THE NEXT CENTURY OF WOOD PRODUCTS UTILIZATION: A CALL FOR REFLECTION AND INNOVATION

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ABSTRACT. Sustainable development has become the umbrella objective for forest management in many countries of the world, and managers are increasingly faced with the challenges of balancing environmental and economic health in their forest management and resource utilization decisions. It can no longer be assumed that abundant raw materials are available simply for the taking. As we enter the next century, a key question is where will we find the wood needed for shelter, fuel, transportation needs, and a host of other durable and nondurable goods? Wood will continue to be a staple of human society well into the 21st century and probably beyond. Changing times will require that we change how the forest resource is managed and used. As we look to the future, we must develop a better understanding of the complex interactions of wood use and the resultant social and ecological considerations. We must find new, more efficient ways to utilize a changing wood resource. The research needed to meet these challenges will be considerable. This paper discusses emerging trends that are affecting us and identifies research options and scenarios that will keep the trend lines of increasing demand, sustainability concerns, and ecosystem capacity from converging. Our goal is sustainable use of forests and sustainable economic development.

INTRODUCTION

It is hard to imagine a world without forests. Forests provide a wide range of benefits at the local, national, and global levels. Some of these benefits depend on leaving the forest alone or subjecting it to only minimal interference. Other benefits can only be realized by harvesting the forest for wood and other products. The shrinking land base and growing human population have heightened the challenge for forestry and forest products utilization to produce the needed types and quantity of trees.

The concept of sustainability is central to sound forest management and the subject of much current debate. Sustainability in all of its facets--ecological, economic, and social-will continue to become increasingly important for stewardship of the world's forests. Forests provide many and diverse benefits to people, including clean air and water, productive soils, biological diversity, goods and services, employment opportunities, community benefits, recreation, and exposure to nature. Forests also provide intangible qualities such as beauty, inspiration, and wonder.

This paper will address the value of wood in human societies, environmental and economic concerns, worldwide linkages and expectations, the case for forest products technology, and ways to meet future challenges.

VALUE OF WOOD IN HUMAN SOCIETIES

A critical consideration in any discussion of the future demand for industrial raw materials is population growth. All projections indicate a great absolute increase in global population in the future. One way to view this is

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that a child born today will live in a world where the population will double during his or her expected lifetime. The greatest growth in population is likely to occur where the standards of living are also expected to show the greatest rise. The result will be a world economy that will grow even more rapidly than the population. This means that demands for resources, which are already high on a per capita basis, will rise even higher.

The historical record of world population growth is dramatic. World population doubled from 1850 to 1950, then doubled again from 1950 to the present [1] (Fig. 1). Over each of the next four to five decades, global population is expected to increase by approximately 900 million. These figures make it dramatically clear that tomorrow's world will contain many more people than today's.

Tremendous quantities of wood are consumed each year throughout the world. Approximately 3.5 billion cubic meters of wood are harvested worldwide annually; slightly more than half of this is used as fuelwood [2]. Approximately 63% of the harvest consists of hardwoods, which are used primarily for fuel in the developing countries. Softwood is primarily used for industry worldwide.

The global per capita consumption of wood is approximately 0.67 cubic meters/year, a figure that has remained essentially unchanged since 1960 [3]. This means that growth in wood demand worldwide is closely following growth in world population. Assuming that this per capita consumption trend continues, population increases alone will add approximately 60 million cubic meters annually to world wood demand [1].

Natural softwood forests of the world are found in the Northern Hemisphere. Hardwood forests dominate the tropical and subtropical regions and the Southern Hemisphere, and they occur in extensive regions of the Northern Hemisphere as well. Overall, hardwoods are present in the greatest volume worldwide. The potential for increased harvest of natural forests in constrained today by a number of factors, including limitations of growth, politics, and economic and environmental concerns.

