



Update

Cutting to the Core of the Pulp and Paper Industry

The yellow- and black-striped paper wasp builds its hulking honeycomb nest by gathering wood fiber and slathering it with saliva, creating a thin, paper-like material it constructs into hives.

In 6th-century China, these fragile shelters, hanging from the sprawling branches of native mulberry trees, were a common sight for Cai Lun, a eunuch, inventor, and politician widely credited with inventing the paper-making process.

Legend has it that the paper wasp inspired Lun to scrape bark from mulberry trees and mash it into pulp with water to create dried sheets of paper. Chinese emperors guarded these papermaking secrets jealously for centuries, but the process soon spread to the Islamic world, where it was refined.

Modern papermaking began in 19th-century France with the invention of the Fourdrinier machine, a device that allowed papermakers to produce sheets continuously, rather than one at a time. Today's papermaking machines are similar to the Fourdrinier device, using a wire mesh to wring water from pulp.

Still, despite its thousand-year history, the pulp and paper industry's fate is unclear. Environmental and societal factors threaten its image and viability.

Pulp is an amalgamation of wood fibers, which are extracted from logs through a mechanical or chemical process. Mechanical pulp is obtained by grinding wood chips with water, while chemical pulp is produced by heating wood with chemicals such as sodium sulfate or sodium hydroxide to liberate fibers. The process occurs in a digester, which is essentially a pressure cooker.

The separated, watery fibers, *i.e.*, pulp, are then thoroughly cleaned to

remove debris and dirt. Next, the pulp goes through a series of rollers that wring water from the material. Most pulp is a mixture of cellulose fibers and lignin, a natural glue within wood that gives the pulp its brown color. Paper producers often remove the lignin by bleaching the pulp, depending on its future use.

For brown grocery bags, the pulp stays unbleached and the lignin remains intact. On the other hand, bleached, white printer paper is created by removing the lignin. Printer paper comprises mostly cellulose fibers, which lend it strength and give it its color, or lack thereof.

After bleaching, a machine forms the pulp into sheets. The machine has a wet end with a looping belt that transfers the pulp to a huge, flat wire mesh that removes additional moisture and creates a web-like sheet of fibers. Next, this white sheet is pressed several times to evaporate leftover water, then further dried — extensively.

The end product is a roll of paper that is 95% fiber and 5% water. The master roll is cut into smaller rolls and further treated with coatings. Various paper machines produce different types of paper — for tissue paper, the manufacturer puffs up the fibers as they dry, while paper for packaging needs to be fiber-dense so that boxes can hold up during shipping.

The papermaking process is highly energy-intensive, but much of the energy is recycled through the process itself, according to the American For-

est and Paper Association (AF&PA). Nevertheless, over the years, many paper companies have tried to reduce chemical and water use, as concerns about energy and sustainability continue to grow.

Along with these challenges, the pulp and paper industry is grappling with digitalization, deforestation, and the logistics of paper versus plastic, a debate that has garnered recent public attention.

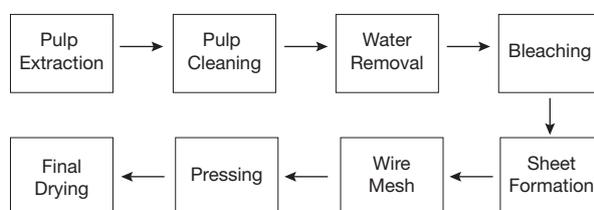
As these changes continue to pervade paper and pulp, the industry relies on its ability to adapt — a characteristic that has kept papermaking alive for several hundred years.

Deforestation and degradation

The Amazon rainforest, a verdant, lush wilderness, nurtures almost 400 billion individual trees, grouped into 16,000 species. It is a cornucopia of life and contributes to the world's expansive forestlands, which account for about 31% of the Earth's surface.

Over the past 50 years, however, the Amazon has lost 17% of its trees, mainly due to the conversion of land for agricultural purposes, such as cattle grazing. According to the World Wildlife Fund (WWF), companies and governments in some tropical areas cut down wide swaths of forest and raze the ground to make way for crops such as oil palm.

