CHAPTER 9

Nature's Filaments

The roots of technology — Forests and cultural memory — Bytes and brains — The biggest leverage is downstream — Multiplying savings — A factor 26 gain — Small trees, big beams — 400 million pallets a year — Field-grown paper

IT IS APPROPRIATE THAT A TEXTILE COMPANY LIKE INTERFACE SHOULD BE in the vanguard of the next industrial revolution. As late as 1830, the words "industry" or "factory" applied only to one endeavor: cotton mills. Industrialism was propelled by textile technologies: James Hargreaves's spinning jenny, Sir Richard Arkwright's spinning mill, and later the water frame and the power loom. Among the first applications of the coal-fired English steam engine, besides pumping out the coal mines, was running the "dark satanic mills" that produced textiles. The spinning jenny and mill together increased the output of a spinner by a factor of eight, then sixteen, and eventually by a factor of two hundred. A jenny with forty spindles cost £6, less than wages for one worker for one year. The advantages to the British from these productivity advances were enormous. The lower costs increased sales at home, displacing imports from India. Conversely, where Indian hand-spun calicoes were once cheaper and of higher quality than their English counterpart, English textiles made on mechanized equipment gained the upper hand, devastating India's industry. In other colonies, English textile imports reigned supreme, and if they couldn't, naval battles and wars were fought (usually with the French) to ensure they did. After Hargreaves's and Arkwright's inventions were commercialized in the 1760s, cotton manufacturing quadrupled in twenty years. By 1800, production increased another tenfold; fifteen years later, at the end of the Napoleonic Wars, production had tripled again. In just fifty-one years, English textile production increased 120 times over.[1]

The history of textiles is intimately linked to child labor and slavery, to colonialism, and to world trade and conquest. Slaves, often taken from Africa in exchange for European textiles, were imported to the American South in vast numbers to pick cotton once Eli Whitney's cotton gin made large-scale cotton farming cost-effective.[2] The West Indies got rapidly colonized to increase cotton exports to England. The modern organic chemistry industry, and many of the chemical companies like BASF that dominate the industry today, got started making aniline dyes for cloth. The very root of "technology," the Greek *technē,* refers to "weaving." The misery and suffering that textile mills occasioned became the seeds of social discontent, spawning the then radical political ideas of democracy, republicanism, and eventually the proletariat-based theories of Karl Marx.

Fibers stretch not only through the history of industry but through cultural and biological evolution: Biologist Peter Warshall describes fibers as the "longish, tough, flexible filaments that connect nature to itself and to human life."[3] The history of the use of fibers is in many ways the history of human development. Early in their cultural evolution, humans began to rig remarkably strong[4] natural fibers, often a coproduct of food production, to create clothes, baskets, ropes, sinews, houses, and many other artifacts. Over time, inventors figured out how to break the chemical bonds of wood to create paper, and then how to turn cellulose into resin and thence into many industrial products.

Fiber comes from many sources. The fiber products of forests include paper, lumber, tire-cord, rayon, and cigarette filters. Non-tree plants give us fiber in the form of cotton, flax, vegetable plastics, fabrics, ropes, et cetera. Livestock provide wool, skins, silk, and so on, while even minerals supply fibers of metal, asbestos, and glass. The oceans and tidal zones give chitosan and wound-healing chitin-based fabrics. All these natural products combine and compete with the vast range of fiber products derived from petroleum, natural gas, and asphalt. As Warshall states, "The market system for fibers is now global with petrochemical fibers (hydrocarbons) supplying the majority of textile, upholstery and industrial cloth, cordage, and related products. Only paper and, in some places, building materials remain somewhat immune from hydrocarbon competition."[5]

Producing any fiber has consequences. Most "natural" fibers are grown in unsustainable ways. Half of all textile fibers come from cotton, whose cultivation uses one-fourth of all agrochemicals[6] and of all insecticides.[7] Conventionally producing a pound of cotton fiber takes about two and a half tons of water, and in rainy areas, causes the erosion of about forty-four pounds of topsoil.[8] From the American South to Kazakhistan, intensive chemical-based cotton-growing has done serious and lasting harm to regions and societies. Similarly, unsound ways of raising sheep and goats have left millions of acres desertified around the world. Sustainable ways of growing wool, flax, hemp (the strongest plant fiber), and even cotton are both familiar and practical. Since 1996, Patagonia, a $165 million-a-year outdoor clothing company, has used only organic cotton for its merchandise,[9] but despite increasing usage by such larger firms as Nike and Levi Strauss, such practices are still far smaller-scale than the soil-mining, subsidized, chemically dependent methods.[10]

The petrochemical industry, which makes the building blocks for synthetic fibers, is also a notable polluter and uses a nonrenewable resource. However, its environmental performance can be (and often is being) considerably improved. Also, as Warshall points out, the advent of "petrochemical fibers undoubtedly postponed the cutting of huge acreage of trees, as well as the clearing of land for cotton." A 300-acre petrochemical plant, plus a rather small acreage of natural-gas facilities, can match the fiber production of 600,000 acres of cotton.[11]

A detailed comparison or even description of the impacts of all fibers, and the opportunities available to offset those impacts, is beyond the scope of this book, but it is worth looking at one form of fiber production, forests, as an example. The forests that produce wood fiber illustrate the issues well, and they form a significant part of the economy: The annual forest harvest is more than twice the weight of all U.S. purchases of metals.[12] While sustainable harvesting and forest management practices are known and often commercially viable, they are not yet widely practiced,[13] so conventional forestry remains a prominent cause of widespread harm to natural capital, degrading natural forests' more valuable ecosystem services.

