Every Age, the Age of Wood

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Man's manifold uses of wood, from biblical times to modern computer applications are reviewed here. In peace and in war, in the Old and the New World, man first turned to wood for his basic needs and later learned to use advanced science to employ wood as his most sophisticated raw material, being infinitely versatile and an easily renewable source. It is confidently predicted that wood will remain a major renewable resource for man's future.

'The earth brought forth vegetation, plants yielding seed according to their own kinds, and trees bearing fruit in which is their seed, each according to its kind. And God saw that it was good'.[1] Certainly the tree continued to hold a prominent place throughout biblical history. Noah built the ark from gopher wood. The first ark of the covenant was made of acacia wood. The famed Cedars of Lebanon framed Solomon's temple. Christ was crucified on a wood cross. And the sorry state of the world is attributed to man having eaten an apple from the wrong tree.

Trees have provided man with fuel, tools, food, and shelter ever since he started his long journey. *The International Book of Wood* points out correctly that 'Man has no older or deeper debt' than that which he owes to trees and their wood.[8]

EARLIEST USES OF WOOD

Here are a few highlights of wood's innumerable contributions to the development of society from prehistory to modern times. They permit us to project what the future may hold for man's oldest renewable resource in the wake of modern technology, scientific research, and increasing economic, social, and environmental pressures.

'A culture is no better than its woods,' writes poet W. H. Auden.[2] That would make an excellent thesis for this review. But in reality the most famous of the early cultures developed in relatively treeless areas along the Tigris-Euphrates, Nile, Indus, and Yellow Rivers. Trees there were small enough to fell with the simple tools available and the sandy and silty soil of the flood plains could be worked easily with wood digging sticks.

How these cultures used the available wood is hard to determine, as wood artifacts have largely disappeared. But certainly the use of wood for fire is one of the first and most significant contributions of this resource to the development of society. In a cave near Peking, China, coals and human remains have been unearthed that are about 4000 years old, indicating that wood was used then for either heating or cooking or both.[8]

No doubt man built early pole structures from the small trees growing along the rivers and later he would build more solid structures from planks, turf, mud, and adobe. The Scandinavians developed the basic principles of timber framing which were probably known in Europe in the Bronze Age,[8] and framing eventually became the pre-eminent method of wood building in the Western World, reflecting developments in structural engineering that had been worked out with wood mostly through trial and error.

Moving off the land and into the water, one of the first uses of wood for water transport was probably a hollowed-out log. Around 4000 B.C. the Egyptians were making ships from bundles of reeds and their earliest wooden boats copied the hull frame of the reed boats. For larger vessels, the Egyptians imported cedar from Lebanon. One reason for the northward expansion of Egypt's influence was to ensure its cedar

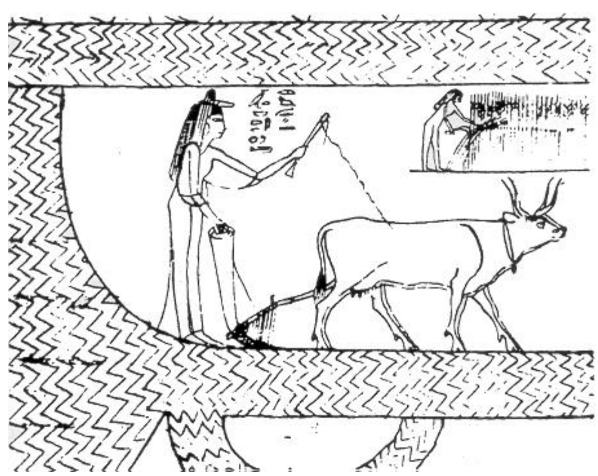

Figure 1. The Egyptian Princess Nesitanebtashru using a wooden plough and reaping. From her funerary papyrus, about 970 BC. (Ann Ronan Picture Library.)

