, as they produce far fewer toxic byproducts. Some of the worst environmental pollutants have come from pulp bleaching that, before the early 1990s, relied on elemental chlorine.

Critics also have bemoaned the paper industry's negative effect on the world's forests.

Unlike the fossil fuels used to make most of the world's electricity, paper is made from vast numbers of trees, which are renewable resources. However, it takes many years to grow a tree, a rate that's exceeded by the rapidly growing demand for paper. (See sidebar: "How Much Paper Comes from One Tree," page 11.)

Consequently, paper producers are relying more and more on privately owned tree plantations that cultivate only the fastest-growing trees, but to stimulate fast growth, tree farmers use heavy loads of pesticides and fertilizers.

One solution to help maintain forest sustainability and lower pollution is to use more recycled paper. The Worldwatch Institute claims that using recycled material to make paper lowers water pollution by 35 percent and air pollution by 74 percent.

In addition to creating pollution and depleting forests, the paper industry is "a very energy and resource intensive process," says George Milner, senior vice president of energy, environmental and governmental affairs at Mohawk Fine Papers in Albany, N.Y. Indeed, the paper industry is the world's fifth largest industrial energy consumer, and paper mills use more water per ton of product than any other industry.

Because of the recent media focus on climate change and the shrinking oil supply, many consumers are demanding that paper companies consider renewable energy. Since about 2002, Milner says he has noticed "a great deal more awareness among our customers, especially our large institutional customers, about the environmental consequences of papermaking."

One way Mohawk and other paper mills have addressed these consumer concerns is to buy wind-generated electricity credits—basically contributions to wind power farms—from their local power companies to offset the large amounts of carbon-based electricity they use.

Figuring out how to fix these environmental problems is a hugely important task, for paper is the backbone—figuratively and literally—of our traded goods, our money, our entertainment and our history. Even in today's electronic age, most of us couldn't go a day without using paper or paper products, which suggests that China's great invention is likely to stick around for another few millennia.

Dixon in Paper

The following Dixon products are utilized by the pulp and paper industry:

Boss Couplings and Clamps

Cam and Groove Couplers & Adapters

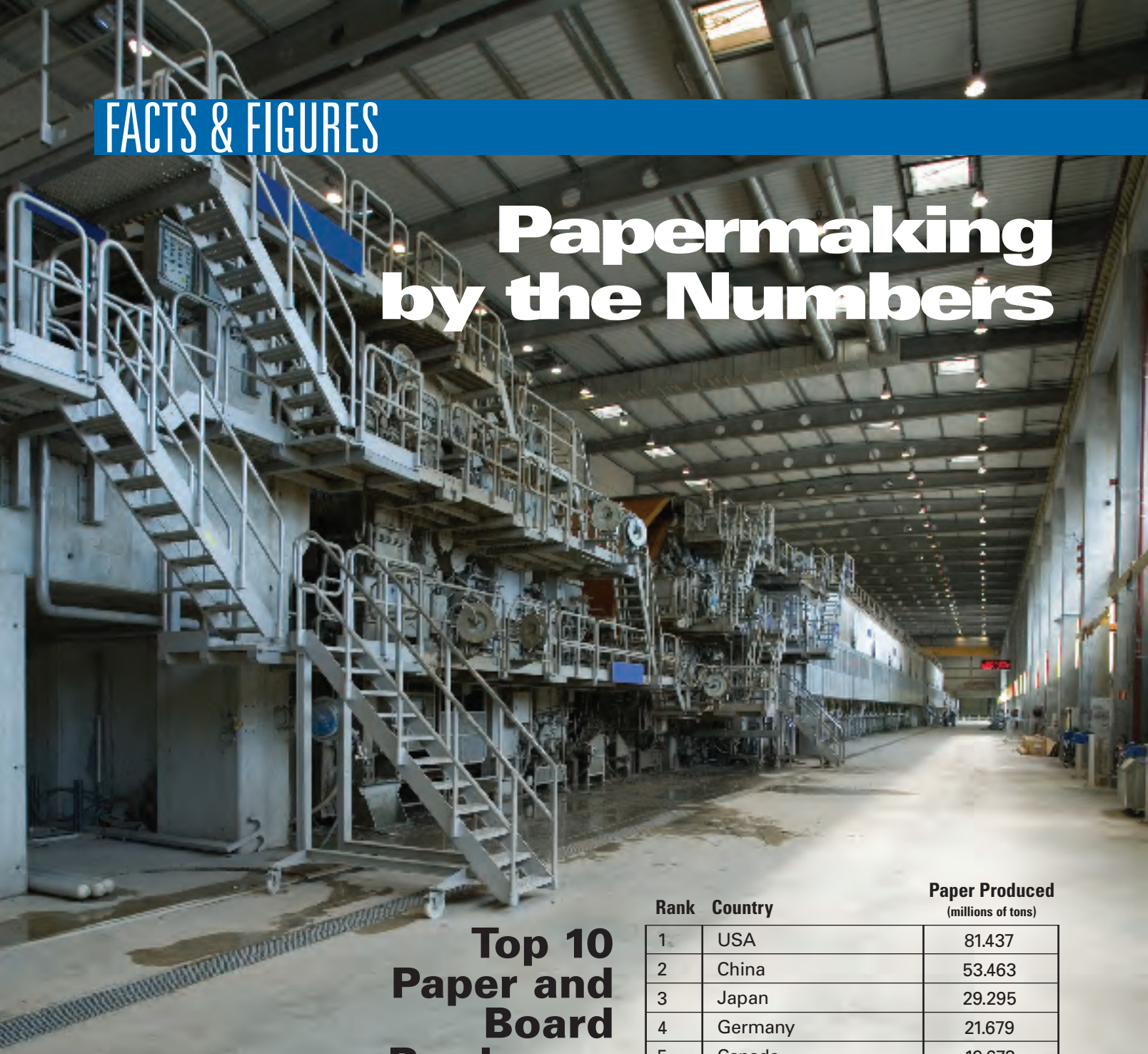
FRLs & Gauges

Black Liquor Ball Joint Armored Hose Assemblies

Contractors Wash Down Nozzles

Mill Hose

Papermaking by the Numbers



Top 10 Paper and Board Producers

(Source: Food and Agriculture Organization of the United Nations, 2005)

Rank	Country	Paper Produced (millions of tons)
1	USA	81.437
2	China	53.463
3	Japan	29.295
4	Germany	21.679
5	Canada	19.673
6	Finland	12.391
7	Sweden	11.736
8	Korea	10.549
9	France	10.332
10	Italy	9.999

World	354.091
European Union	97.570
World Developed Countries	245.136
World Developing Countries	108.955