Forests are cut primarily to produce paper products and lumber in roughly equal volumes, although the former is growing faster while the latter use fetches two to five times higher prices per unit of wood volume (and even more for veneer logs).[14] From the early 1960s to the mid-1990s, as per-capita U.S. consumption of timber products held constant or even sagged a bit, per-capita paper-product consumption nearly doubled. The world consumes five times more paper now than in 1950.[15] U.S. offices' paper use soared from 0.85 to 1.4 trillion sheets (about 4.2 to 7 million tons) just between 1981 and 1984, as early desktop computers and laser printers were being introduced.[16]

Other countries did not lag far behind America's wasteful ways. From 1970 to 1990, paper production rose 4 percent a year in Japan, and in Southeast Asia, 8 percent, compared with 2.5 percent in the United States. To keep up with the vast volumes demanded, papermaking, like logging, has changed in many regions from a handicraft to an industrial commodity enterprise of almost unimaginable scale.

A traditional rural Nepalese paper factory is an outdoor area the size of a living room with a production process that is simple, labor-intensive, and cheap. The fibrous inner bark of a certain tree — analogous to the Chinese mulberry tree from which paper was developed nineteen centuries ago — is stripped, soaked, and pounded in wood-ash lye. The resulting slurry of fibers is treated and washed in a series of small ponds. Pieces of cloth stretched on wooden frames are dipped into and raised up through the slurry so they are coated with a thin layer of fiber, then are propped up to dry in the sun. The resultant rice-paper-like sheet sells for about a dime in Nepal or a dollar in New York art-supply stores. In the almost cashless rural Nepali economy, the paper is a precious product, reserved largely for religious and ceremonial purposes.

Modern Western paper factories are gigantic operations costing upward of a billion dollars. A big paper mill uses energy at the same rate as a small city. Paper mills turn entire forests — a seventy-five-acre clearcut per mill per day[17] — into hundreds of different high-performance products by the freight-train-load. The logs are chipped and boiled in gigantic kettles of acid, or ground between huge plates run by thousands-of-horsepower motors, to release the cellulose fibers from the surrounding lignin and hemicellulose. Papermaking machines bigger than a house echo the Nepali hand-run process, but at a vast scale, forming a web of fibers that thunders through steam-heated driers and onto shipping rolls with the speed of a locomotive. All this supports a culture in which paper is universally available, priced at perhaps a penny a sheet, and rarely paid for or thought about by its users.

Paper accounts for about 2 percent of world trade and 2.5 percent of world industrial production;[18] its U.S. shipments, over $132 billion a year, are comparable in value to primary metals and minerals, or to 90 percent of petrochemicals.[19] Yet much of the paper produced is used only for a short time and then discarded: Only about a tenth of the global paper stream goes into "cultural memory" — long-term storage in such forms as files, records, and books.[20] Much of the rest of printing and writing paper, which represented 28 percent of 1992 paper and paperboard consumption, finds its way into the office paper chase. The average American officeworker is estimated to use a sheet every 12 minutes — a ream per person every two and a half working weeks — and to dispose of 100–200 pounds of paper per person every year.[21] This paper accounts for as much as 70 percent of typical office waste. During the years 1972–87, America's discarded office printing and writing paper grew almost five times as fast as the human population, miscellaneous office paper over five times, and copier paper almost ten times — a 150 percent absolute increase.[22]

SUBSTITUTING BYTES AND BRAINS FOR PAPER

The elusive goal of substituting "electrons for fiber and pixels for paper"[23] is a worthy challenge. Multi-gigabyte hard disks that can search an entire library's worth of data in the blink of an eye are priced at the equivalent of pennies per ream of double-sided paper information. Some pioneering businesses have almost achieved a paperless, all-electronic office. But the initial cultural, financial, and practical barriers are often daunting.