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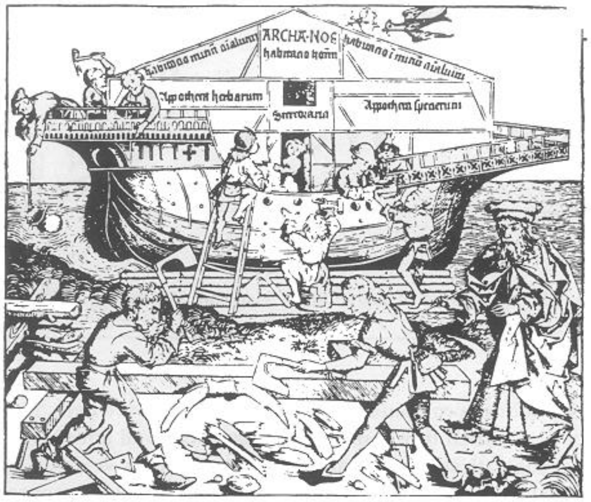

Figure 2. Noah supervising the building of his wooden Ark. From: Hartmann Schedel *Liber chronicarum mundi (Nuremberg Chronicle)* Nuremberg (1493). (Ann Ronan Picture Library.)

supply. Records show that the Egyptian shipbuilder could use wood on a grand scale. Queen Hatshepsut's barge, built in 1500 B.C. to transport granite obelisks from Aswan to Thebes, had a displacement of some 7500 tons, and 30 oar-powered tugs were needed to tow it.[8]

WOOD IN GREECE AND ROME

Thanks to Theophrastus, a pupil of Aristotle, we know what was available for shipbuilding in Ancient Greece. He writes: 'The ship-building woods are silver fir, fir, and cedar. Silver fir is used for lightness; for merchant ships, fir is used because of its resistance to rot. In Syria and Phoenicia, cedar is used because of the lack of fir.'[8]

Technological improvement in land transport was slower than that of water transport. From 7000 B.C. onward, wood sledges were used for heavy loads such as stones, and archeologists reason that the massive stones in the great monument at Stonehenge, UK, must have been moved on sledges placed on rollers, which may have inspired the discovery of the wheel. But we still have no record of when and where the wheel was invented, though surely the first axle was made of wood.

Another significant contribution of wood to the ancient world was for war devices. Examples include the catapult, which enabled a man to attack his enemy from a safe distance, the battering ram and scaling ladder, the tortoise, and the siege tower. Although the choice of materials for these purposes was quite limited, the properties of wood made it eminently suitable. High strength and low weight were highly valued characteristics of wood then, just as they are today. These siege engines were integral to the expansion of both Greek and Roman civilizations and of the science, technology and philosophy that developed under the tutelage of the great thinkers and teachers of the times.

Ancient man was using wood to conquer his world as well as build it and explore it. Then some unknown woodman in Ancient Greece invented a primitive wooden lathe, and man found himself on the threshhold of the age of machines. When he entered that age, he would find ways to make wood work for him to unprecedented degrees. From the basic concept of the lathe and the ability to shape wood to circular symmetry developed new concepts of both materials use and machine development.

EUROPEAN WOOD-AND-WATER TECHNOLOGY

The historian Lewis Mumford divides the machine age of the last 1000 years into three phases. The first, between the 10th and 18th centuries, is a water-and-wood complex he calls the eotechnic phase. The second is described as a coal-and-iron *paleotechnic* phase. And the third is the electricity-and-alloy *neotechnic* phase.[10]

Wood was the paramount material of the eotechnic phase. It was used for buildings, tools, machines, windmills, watermills, carts, brooms, buckets, shoes, cradles, beds, and beer barrels. One hundred years after the printing press was invented, it was still made of wood. In fact, most of the key machines and inventions necessary to universalize the machine were first developed in wood and promoted during this period.