This can be devastating for wildlife and society — around 80% of Earth's animals live in some type of forest, and many people rely on forest



◀ Papermaking is a multi-step and energy-intensive process. It focuses mainly on the removal of water from pulp, to create dried sheets of paper. Paper companies are working on the process more energy-efficient.

resources and jobs to survive.

The main culprit of deforestation is agriculture, the WWF reports, but illegal and unsustainable logging contributes most prominently to forest degradation, which ultimately leads to deforestation. In some tropical forests, patches of land are entirely cleared to create plantations of fast-growing trees that will be turned into pulp.

These practices are rare in the U.S., according to some scientists. “In North America, deforestation is not happening,” says Mark Pitts, the Executive Director of Printing, Writing, Pulp and Tissue at AF&PA, “That’s what happens when you take what was forest and put it to some other use. The reality is that when there is a healthy demand for paper, that provides an incentive for landowners to keep forest as forest rather than transform it. That’s not always understood by the public; it’s in those geographical areas where consumers want paper that forests are maintained and growing.”

The U.S. paper and pulp industry conducts sustainable forestry, Pitts says, which means continuously replanting more than is harvested to ensure that there is a sustainable amount of trees and fibers.

Companies also often use wood residuals from saw mills and furniture factories to make paper, as well as



▲ Deforestation and degradation are still significant issues in areas where illegal logging is common. Every minute, the world loses the equivalent of 27 soccer fields of forest.

recovered fiber from recycled paper. Only about 38% of the material that goes into paper comes from harvesting trees, says Pitts.

According to the WWF, many paper companies, including industry giants such as Hewlett-Packard and Procter & Gamble, have committed to independent guidelines set by the Forest Stewardship Council to only source wood that follows sustainable guidelines. These standards go beyond what the law requires, even in the U.S., in terms of consultations with local people, protecting animal habitats, and restrictions on pesticide use.

But unsustainable forest management is still a serious concern in some parts of the world, such as Indonesia, where illegal and unsustainable logging is lessening but is still widespread. The Earth is losing 18.7 million acres of forests annually, which is equivalent to 27 soccer fields every minute.

And with the pulp and paper industry consuming 40% of all traded wood worldwide, unsustainable products make their way into the U.S. Although the industry within the U.S. itself may not practice harmful logging, consumers may still be buying paper that contributes to forest degradation.

Beyond the destruction of habitat, deforestation and degradation also impact the global environment. “The burning of forests and clearing of soil can contribute 10–20% of all global greenhouse gas emissions,” says Linda Walker, the Senior Director of Corporate Engagement at WWF. “But trees can also take carbon dioxide out of the atmosphere — by protecting existing forests, restoring forests, and improving forest management, we could jointly sequester 5–7 billion metric tons of CO₂ from the air.”

According to Cecilia Alcoreza, Manager of Forest Sector Transformation at WWF, trees are the most

efficient natural machines for reducing carbon on Earth. Protecting them is of utmost importance.

Paper versus plastic

The rise of single-use plastics has caused a chain reaction of protests, media uproar, and anti-plastic laws across the globe. Every year, five trillion single-use plastic bags are used globally, and every minute, one million plastic drinking bottles are purchased. Half of this plastic is thrown away after only one use.

Plastic waste is a major contributor to ocean pollution, and can persist in the environment for centuries. Eight states (California, Connecticut, Delaware, Hawaii, Maine, New York, Oregon, and Vermont) have enacted bans on single-use plastic bags, most of which will take effect within the next year. Cities such as Seattle and San Francisco have banned plastic straws. Society, which has become reliant on single-use products, has begun seeking alternatives to plastic.

Many consumers and companies have turned to paper as a substitute for plastic, whether for paper straws, paper bags, or even paper takeout containers. But is paper really the superior option over plastic?

According to Terry Webber, the Executive Director of Packaging at



▲ Single-use plastic waste has become a significant environmental issue as it clogs landfills and pollutes the ocean, where it can persist for hundreds of years.

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AF&PA, it's important to recognize the importance of plastic in essential applications, such as in shelf-stable food packaging, where it provides a moisture and oxygen barrier to keep food from spoiling.