Dan Caulfield, the CEO of Hire Quality, a Chicago job-placement service, decided to make his company all-electronic.[24] The transition was traumatic: At one point, Caulfield, an ex-Marine, seized and burned every scrap of paper he could find around the office, even important work products, in order to dramatize what a complete cultural change was needed. The firm had to spend nearly $400,000 on equipment and setup before it could do virtually everything onscreen and nothing on paper (all incoming paper is immediately scanned into data files). This investment, however, laid the foundations for durable competitive advantage. More than 200,000 candidates' files can be instantly searched by over 150 data fields. A single keystroke E-mails job descriptions from clients to job banks. The cost to process a job application has been cut by about three-fourths, the number of calls to pin down a referral by about half, and the time to fax ten resumes to a client by nine-tenths. (Nine-tenths of the paper previously used for that operation was also saved, but the saved time proved to be far more valuable.) More precious still are the better service quality, and the faster and smarter information flow, decisions, and teamwork that come from redesigning the business around people, not paper. The Danish firm Oticon found this when its electronics revolution, intended to yield sounder and quicker decisions, had the side effect of reducing its paper use by roughly 30–50 percent.[25]

Dutch business therapist Eric Poll[26] sought to take advantage of ubiquitous computers without having to redesign an entire business around them. A few years ago, he decided that his workplace — Dow's European headquarters at Horgen, Switzerland — had too much paper flying around, so he introduced three new practices as an experiment:

- Any paper or electronic message (many of which are subsequently printed) would automatically return an electronic reply saying whether the recipient had wanted it. This created a polite way to say, "It's ever so kind of you to think of me in this way, but I really don't think I should have received this information."
- Distribution lists were abolished, so multiple addressees had to be manually listed each time, discouraging unnecessary transmissions.
- Any long paper or book had to be sent with a short summary — easy for the sender if she had read the publication, and convenient for the recipient, but if the sender hadn't read it, why was she passing it along?

These innovations cut paper flow by about 30 percent in six weeks — and the "nega-information" improved labor productivity by even more, because now people had more time to read the things that really merited their attention. This was all the more impressive because a big potential source of further savings was left untapped — rewarding administrative assistants, who are most burdened by excess paperflow, with a share of the savings achieved by reducing it.

Electronic communications can save paper, time, and money in the most complex commercial transactions normally requiring very voluminous documents. BankAmerica Securities arranged a $4 billion syndication for Compaq Computer Corporation, for example, using a secure website to provide information to the lender group and distribute the draft loan documents. This saved over 11,000 pieces of paper — nearly 5 million a year when extended to all the syndications led by that one bank.[27]

Some short-term paperflow, like junk mail and handbills, is completely ephemeral, and can easily be dispensed with. A significant fraction, though, goes to such temporary but useful periodic reference works as telephone directories and catalogs. Both face competition from electronic media. A single CD-ROM, costing pennies to press, can contain every telephone directory in the United States — a quarter million pages. Even denser media like DVD-ROMs are becoming popular; a world phone book on a disk is practical today. Better still, anyone with Internet access can simply look up white, yellow, and other specialized kinds of phone book pages on various websites for free. This service is no slower or less up-to-date than today's decaying U.S. phone-company directory information service, and is often more informative. The new electronic media are also starting to come with convenient handheld readers. A physician can get the 3,000-page *Merck Manual,* plus the *Physician's Desk Reference,* on a single CD-ROM that's portable to the bedside, and retrieve any information in seconds. Mail-order catalogs, too, are increasingly threatened by much cheaper and handier Internet commerce.

Even greater gains in productivity and effectiveness are available to architects and engineers who replace roomsful of heavy paper parts catalogs with electronic versions. Instead of laboriously copying and scaling drawings from books for insertion into electronic drawings, they can do so with a keystroke from a CD-ROM. InPart Design, Inc., a startup company in Saratoga, California, claims that downloading digital drawings for fewer than ten parts from its more than 150,000-part online library (for $20 each) saves more than enough redrawing labor to pay its one-time $1,000 software license fee; after that it's pure gravy.[28] This option is gradually becoming popular in all kinds of design, and is being linked with Web-based commerce so that having decided what to specify, you can have an intelligent software agent find the best buy and order it. Hundreds of newspapers and magazines, too, are already published on the Internet; most are available free and with powerful search engines. At this point, these are still viewed as complements to print media. Should that change, the displacement of physical with virtual newspapers would be no small matter, since newsprint is a sixth of all U.S. paper production: The Sunday *New York Times* alone uses some 75,000 trees per edition.[29]

COMBINING SAVINGS SYSTEMATICALLY

At the heart of this chapter, and, for that matter, the entire book, is the thesis that 90 to 95 percent reductions in material and energy are possible in developed nations without diminishing the quantity or quality of the services that people want. Sometimes such a large saving can come from a single conceptual or technological leap, like Schilham's pumps at Interface in Shanghai, or a state-of-the-art building. More often, however, it comes from systematically combining a series of successive savings. Often the savings come in different parts of the value chain that stretches from the extraction of a raw resource, through every intermediate step of processing and transportation, to the final delivery of the service (and even beyond to the ultimate recovery of leftover energy and materials). The secret to achieving large savings in such a chain of successive steps is to multiply the savings together, capturing the magic of compounding arithmetic. For example, if a process has ten steps, and you can save 20 percent in each step without interfering with the others, then you will be left using only 11 percent of what you started with — an 89 percent saving overall. Wood fibers, because there are many separate steps in their production and use, offer many kinds of successive savings to be multiplied. They nicely illustrate the feasibility of radical reduction in the harvest required from forests — a key element of natural capitalism.