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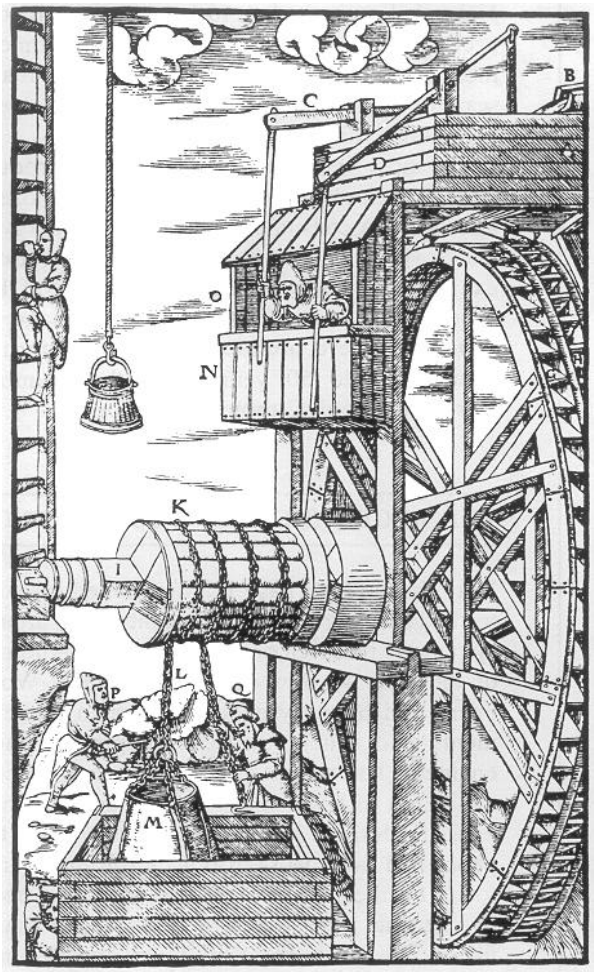

Figure 3. Wooden macro-engineering in the 16th century. Agricola in his *De re metallica,* Basle (1556), produced the first mining technology work and here illustrated is a reversible hoist for raising ore from a shaft. The operator, *0,* in his hut, *N,* through levers *C* and *D* can regulate the water flow, *B,* to fall on wheel *E* or *F,* thus rotating it in either direction. The leather bucket *M* can thus be raised or lowered. (Ann Ronan Picture Library.)

Mumford stated, 'Had it not been for the demand of metal coins, armor, cannons, and cannonballs during this period, the need for metal would have been relatively insignificant.' In all operations of industry, wood played a predominant part. The full significance of this early use of wood for materials and machines cannot be appreciated without noting its effect on society. For example, wood for paper and printing presses changed the course of human history as it then became possible to store accumulated knowledge, making it available to more people, who could build on it through additional research and development. Paper and printing presses spurred the advance of science and technology to the industrial revolution, an implication far beyond the obvious materials which these inventions made possible.

The 'eotechnic phase' produced many other great mechanical achievements with far-reaching social implications. Alongside these achievements it left a rich legacy of great cities, great buildings, cultivated landscapes, and beautiful paintings.

In Europe the water-and-wood phase reached a high plateau around the 16th century with the work of Leonardo da Vinci and his talented contemporaries.[10] At about this time, the availability of timber diminished, particularly in the UK. The scarcity was caused by the expansion of agriculture, the increasing use of wood as a structural material and fuel, and from growing demands of the smelting furnaces. To smelt one cannon took several tons of wood.

By the 17th century, Europeans were turning to coal for the domestic hearth, and when the secret of smelting metal with coal was discovered, coal became the unique basis for industrial technology until late in the 19th century.

AMERICA'S WOODEN EXTRAVAGANZA

In early 19th century America, a seemingly inexhaustible supply of timber existed. The technology here was geared to exploiting the use of all natural resources to make up for the scarcity in capital and labor.

But the technological advances of the 19th century, along with the increasing population, would have a major impact on American forests. Railroads, telegraph lines, charcoal-fueled steel mills, and other industries were consuming immense quantities of wood. The Civil War made a heavy demand, too. One gun factory alone used 28 000 walnut trees for gunstocks. During the latter half of the 19th century, the volume of lumber produced each year rose from 4 thousand million board feet to about 35 thousand million[6]

As with many other industries of this time, lumbering was a highly competitive business. Quick profits were the name of the game. This encouraged careless and extravagantly wasteful harvesting and manufacturing methods. The visible devastation that resulted encouraged a new concern for America's forests. Theories were published that purported to prove that the fall of ancient empires, radical changes of climate, and the spread of epidemics could be attributed to deforestation.

But America's wood-and-water phase reached its own plateau around 1850, about 200 years after that phase had peaked in Europe. Our heads were turned by European technology that was now based on the coal-and-iron complex. Some of our traditional uses of wood -for fuel, pavement, sailing ships, charcoal, and iron smelting - were taken over by coal, steel, and stone. However, demand for timber was maintained as many new uses of wood, for paper, plywood, telegraph and telephone poles, railroad ties, and increasing technical complexity of our society. Nevertheless, in the late 19th century the use of wood products had begun to level off. For the time being, most of the country stopped worrying about a timber scarcity. Coal was abundant and iron and steel could be manufactured.