Although estimates vary, the total area of forest plantations in the world amounts to between 120 million and 140 million hectares, and it is increasing in both temperate and tropical countries. In the tropics especially, the present rate of

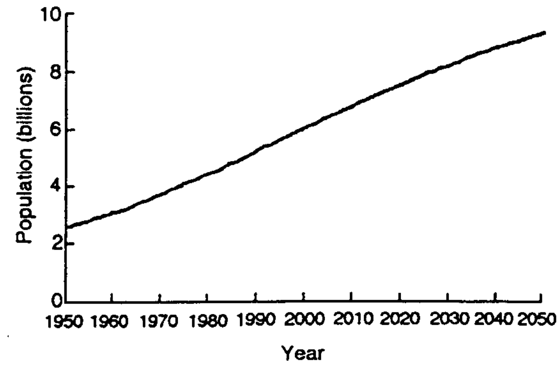


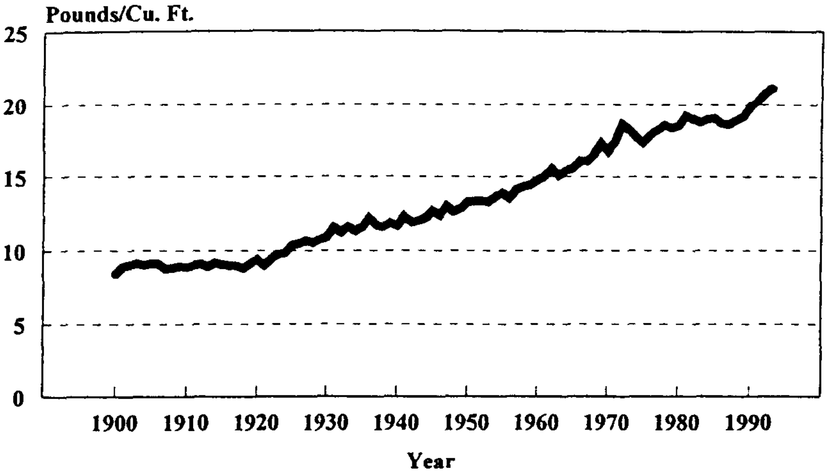
Figure 1. World population, 1950-2050.
Source: U.S. Bureau of the Census, international data base (www.census.gov/ipc/www/img/worldpop.gif).

plantation establishment is double that recorded in the 1960s and 1970s [4,5]. Tree plantations generally produce more wood per geographic area than do natural forests because they are usually established on highly productive sites, intensive silviculture is practiced, and genetically selected growing stock is used. Plantations will clearly play a significant role, and perhaps even a dominant role, in providing future wood supplies. Whether the plantation wood grown each year is sufficient, in both quality and quantity, to meet anticipated increases in demand remains to be seen.

ENVIRONMENTAL, SOCIAL AND ECONOMIC CONCERNS

Environmental, social, and economic concerns must be considered together. Ecological sustainability must provide a foundation upon which forest management worldwide can contribute significantly to economic and social sustainability. Conservation and wise management of forests can promote sustainability by providing for a wide variety of uses, values, products, and services, and by enhancing society's capability to make sustainable choices.

When the concept of sustainable development was presented by the United Nation's World Commission on Environment and Development in 1987 [6], attention shifted to environmental concerns. However, the concept was one of balance: the environment and the economy cannot be treated separately. Material needs must be met in ways that preserve the biosphere, and concern for the biosphere must recognize material needs. Another important concept embedded in this strategy is recognition of both the short and long term. The Commission's report clearly stated that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."



USDA Forest Sevice Figure 2. (FPL) U.S. product output per roundwood input [7].

WORLDWIDE LINKAGES AND EXPECTATIONS

The question of conservation and utilization of forest resources must be balanced and is at the very essence of the work of all of us who are concerned with the management and utilization of natural resources for sustainable development. The discussion of conservation and utilization must focus on how the needs for conservation and utilization can be combined harmoniously to derive the maximum benefits for present and future generations.

Finally, the theme of worldwide linkages and expectations means that the way in which wood is processed must be developed in a global context to achieve success in sustainable development. Local decisions regarding timber harvest and use have clear implications for other countries. Given the rising demand, in developed countries local decisions not to harvest create a higher economic incentive to harvest elsewhere. In countries where natural forests are not managed for regeneration, short-term harvest decisions can affect the availability of all forest resources in the long term.