The best way to save resources is to emphasize the savings that occur closest to the customer, all the way downstream. The logic is precisely that of the "To Leap Forward, Think Backward" section of chapter 6. There we found that in a pumping system, ten units of fuel must be burned in a power station to deliver one unit flow from a pipe. The opposite is therefore also true — saving one unit of flow in the pipe can save ten units of fuel at the power station. Likewise, if (say) three pounds of trees must be cut in a forest in order to deliver one pound of paper, then saving that one pound of paper will avoid cutting three pounds of trees. The many compounding losses from tree to paper can be turned around backward into compounding savings. The savings with the greatest leverage are thus those furthest downstream.

The biggest savings can come from asking how much ultimate satisfaction a consumer obtains from each unit of end-use service delivered. No matter how wonderfully efficiently we convert forests to logs to pulp to paper, it's all for naught if the result is junk mail that nobody wants and that is thrown away unread and sent to landfill (as most of it seems to be). Every unit of such unwanted or despised "service" that can be avoided will in turn avoid the entire chain of compounding losses all the way back to the forest, saving the largest possible number of trees — and amount of forest damaged by cutting them down.

A good candidate for such elimination is overdesigned[30] or needless packaging.[31] Most industrial and some food packaging can be promptly cut by 20 to 50 percent.[32] A major German retailer found that 98 percent of all "secondary" packaging — boxes around toothpaste tubes, plastic wrap around ice-cream cartons — is simply unnecessary.[33]

The use of paper and lumber worldwide, for services wanted and unwanted, has shown an unbroken pattern of growth for the past fifty years. The consumption of wood fiber correlates strongly with overall affluence, leading analysts to believe that demand for forest products will greatly expand in the next century as population and living standards increase. Naturally, most analysts have assumed that the only way to meet growing demand for wood fiber is to produce more of it. But of course customers aren't demanding railcar-loads of raw wood fiber; rather, they're demanding the end-use services that the fiber ultimately provides to them, like support for a wall or for reading a book. To provide the same services with less fiber, therefore, we need to look more carefully at each step along the journey from forest to customer service. A helpful approach is summarized by a formula that combines the various factors that cause extraction of trees from forests. The formula then divides the product of those factors by the various ways to make the whole process more efficient. The result reveals the total potential for savings.[34]

The formula starts with:

- **Human Population,** which is multiplied by
- **Affluence:** the average amount of a given service each person consumes, which is multiplied by
- **Unsubstituted Fiber:** how much of the demand for the services provided by forest products is being met by wood fiber rather than by substituting non-wood materials, which is multiplied by
- **New-Materials Dependence:** what fraction of the items that provide those desired services is made from new fibers rather than from recycled fibers, new items rather than repaired or remanufactured, throwaway instead of durable goods, et cetera.

The product of those terms represents how much wood fiber would be needed if all the efficiencies in harvesting, processing, and using that fiber stayed constant. But these efficiencies can be improved. To identify where more service can be provided with less fiber, the result calculated above (the supposed need for fiber) must next be divided by the product of four kinds of efficiency improvements:

- **Field Efficiency:** how efficiently forests are turned into such primary products as logs or pulp, multiplied by
- **Conversion Efficiency:** how efficiently those intermediate forest products are turned into such intermediate goods as paper or lumber, multiplied by
- **End-Use Efficiency:** how efficiently those finished goods are turned into such delivered uses or services as a building or a presented document, multiplied by
- **Functional Efficiency:** how efficiently those uses increase human satisfaction by creating happiness or meeting objectives.

Population and Affluence are obviously important, but it may be difficult to establish how much flexibility they offer. Functional Efficiency and New-Materials Dependence, while potentially very significant, are also hard to define. However, even focusing on just the other four of the eight terms — on Fiber Substitutions, Field Efficiency, Conversion Efficiency, and End-Use Efficiency — reveals a potential (in five case studies and many anecdotal examples) for a roughly 75–80 percent reduction in the new wood fiber needed to provide popular services, from new homes to the morning newspaper.[35] The more detailed the assessment, the more opportunities for savings emerge.

It is possible to eschew needless messages, get off junk-mail and unwanted distribution lists, adopt E-mail (and learn not to print it out), edit with groupware, and preview documents on the computer screen before printing them. All these things increase Functional Efficiency — the class of savings that are furthest downstream and therefore most valuable. How about the paperflow that is required after that? The next step, also offering big paper savings with the same or better services, is to maximize End-Use Efficiency. (Being the next-to-furthest-downstream opportunity, it, too, has high leverage for savings.) End-Use Efficiency offers many important ways to save paper and money. Most photocopied or laser-printed documents would be easier to read, carry, and file if automatically printed double-sided. The modest extra cost of adding a duplexer is quickly recovered from the saved paper, file and supplies-inventory space, et cetera. If the duplexer is already a feature, it costs nothing to activate it as the default option.[36] Drafts can be printed with smaller-than-final margins and fonts, within reason; or better still, they can be edited only electronically. Fax cover sheets are seldom necessary. Two-way returnable envelopes are handy for bills and save 60–70 percent of envelope paper. Barcoding, especially the information-rich two-dimensional variety, can displace production- and shipping-tracking paperflow by containing details about a product's life history, customer information, legal documents, et cetera all on one small label. E-mail, by which this book was largely written and edited, already transmits over ten *trillion* words a year,[37] and it's a lot easier to find an old message by a computer search than by rummaging through a file cabinet.