The most significant decline in wood products use since then has been in fuel wood. One hundred years ago the USA consumed 4 exajoules of energy a year, and 3 were provided by wood. Today we use 75-80 exajoules, and only 1.6 is provided by wood. Lumber production statistics estimate 35 thousand million board feet were produced around the turn of the century, while 50 years later that number had increased by only 2 thousand million.[6]

Figure 4. The Master's Masterpiece: the violin called *Le Messie* made by Antonio Stradivari (1664-1737) at Cremona in 1716. Made partly from maple wood, still today the preferred material, it is with its almost unworn varnish and its carving in pristine condition, the centre piece of the Hill Collection of Musical Instruments at the Ashmolean Museum, Oxford with whose kind permission it is here illustrated. Its length is 593 mm, its greatest width 213 mm and its depth varies from 29 to 32 mm; it was last played in 1891. Its complete history from 1716 is fully documented and it acquired its name, *The Messiah,* from the fact that one of its owners, Luigi Tarisio, always talked about it but would never show it to any other collector. Delphin Alard is credited with the sardonic exclamation: *'Ah, ca, votre violon est donc comme le Messie ; on l' attend toujours, et il ne parait jamais.'* See: David D. Boyden *Catalogue of the Hill Collection,* Ashmolean Museum, Oxford (1969).

chemicals entered the picture. The selection from among competing materials was based partly on cost and availability and partly on properties and performance. It is also noteworthy that such a range of choices coincided with the rapid mechanization and

THE BEGINNINGS OF WOOD SCIENCE

Note that so far I have not mentioned research. Up to the latter part of the 19th century no appreciable systematic research on wood occurred - no research of the type we now call wood science. Wood had been used by early experimenters to make instruments and other research equipment, and early engineers had used it as a construction material and a material with which to work out engineering problems and designs. Methods for pulping wood to make paper had been worked out by the paper industry, too.[14] Further, both cotton and wood had been used by chemists as a source of cellulose for man-made fibers. This led to the 1892 Cross and Bevan patent on *viscose* and Stearn and Topham's subsequent work on spinning this into filaments that were known as *viscose rayon.* At about the same time Schutzenberger and then Cross and Bevan worked out cellulose acetate reactions with solvents that led to the ability to produce that compound as both film and fiber. These advances provided a base for the subsequent technology of nylon and established the principles by which countless numbers and kinds of linear high polymers can be synthesized.[3,9]

The carriage business provided an early milestone for a new era of wood research. In 1889 the Carriage Builders Association was concerned about the scarcity of northern oak, a species long preferred for their craft. The builders wondered if southern oak, in plentiful supply, possessed the same desirable characteristics as the northern species. The Division of Forestry of the US Department of Agriculture stepped in to help solve the problem. Its research confirmed that suitable material could be obtained from the South as well as the North.[11]

This incident was an important step toward comprehensive wood research as we know it today. From 1890 to 1910, small amounts of money were appropriated by the Division of Forestry to universities for wood research. Studies of the mechanical properties of wood were begun, along with wood preservation and wood drying studies. Naval stores