THE CASE FOR FOREST PRODUCTS TECHNOLOGY

Given this changing context, what roles will forest products play in relationship to forests and forestry? In our opinion, forest product technology will play a central role in meeting these challenges for the following reasons:

- Management is and will continue to be necessary to achieve desired forest conditions.
- Management that includes wood removal is a cost-effective way to achieve ecosystem health.
- Wood technology will help provide choices for the management and use of the forest.
- Sustainability must recognize the interdependence of the environment and the economy.
- Management for wood fiber will maintain prominence, but not dominance.
- We need to understand and embrace the values the public is not willing to forego.
- Conservation of wood fiber, not competition of wood with other raw materials, will be the focus of wood product research

A brief historical review is appropriate as one way of pointing out how a decline in wood resource availability can be at least partially offset by increasing efficiencies in the use of the wood resource. In the United States, for example, product output per unit of wood input has risen by about 300% over the past century (Fig. 2) [7].

Management necessary to achieve desired forest conditions

For centuries, forests have been affected by both natural and people-induced influences. As populations grow, both the direct and indirect influence of people will become greater. Whatever our desire with respect to forest condition, management-as compared to no management or interference—is essential.

In the August 1992 issue of *Natural History,* Jared Diamond [8] pointed out the fallacy of the notion that no interference will lead to desired conditions. The author described a 526-hector forest reserve in the U.S. State of Missouri that was surrounded by agricultural land. When left to survive naturally, the area became overrun with deer and devoid of understory vegetation. The surrounding land supported an excess deer population, which affected all other plant and animal species in the forest reserve. Here, a small area was affected by activities adjacent to it. As we all know, effects can also be widespread and the source of the problem can be some distance away. Problems associated with acid deposition are one example.

The influence of management is easily demonstrable, but it is only part of why management is needed to achieve our goals. Nature itself prefers change [9]. As forests evolve, changes occur. To maintain a particular condition, management is necessary.

Wood removal a cost-effective way to achieve ecosystem health

Forest management costs money. Wood removal can generate a return to cover these costs. This is the principle when forests are managed for wood production. Over time, however, forest management has evolved-first to include multiple uses and, more recently, to assure health of the forest ecosystem.

With the evolution in management has come a change in the species, sizes, and quality of wood fiber available from the forest. Material formerly left in the forest may now be creating forest health problems, such as susceptibility to fire or insect infestations. Processes that are oriented to use of various sizes of material and that are less species-specific can offer a value-added opportunity. This in turn can help cover management costs, and meet wood fiber needs as well as other management objectives.

Choices for management and use of the forest through wood technology

Rising population and associated increases in demand are not something new. In the United States, our forest land base is about two-thirds the original forested area. Over the past century, population has more than doubled, yet we've been able to accommodate increases in wood fiber demand, along with rising demands for other uses for the forest. To a great extent, we have been able to keep pace with demand and improve our forest-related situation because of new technology. We know how to grow trees faster and better, how to use wood more efficiently, more safely, and longer, and how to manage forests for a variety of uses.

This means that in addition to meeting demand, technology has made another contribution that may be even more important. The choice has been made easier–made possible in many cases-for those who need to decide how forestland should be used or managed. Science has perpetuated choices for forestland uses.

Interdependence of environment and economy

In 1992, a report of the National Commission on the Environment [10] endorsed the concept of sustainable development and went one step further. The Commission stated that "long-term growth depends on a sound environment, and resources to protect the environment will come from economic strength." The Commission's point is important in both respects. First, if we fail to keep the environment and ecosystems healthy today, society will face some real problems in the future. Second, and equally important, a healthy economy is essential to a sound environment.

The relationship is circular: people can't achieve economic strength without a healthy environment, and they won't care as much about the environment if they don't have jobs and dollars. We need to be equally concerned about the economic well-being of our population and our communities, and the well-being of our environment.