These examples only cover the stages of Functional- and End-Use-Efficiency savings. Further upstream there are such steps as reducing New-Materials Dependence. This means reusing the back of used or spoiled paper for internal drafts and notes; recycling paper into new paper (or into lower-quality products that displace other wood fiber); or using lighter-basis-weight paper (less fiber per ream but with the same printing and viewing qualities). Then there are Substitutions that make paper from nonwood fiber, some of which is actually of higher quality than wood fiber.[38] There are Conversion Efficiency improvements that wring more paper from each ton of pulp or more pulp from each log. Finally, there are Field Efficiency improvements that get more volume of pulp logs per year from each acre of forest without damaging or destroying surrounding trees.

In the end, how much logging can be avoided through worthwhile improvements in practice at every stage of the office-paper value chain, treating it, for simplicity's sake, as one homogeneous process and market? If we use "nega-information," or convert to a truly paperless office (an unfulfilled dream so far), then a full 100 percent of the logging now done for making office paper becomes unnecessary. Tree-free paper is another option, though that may simply shift the harvest from forests to other crops or "wastes" grown in other places. In that case, the relative fragility or value of each crop or feedstock would have to be considered. What if changes were not so drastic but were more invisible and incremental? The results can still be surprising. Consider the possibilities of combining the following reasonable assumptions about downstream-to-upstream opportunities in a hypothetical office printing and copying paper value chain:

- **Functional Efficiency:** 10 percent reduction in paper use due to E-mail and procedures that curb unwanted printouts[39] = Factor 1.11 savings (that is, 1.11 times more service is obtained from the same resource use)[40]
- **End-Use Efficiency:** 50 percent reduction in paper use by instituting double-sided printing and copying, scratch-paper reuse, et cetera = Factor 2.0

- **Conversion Efficiency:** Pulp-mill conversion efficiency increase of 5 percent via process and equipment upgrades = Factor 1.05
- **Field Efficiency:** 400 percent increase in pulpwood yield per acre by specifying softwood plantations[41] rather than unmanaged natural forest = Factor 5.0
- **Materials Cycle:** 25 percent reduction in fiber required per sheet of paper by switching from 60-pound to 45-pound basis weight[42] = Factor 1.33
- **Unsubstituted Fraction:** 10 percent reduction in wood fiber use with supplemental nonwood (for example, straw) fiber plus 30 percent net reduction from paper recycling[43] = Factor 1.67

Assuming there are no economic "boomerangs" (for example, savings reduce or shift relative prices so much that more wood is used), these improvement factors would multiply out to a Factor 26 saving, or a 96 percent reduction in demand for acres of pulpwood forest harvest. Much of that saving is due to the switch to higher-yield plantations. Without that switch, the potential savings are still an impressive Factor 5.2 — quintupled resource efficiency, or an 81 percent reduction in extractive demand. With less growth (or even some shrinkage) in human population or affluence, or counting more technical opportunities, we could do even better.

Naturally, *combining* several kinds of improvements multiplies their savings even further. In Pará, Brazil, for example, improving harvesting practice by a straightforward 28 percent *and* sawmill efficiency from 35 percent to 50 percent means that a given net lumber yield could be achieved by harvesting 45 percent less forest. Comparably simple improvements already being achieved by one major Brazilian firm could improve harvest and mill productivity by 30–50 percent. If Brazil's sawmills became as efficient as their best Japanese counterparts, if field practice improved, and if the expected Brazilian tree-growth improvements of up to two- or threefold occurred, then 60–83 percent fewer harvested acres would deliver the same forest products at the mill gate.

NEW MATERIALS, NEW DESIGNS

Another area where wood fiber can be used more productively is in structural elements. The same concept as lighter-basis-weight paper can be applied to the construction trade. "Engineered wood products" like TrusJoist MacMillan's "Parallam" have about 1.8–2.4 times conventional lumber's product yield per unit of fiber, and can use younger, softer, lower-quality trees. With careful design, such "synthetic hardwood" products can achieve even greater efficiencies in converting raw timber into structural performance, albeit with additional inputs of energy and adhesives (which can be wood-derived). For example, a house floor would be just as strong and solid using engineered-wood-product I-joists weighing 44 percent less than traditional solid lumber. (The floor also won't squeak.) These savings compound because I-beams manufactured from engineered wood can also make houses' roof and floor supports so stiff that no internal load-bearing walls are needed. This allows layouts to be completely flexible, yields more useful living space per unit of external walls, and reduces the lumber needed for the internal walls, which need no longer be structural.