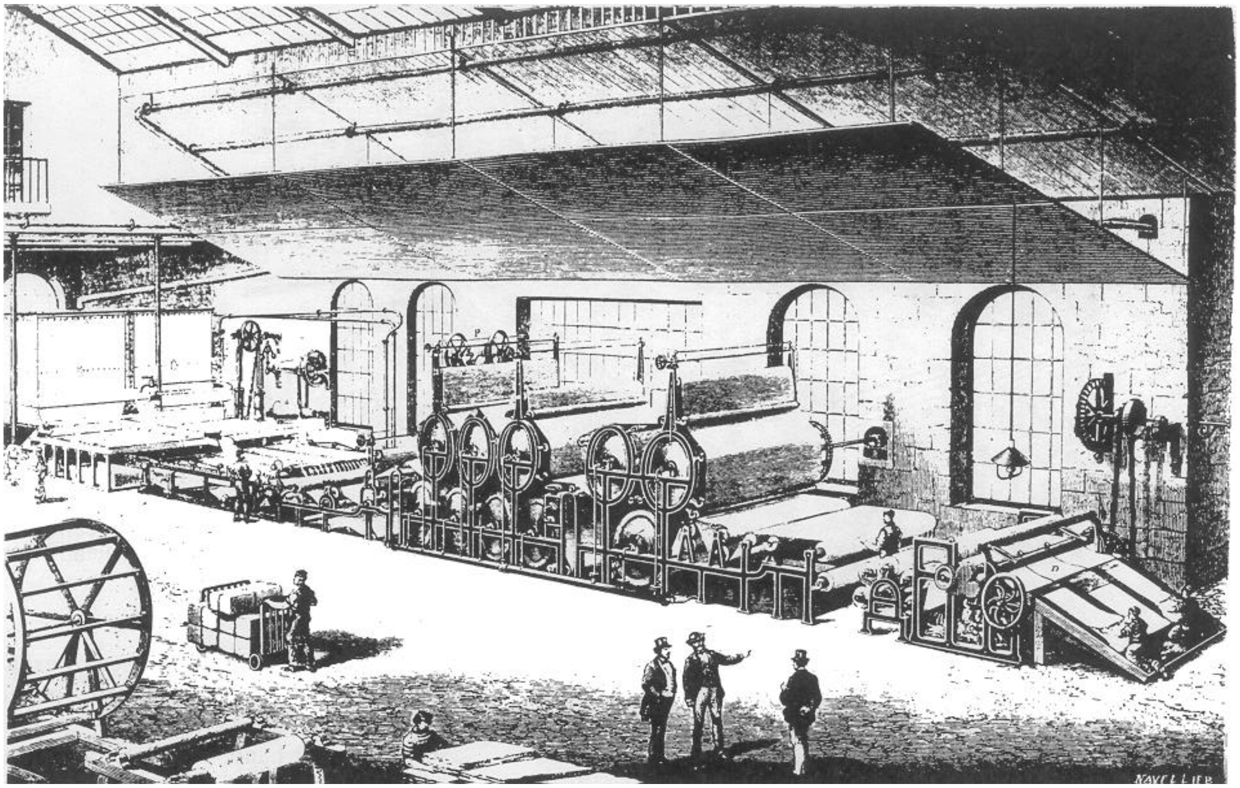

Figure 5. One of the first machines for continuous paper making, from wood pulp at left to cut sheets at right, was produced by Bertram and illustrated in Le Figuier's *Les Merveilles de l'Industrie* in 1870. (Ann Ronan Picture Library.)

research was started in the South. A small experimental pulp mill was erected in Boston, and wood chemistry and wood preservation were also studied there in a small way.

THE FIRST FOREST PRODUCTS LABORATORY

Then in 1910 the Division of Forestry, in cooperation with the University of Wisconsin, established the world's first comprehensive forest products-laboratory in Madison, Wisconsin, to centralize the federally sponsored wood science efforts in the country. The birth of a full-fledged wood research laboratory could not have happened much earlier. The leaps and bounds science had taken in the 19th century provided the necessary foundation for such a laboratory. Each of the major branches of experimental science made such great progress then that in retrospect its earlier state seemed rudimentary. Scientists would call this century the Golden Age.[4]

But even more vital to the development of wood science was the extensive knowledge of wood that already existed. Credit goes to the woodman, of all ages and all cultures. His trial and error method for discovering which wood was best for his needs produced a storehouse of practical knowledge on the properties of various species, and his use of wood for building dams, locks, mills, bridges, wheels, levers, and rollers laid the groundwork for comprehensive engineering.

So the woodman's legacy was invaluable to wood science, which was beginning to make some real progress in the early 20th century. Research on wood drying led to the first of a number of patents granted on the humidity-regulated dry kiln. Dry kilns were rapidly accepted in lumber manufacture to accelerate and control the long and expensive process of drying lumber.