In other arenas, paper can be the more sustainable option. "In terms of decomposition and marine debris, paper does overcome some of the challenges that plastics pose," says Pitts. "You can feel good about using paper — it comes from a renewable resource, it uses primarily renewable energy from the process itself, and it can be more easily recycled. We put a lot of recycled content into our products. From that perspective, we think it has a lot to offer to a public that's concerned about the environment."

While paper may sometimes seem like the safer option, consumers and companies must be cautious of overusing paper and simply replacing massive amounts of single-use plastic with single-use paper.

"There shouldn't be just one degradable material," says Alcoreza. "Today, the easiest material to move away from plastic is paper. But what happens if we start sourcing wood for paper even more than we do already? We will have to monitor more natural forests as producers increasingly plant industrial plantations. If paper is not produced in a responsible way, its use will have a similar impact as plastic."

Alcoreza emphasizes that paper can be made not only from wood, but also from materials such as bamboo, wheat straw, and other agricultural waste.

There is no one answer to the plastic waste crisis — instead, scientists, businesses, government, and consumers must work together to find a solution that weighs the sustainability and environmental impact of each material, keeping in mind society's reliance on single-use products.

Digitalization and the future of the paper industry

"The paperless office was predicted decades ago," says Pitts. "But it hasn't happened yet."

Nevertheless, pulp and paper industry leaders haven't buried their heads in the sand — they understand that how people communicate and conduct business is changing. But at the same time, paper provides a valuable experience for many people, Pitts says, and it is very much embedded in day-to-day life.

Outside the office, paper is still prominent in products such as packaging, tapes, labels, personal care products, and books. While overconsumption of paper anywhere can be unsustainable, printed books are on the rise and studies show that printed textbooks can be more useful for retaining information.

The question of digital versus print is also more complex than it seems. Should consumers write information down on paper that can be recycled later, or take notes on a laptop that negates the need for single-use products, but still needs to be

charged and whose production required significant energy?

"You don't see too many industries that have been around since the 18th century," says Pitts. "Paper is one of those, because we've been able to adapt to change, and I don't see that changing. I think we'll see paper in people's lives for years to come."

—Nidhi Sharma

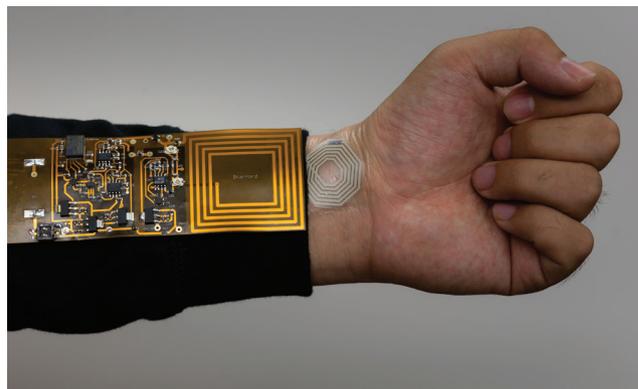
Making Wearable Technology More Readily Wearable

More and more fitness buffs are strapping wearable monitors onto their wrists and triceps to track their pulse and breathing rates as they run, lift, jump, and even swim. But devices such as the Fitbit or Apple Watch, despite their technical capacity, are generally clunky.

"Currently, wearable technology is not so wearable," says Simiao Niu, a chemical engineer at Stanford Univ. "It is packed with electronic components that make it rigid and uncomfortable — and it can be difficult to get as strong of a signal as you would with conformable sensors."

At Stanford, chemical engineers are monitoring breath rate and pulse using a soft, flexible sensor that sticks to the skin like a bandage. They say it is easy to wear and good for continuous observation. To measure physiological signals, the sensor sticker tracks changes in strain. If you press your fingers to the inside of your wrist, finding your pulse is simple — the beat shifts the skin up and down, similar to the way the abdomen moves as we breathe in and out, or the way the heart surges against the skin as it beats.

The sensor is made of an interlocked network of carbon nanotubes layered atop a soft polymer substrate, a film of hydrogenated styrenic thermoplastic elastomers (SEBS). The nanotubes are dissolved in water and the solution is



▲ Chemical engineers at Stanford Univ. have developed a bandage-like sensor that sticks to the skin and monitors pulse and breathing rates, sending information to an external reader attached to clothing. Image courtesy of Zhenan Bao lab.