Designing from scratch with engineered wood products can yield even larger savings and many side benefits. For example, artfully designing an engineered wall framing (EWF) system has been demonstrated to save 70–74 percent of the wood in a wall, or about 50 percent in the entire house.[44] The wall used Timberstrand oriented strandwood studs made by pressing together small-diameter, low-grade hardwoods. The synthetic studs were so much stronger and more predictable than commodity-grade studs, and so free from knots, defects, or other irregularities, that they could provide about four times as much service per unit volume of delivered wood. To be sure, the compressive manufacturing process involved here meant that more than one cubic foot of (younger, lower-quality) raw wood had to go into each cubic foot of engineered wood products, along with a good deal of energy, typically derived from wood wastes. But such a dramatic saving, if widely practiced, would be highly cost-effective. The total materials-plus-labor mature-market cost of the wall was $433 *lower,* it was stronger and more durable and stable, and it could be built more quickly and easily.

Moreover, the wall accommodated almost twice the thickness of insulation (paid for by saved wood and labor), and the engineered studs, being thinner than lumber studs, reduced heat leakage through the wood. This doubled insulating value was the key to eliminating the house's heating and cooling equipment in an extreme climate (temperatures as high as 113°F), while improving comfort and reducing mature-market capital cost by about $1,800 and life-cycle maintenance cost by about $1,600.[45] With such inherent advantages, it's not surprising that sales of engineered wood products have lately been expanding by about 25 percent a year. They are now used by most U.S. builders, and are even traded as Chicago Board of Trade futures.

New ways to assemble small pieces of lumber into larger sections have begun to make it profitable to substitute small trees, little-used species, and "waste wood" for premium and old-growth timber.[46] Scrap wood, even if green, can be "fingerjointed" together to recover 500–700 board-feet of good dimensional lumber from each ton of what was previously wood waste. Thick boards can be made by gluing together edgewise a series of trapezoidal-section blocks cut in pairs from logs only about 4 to 5 inches in diameter. Alternatively, logs of this size can be squared and sawn into quarters; rotated so that their beveled outside corners are now placed facing the middle; and then glued together into a hollow-core square beam substantially larger than could have been cut from the original log. I-beam joists can be made by inserting a sheet of flakeboard between two peeled pine poles, in effect edging the sheet with a stiff beam on each side. The resulting structure can offer the stiffness of far more massive beams.

Another example of saving fiber through clever structural design is the Bellcomb[47] system of cardboard-like honeycombs sandwiched between sheets of cheap strandwood (pressed like chipboard, but using tough fibrous strands of wood). The sandwiches are prefabricated in many precisely cut shapes that fit tightly together like a child's miniature house kit — only this kit can be full-sized. Two unskilled adults could assemble a snug cottage from such components in a half hour and then, if the joints haven't been glued together, disassemble it even faster. The resulting structure is airtight, fire-resistant, optionally recyclable, and easy to superinsulate by adding foam layers into the sandwich. Its early versions saved 75–85 percent of the fiber but offered the same strength as conventional wood structures. Another firm, Gridcore (of Long Beach, California), makes honeycomb panels from 100 percent recycled agricultural fibers for furniture, cabinets, stage sets, and other items needing light weight.

Still another important wood-saving development is modern Glulam beams, which glue together many layers of wood to replace massive solid beams. This plywood-like principle achieves greater strength per unit of cross-sectional area than solid wood, especially if the layers are tailored to provide the type and direction of strength that the application will require. This strategy reduces the total amount of wood needed to span a long distance, which in modern European practice can be astonishingly large, and it substitutes younger for old-growth trees. A recent innovation achieves even better results by sandwiching carbon-fiber, aramid, or other superstrong synthetic fibers in between layers of wood. This combination can save two-thirds of the wood previously required, cut total costs, and make light, airy beams attractive for large structures.[48]

CLOSING MATERIALS LOOPS

Wood recycling is also an increasingly competitive area, as was noted in chapter 5's discussion of profitably recycled building materials. Another example of a product that can be substantially rethought is wooden shipping pallets, whose manufacture uses about 11 percent of the total lumber and an astonishing two-fifths of the hardwood cut in the United States.[49] There are now some 1.5 billion pallets in the United States — six pallets per American. Another 400 million are made every year. And Henry Ford's devotion to pallets' reuse, repair, and remanufacturing is now rare: Broken pallets are seldom mended, and even sound pallets are usually discarded; this wastes each year as much wood as would frame 300,000 average houses. Some firms are finding that minor changes in packaging patterns can greatly reduce pallet requirements per ton shipped.[50] Others are eliminating pallets or using rugged, easily recycled ones made of waste plastic. Others have realized that discarded pallets — which cost New York City businesses alone about $130 million a year to dispose of — are a better-than-free raw material for community-based remanufacturing. One such recent startup, Big City Forest in New York's Bronx,[51] produced 50,000 recovered pallets and some furniture from 54,000 input pallets in its 20-month pilot phase. This saved 1,500 tons of wood (over 1 million board-feet), and $500,000 for area firms. Rainforest Action Network estimates that reclaiming even half the discarded pallets from the largest 50 U.S. metropolises could provide 2,500 inner-city jobs and 765 million board-feet of annual lumber, equivalent to 152,000 acres of timberland.[52] Changing commercial incentives can help make this happen: Some German pallets, designed to be uniform, durable, and reparable, are even barcoded so the original maker gets a royalty-like credit each time it's reused and a charge each time it needs mending — a lifetime incentive to build it well.