TIMBER MECHANICS

Timber mechanics studies were also underway, with the object of providing a full array of systematic, standardized engineering data about American wood species. From this work emerged a system of grading rules, working stresses, and design specifications that provided a scientific basis for use of wood as a structural material. During World War I, wood scientists began pulping research on a variety of species not then used for paper, notably the southern pines and hardwoods. A process using these species was demonstrated in 1931, and the first southern newsprint mill using it was opened in 1949.[7]

During World War II, wood research covered the whole gamut of possible wartime uses of wood:

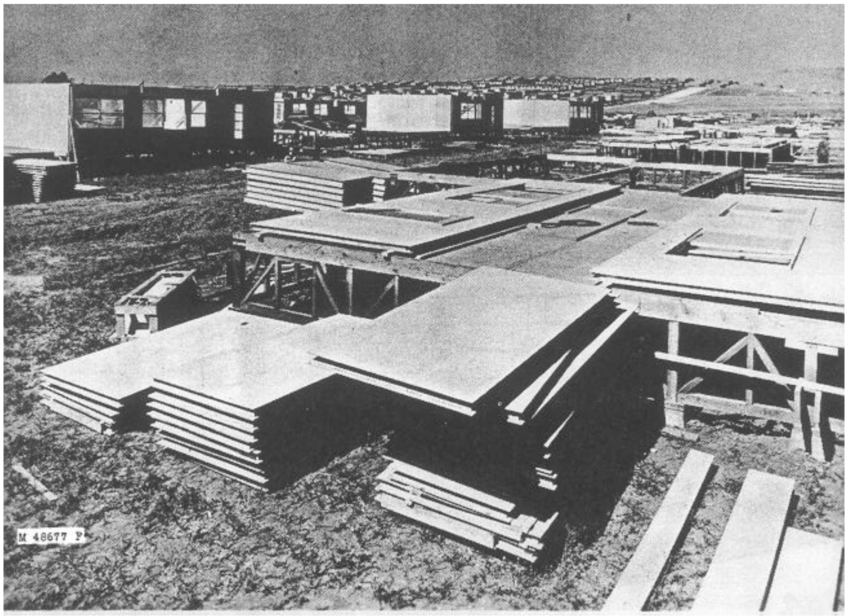

Figure 6. During World War II (1939-1945) many US Army training camps were entirely constructed from wooden huts.

airplanes, boats, structures, containers, paper, and adhesives durable in all kinds of weather. After the war, research led to the application of these new inventions in civilian life.

Man was now into what Lewis Mumford calls the electricity-and-alloy or neotechnic phase of his technical development. The importance of timber products declined, on a relative scale, as the importance of minerals increased, due in part to abundant low cost energy in the form of coal and then petroleum. It is worth noting, however, that tonnage of timber products produced in the USA then exceeded that of all metals and plastics combined, just as it does today. So, while timber declined in relative importance and public awareness, it remained the major product of American manufacture.

WOOD AS RENEWABLE RESOURCE

Today low cost and accessible energy can no longer be taken for granted. We are back to a point where many people, including materials scientists and engineers, are beginning to appreciate the need for renewable resources like wood. This appreciation is heightened and fed by the fact that the USA finds itself blessed with a timber inventory that is increasing each year. Unfortunately, much of this is not of the large clear sixes and high quality to which we are accustomed.

No doubt the rising demands of a growing population will make wood even more attractive. Glesinger stated that 'there exists an enormous pool of interchangeable materials for an almost infinite variety of uses and in this pool wood has always been and remains a major element essentially on account of three characteristics: it is versatile, which makes it an almost universal raw material; it is renewable, in contrast with minerals threatened by exhaustion, and it offers almost unsuspected possibilities of expansion'.[5]

On the other hand, the past abundance of timber and the dispersion of the industry have worked against advances in technology for the efficient production, conversion, and use of wood products. Fortunately, and despite its relatively recent origin as a recognized field of study, wood science has had an appreciable effect on wood technology as well as science in general. The study of wood chemistry has contributed to our understanding of the principal components of wood - cellulose and lignin - and their reactions. Early research on hydrolysis of cellulose was prompted by fuel needs in World War I, but contributed much to our knowledge of this form of chemical reaction. Similarly, research on nitrocellulose was prompted by the needs for explosives. Accompanying studies of saccharification and fermentation are contributing much to our scientific knowledge in those areas. Engineering studies of wood as an orthotropic material contributed strongly to the concept of sandwich construction, now commonly used in aircraft design, as well as to the early development of glass-fiber-reinforced plastics in the 1950s and 1960s.

NEW APPLICATIONS AND USES FOR WOOD SCIENCE

Today wood science is seeking options for more effective management and use of the timber resource. The goal is increased dependence on wood, wood fiber, and wood chemicals to meet human needs. Are we successful? An overview of our progress in the major wood research areas will help answer that question. In the pulp and paper industry, research confronts two obstacles: first, the existing technology was established when fuel costs were low and environmental restrictions negligible; and second, the increasing demand for paper is putting strong pressure on supplies of softwood needed for building and other traditional demands, as well as for paper.

Just recently wood scientists developed and pilot-tested a new press drying concept that enables manufacture of stronger paper from 100% hardwood pulp than is currently being made from softwood. Strong paper from hardwood had not been a realistic option until the press dryer was invented. The new process conserves energy in pulping and papermaking. It also opens new opportunities for the abundant supply of low quality, low value hardwoods in many eastern forests to be transformed into strong papers for containers and other engineered products.

A second area of research focus is panel products. They are one of the fastest growing uses of wood in the forest products industry. The problem here is the rising cost of petroleum and the effect this has on the price of adhesives, which accounts for a large part of the cost of panel products. Intensive research is under way to find adhesives which set more rapidly at lower temperatures and have other characteristics that can lower the cost of the gluing process.

Development of adhesive technology is a key to using low grade material to make high grade product for both structural and decorative uses. An example is a recently developed flakeboard product made from hardwood trees of little marketable value. The flakeboard is engineered so that it can perform at least as well as any commercial roof decking now in use, again broadening options to use renewable materials for major structural applications.

Lumber is another research focus. When timber was plentiful and cheap, lumber was produced on simple equipment. But our resource has changed: the timber is small, it has more defects, and the composition of forests is shifting toward less desirable hardwoods. In addition competition with other materials has substantially increased.

Research can retard or reverse the trend away from lumber by providing options to reduce its processing costs, improve the yield, and improve the quality. This is being achieved to a remarkable degree with computer control of sawing processes. Automated systems, particularly those involving defect detection and machine grading, offer much promise, too.

Another big area where research can help us extend our timber supply is in the use of wood as an engineering material. Improved information on wood properties, coupled with advances in wood design and fastenings, is providing a substantial base for developing more efficient ways to use wood in construction.

An outstanding example is the truss-frame system of housing construction. It uses the truss principle to greatly increase efficiency of wood framing methods. At the same time, engineers and architects need to know what the wood scientist is discovering about the properties of wood. The Heritage Workshop Series, sponsored in recent years by the US Forest Products Laboratory, offers a forum where the wood scientist can communicate this knowledge, as well as distribute educational materials to engineering professors and students.

WOOD FOR FUEL AND CHEMICALS

Yet another research focus is on use of wood for fuel, which still plays a big part in man's existence. Today about half of the world's annual wood harvest is burned for those same products primitive man valued from his wood fire -heat and light. But much of this is in the less developed countries. In most developed countries, use of wood for fuel peaked in the last century. But with the energy situation as it is today, even developed countries are turning to wood for fuel. It is renewable, relatively cheap, low in ash content and negligible in sulfur content.

On the other hand, wood is bulky, has less than half the heat of combustion of fuel oil, and in its green state is heavy to ship. Furthermore the cost of a wood-burning system may be three to four times that of a gas-burning installation because of fuel storage, handling, and air quality control systems. These drawbacks have kindled interest in production of liquid and gaseous fuels from wood. Much research is devoted to improving existing technology and devising new approaches, but such fuels are still expensive compared with petroleum-based fuels.

Finally, closely related to the conversion of wood to liquid or gaseous fuel is the use of the chemical storehouse that is wood to produce a wide range of *silvichemicals.* Research has shown how to produce useful products from cellulosic polymers, wood and bark extractives, oleoresins, and pulping liquors. Many processes of these types already form the basis of chemical production on a commercial scale. But the potential to use wood as a chemical feedstock is much greater than has so far been realized. Whole wood can be gasified, liquefied, or pyrolyzed in ways comparable with those used for coal to yield a wide variety of chemicals. Cellulose, as a glucose polymer, can be hydrolyzed to monomeric glucose by acid or enzymes, and the glucose then fermented to ethanol. The ethanol can be used as a fuel or as a source of other important chemicals such as ethylene or butadiene.