The most familiar method of fiber recovery recycles not wood but paper. Encouragingly, each year since 1993, the United States has recycled more paper than it has landfilled (excluding incineration), and despite frequent imbalances between supply and demand, the market for recycled paper is gradually both growing and stabilizing. Paper recycling, which in 1994 was of a volume sufficient to fill a 15-mile train of boxcars daily,[53] is expected to contribute about 47 percent of fiber inputs to U.S. papermaking by 2000,[54] compared with 1996 figures of 96 percent in Holland and 52 percent in Japan.[55] Some potentially recyclable streams also remain untapped. Twenty million tons of urban wastewood, equivalent to 7 percent of the forest harvest, enters municipal waste dumps every year.[56] In the late 1970s, Los Angeles County logged daily landfilling of 4,000–5,000 tons of pure, separated tree trimmings and similar material. Now, 2,500 tons a day go to soil improvement, community gardens, and landfill cover — helping hold landfill tonnages constant despite population growth.[57]

Simple process innovations can make recycling an even more attractive option. Green Bay Packaging Company in Green Bay, Wisconsin — a state that banned all paper from its landfills in 1995 — improved its manufacturing processes enough by 1992 to be able to eliminate all the effluent discharge that had been a waste product from making all-recycled containerboard. This progress means that paper-recycling plants can be built far from any waterway or treatment plant, reducing the cost of fiber, water, solid-waste disposal, energy, labor, investment, and transportation. The company began exploring a nationwide network of such regional minimills that it hoped would take market share from large virgin-materials mills much as steel minimills had done. Moreover, during its first year, while recycling 200,000 tons of wastepaper, the firm's zero-discharge mill raised the normal-best-practice fiber recovery rate from 85–90 percent to 97–98 percent — equivalent to saving another 20,000 tons of wastepaper from going to landfill annually — and thus became the industry's low-cost producer.[58]

Even more fundamental technical innovations are on the horizon. Japanese firms are reportedly developing "recycle copiers" that strip off old toner so a sheet of paper can be reused up to ten times. In the United States, Decopier Technologies[59] is launching the Decopier, which is expected in a few years to remove toner with so little harm that paper could be used up to five times and transparency film up to ten times. (The current version doesn't yet permit reuse but can substitute recycling for shredding.) Other coming innovations in polymeric ink technology would allow ink to "float" off paper when immersed in 130°F water. The ink is collected, shipped to a local manufacturer to add more aqueous bonding agents, and then reshipped to the printer to be used continuously in closed loops. Although such ink would be expensive, it would never be thrown away. And because the paper fibers need not be chemically scalded to remove the ink, they can last ten to thirteen times longer than conventionally recycled paper fibers.[60] This single technique, if universally adopted, could reduce forest pulp use by 90 percent. It would also reduce the amount of hazardous and toxic ink residues that end up in landfills. Another candidate for such major paper savings is E-paper, a flexible and cordless computer screen that looks like a sheet of paper, uses no energy for storing images or for viewing, and can be electronically written and rewritten at least a million times. A million sheets of ordinary paper "would cost thousands of dollars and make a stack more than 300 feet tall." Nick Sheridon, its inventor at the Xerox Palo Alto Research Center, thinks it could be economical to produce and could be available by 2000.[61]

Recovered and nonwood fiber can also be supplemented or replaced by wood or nonwood fiber harvested from special plantations. For both structural and pulp uses, input-intensive temperate or tropical "fiber farms" show promise as a way to relieve pressure on primary or legacy forests. One plausible estimate indicates that the entire world demand for industrial wood fiber for all uses (excluding fuelwood, which is slightly larger) could be supplied by plantations on "good forest land" equivalent to only 5 percent of the currently forested global land area,[62] or about 490 million acres.[63] *Very*-high-yield plantations covering the equivalent of one half to one percent of current forest area — 57–99 million acres, no more than the area *currently* supporting industrial forest plantations[64] — could in principle meet today's world demand for wood fiber for all purposes at present efficiencies of use. Improving downstream efficiency by a total of, say, three- to fivefold in the long run could reduce the land needed to only a tenth to a third of one percent of current forest area. This is a land area as small as New Hampshire and Vermont or as large as Louisiana or Iowa. This means that existing high-yield industrial plantations (which already occupy 35 million acres), if cultivated more intensively, could in principle provide for the world's entire *efficient* wood-fiber needs. Those plantations' area is comparable to the amount of tropical forest *lost each year* in the early 1990s.[65]