As an alternative, use of glucose as substrate for fermentation would make possible production of antibiotics, vitamins, and enzymes. Hemicelluloses can easily be converted to simple sugars which can be used to produce either ethanol or furfural, a potential raw material for nylon or other synthetics.

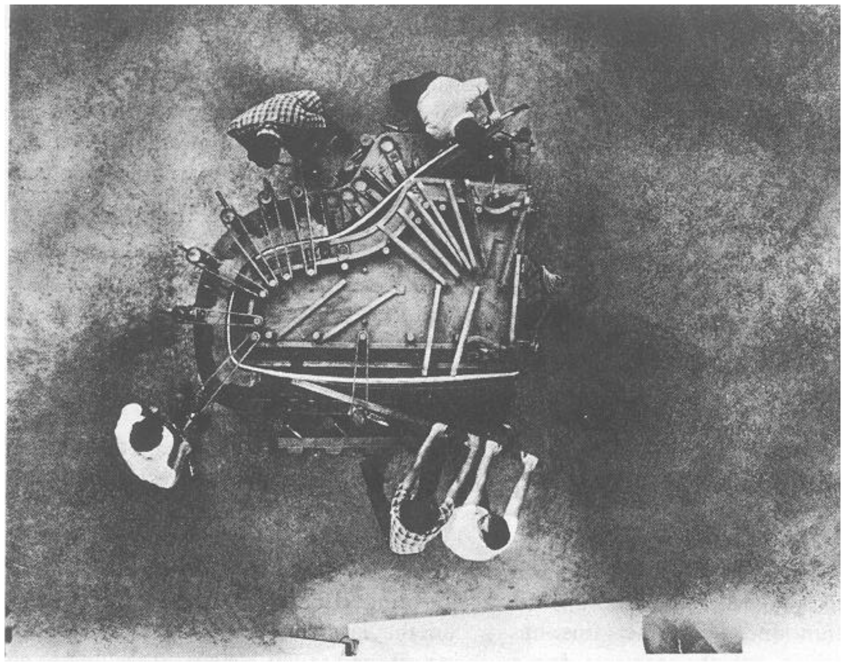

Figure 7. Bending the rim of a grand piano, using as many as 22 continuous layers of selected eastern rock maple wood, is the method used over the last hundred years by a famous firm of piano makers. (Courtesy Steinway and Sons, New York.)

Lignin can be pyrolyzed, hydrogenated, and hydrolyzed to yield phenols, which can be further processed to benzene. Once the technology and economics are feasible, future plants will manufacture a variety of these very significant chemicals from wood, now derived from petroleum or other resources.

I believe that the greatest contribution of wood to our energy budget may be an indirect one, achieved by using wood in place of energy intensive materials.[12,13] Most forest products are made with small requirements for fossil fuels as compared with substitutes. It takes about 0.2 ton of coal (energy equivalent) to process a ton of wood. A ton of aluminum, by contrast, requires about 10 tons of coal. Steel requires 2 tons and plastics about 6 tons of coal.

If wood as a material and as a fuel is to help free us from fossil-fuel dependency, then research and development to reduce costs of harvesting, transportation, processing, storage, and conversion must move full-steam ahead. Harvesting systems and techniques that can improve operating efficiency in small timber, in salvage operations, and on steep terrain, are essential keys to improving utilization.

WOOD FOR EVERY AGE

Opportunities like these and others for more effectively managing and using our wood resource are as numerous as the uses of wood itself. And if we are running toward the goal of supplying the greatest good for the greatest number of people for the longest time, wood, as a resource for materials and energy, matches all running mates. We are betting on the wood scientist, along with the engineer, the forester, and the architect, to enable wood to contribute substantially to the materials we need and the energy to use them. And though I believe a major role of wood in the world's economy still lies in the future, the Age of Wood is both a time-to-come and a past era. The Age of Wood was, is, and will be Every Age.

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Wooden Figure by Henry Moore at the Tate Gallery, London.