Whether to encourage the use of genetic engineering for high-yield plantations is a complex issue with trade-offs not yet well understood. Today about a third of all wood-fiber and pulp production takes place on industrial plantations (with stocks consisting of one-third exotic and two-thirds native species); somewhat more from second-growth forests (which are nearly all under management); and only about one-fourth from dwindling old-growth forests.[66] Dependence on plantations, notably high-yield ones, would not automatically mean protection for primary forests, but it would surely help undercut the argument that it is necessary to cut mature, ecologically diverse forests. Those forests are part of a dwindling natural capital that provides benefits beyond the extraction of board-feet and tons of pulp. Old-growth forests support indigenous people, fish, and wildlife. They protect biodiversity, hold water,[67] provide recreation, beauty, and spiritual renewal. They also clean the air, and potentially sequester enough carbon to offset one-fourth of worldwide CO_2 emissions.[68] Most assessments find that these functions are many times more valuable than the commodity value of wood fiber,[69] especially if that fiber is to become a throwaway wrapper for a hamburger or an envelope for an unwanted credit-card solicitation.

Many societies are becoming increasingly aware that fiber value is a poor surrogate for the entire value of a forest, especially if the former destroys the latter. For example, in early 1998 China announced a decades-long, more than $30 billion program to try to reforest the watersheds of its two largest river systems. An immediate $12 billion commitment was underlined by the massive Yangtze River floods that killed 3,700 people, dislocated 233 million, and inundated 60 million acres of cropland later that year. All logging in the relevant watersheds has now been prohibited (though actually stopping it may prove more difficult). In China as in America, proper management of the forest resource for *all* its social values would have avoided the need for such costly remedial investments.[70]

ALTERNATIVE FIBERS AND FURTHER INNOVATIONS

Some nonwood fibers are already widely employed for structural uses. For example, bamboo, which is stronger per unit mass than steel and constitutes 6 percent of global fiber production[71] (an amount second only to wood fiber), is widely used in Asia for scaffolding even in high-rise construction. It also makes excellent small to medium-sized structures, and in some circumstances can even replace rebar.

Kenaf, an East Indian hibiscus akin to okra and cotton, is beginning to emerge as a viable wood substitute. Kenaf grows quickly, with low inputs, in a wide range of conditions, and can yield several times as much fiber per acre as wood — possibly at lower cost if produced and processed at industrial volumes. Although it is inconveniently seasonal, requiring storage for year-round paper production, its fiber, like that from many varieties of alternative crops, is markedly superior to that of wood. Another alternative is industrial (nonpsychoactive) hemp, which yields 20–30 tons of dry fiber per acre annually, exceeding the output of most tree species. It has many remarkable properties that led the U.S. government to promote its production in an earlier era. Its potential is now starting to be revived by Canada, Hungary, and such states as Kentucky, Vermont, and Colorado. Such other alternative fibers as elephant grass, canary grass, and bagasse (sugarcane waste) are also more productive fiber sources than any but the fastest-growing hardwood plantations.

Most important, agricultural residues *currently available* in the United States exceeded 280 million tons a year in 1994[72] — essentially the same, uncorrected for moisture differences, as *the entire world consumption of paper or the total U.S. wood harvest.* A substantial part of those residues is being wasted — burned, rotted, or landfilled — rather than used for products or for building soil fertility. However, the resulting business opportunity is starting to be grasped. Since 1980, nonwood paper production has grown more than three times as fast as wood-based paper, and now represents about 8 percent of world paper fiber input.[73] It provides less than one percent of America's paper, but as much as 80 percent of China's. By 1998, tree-free paper was made in 45 countries and provided 11 percent of the world's paper.[74] Both recycled and alternative-fiber paper typically can be produced with "minimill" technology at a much smaller scale than classical virgin-fiber paper, potentially reducing transportation energy. Many of these alternative fibers can also be well integrated with sustainable farming and forestry practices. For example, certain farmers' cooperatives in Oregon leave 90 percent of their formerly burned straw as stubble mulch to improve tilth and prevent soil erosion, and sell the other 10 percent to the Canadian firm Arbokem. The company turns it into chlorine-free agropulp plus effluent sold as fertilizer. The farmers' earnings from even this small portion of their straw can raise their income per acre by 25–50 percent.[75]

The innovations illustrated by these anecdotal examples, and the far larger potential still unexploited, provide good reason to believe that efficiency and substitution throughout the value chains of forest products can displace most or all cutting of natural forests — freeing them for more valuable roles such as habitats and wellsprings of spiritual renewal — while providing the same or better services. Similar opportunities for protecting and restoring natural capital apply to essentially all the other kinds of fiber, too. Obtaining the fibers we need to carry out the tasks of everyday life need not cost the earth.