Prominence, not dominance, of management for wood fiber

Concerns have been raised that wood fiber will gradually be phased out as a primary management objective on many forests worldwide. However, rising demands and the economic balance needed for sustainability suggest that this will not happen. Our feeling is that wood fiber will remain a prominent objective for forest management, but it will not be as dominant as in the past.

Wood processing technology will play a vital role by serving to expand the forest manager's options as new products and processes that can use nontraditional fiber supplies are developed. It will also establish some limits to management options by defining the economics of fiber removal and use.

Understanding and embracing public values

In the past, the forester's knowledge and skill guided management choices. Objectives were more sharply definable, often limited to optimizing wood production and cost efficiency. The forester "educated" the public on why certain actions were taken. Public oversight was minimal. To&y, the public is more aware of forest management issues and more vocal about what they want from the forest and how it affects their quality of life. They are telling us to be more environmentally sensitive to all aspects of the ecosystem, to make forests look more natural, to include beauty as a management objective. This attitude is exemplified by opposition to practices such as clearcutting and chemical control of pests. Today's headlines clearly illustrate changing public expectations.

Aldo Leopold [11] illustrates this point in A Sand *Country Almanac* when he relates why he believes woodcocks prefer sandy areas, even though food supplies and cover are more abundant elsewhere. Leopold surmises that the woodcock, a small bird, has an optimum place to strut and dance where there is little or no groundcover and few obstacles to hinder or hide his performance. The point is that the woodcock's choice of where to live has little to do with economic standard of living, but everything to do with the quality of the site for his mating dance. Leopold notes that "economists have not yet tried to resettle woodcocks." Woodcocks have other more important values.

We need to understand and incorporate the values the public is not willing to forego. These values set some limits on what can and can't be done, and they must be used to help guide our research and management design. In short, we must use the "woodcock model" to gain public acceptance.

Conservation of wood fiber, not competition

Over the years, wood products research has focused on extending recovery, durability, safety, and use, often with the goal of making wood products more attractive to consumers and more economic to manufacturers, relative to other raw materials. Today the focus is similar, but the goals have changed. Rising demands have meant that we need to look at all resources and use them independently or in combination, where they are best environmentally and economically. The goal is now conservation of all raw materials in concert to meet people's needs.

MEETING THE CHALLENGE

Forests are being squeezed between growing needs and a shrinking resource base. The pressure being placed on the resource also pushes technological developments to help divert those pressures. Historically, technology has aided conservation by making more efficient use of resources. That trend will need to accelerate to meet today's challenges. Key areas for research and development are use of the changing wood resource, extension of the resource, and environmentally friendly technologies.

Use of the changing wood resource

Tomorrow's wood product manufacturers will face a distinctly different resource than that available today. The character of the wood supply varies with the management regime. Plantation-grown trees are likely to be single species, even age, even-size class, relatively uniform, and genetically improved. Trees produced under sustainable forestry principles are likely to be more diverse—of mixed species, uneven age, and mixed size classification. As the concepts of sustainable forestry and sustainable development move into practice, industry will most likely find itself needing to utilize a much more diverse raw material supply than it has in the past.

In contrast, industrial processes and products usually benefit from a uniform, stable raw material supply because they can be optimized more readily. In addition, product variability is generally reduced and processes are more stable. With a more diverse raw material supply, new technologies will be needed to overcome the problems of product and process variation. Today, technologies such as composite products, nondestructive evaluation, mechanical grading systems, and engineered wood products play an increasingly important role in adapting to a changing timber resource.

Composite technologies are generally more flexible in type and quality of material used than are solid lumber wood products. One composite experiencing remarkable growth is oriented strandboard (OSB), a product made from wood particles aligned to obtain the best engineered properties. OSB is being used in place of plywood because of the difficulty of getting veneer-grade logs and because it can be made from a wide variety of species and sizes. OSB now represents more than 25% of the structural panel market, and the demand continues to grow. The raw materials for many OSB manufacturing plants are underutilized species like aspen and yellow-poplar.

Another technology that has allowed the use of different species and sizes is nondestructive evaluation (NDE) technology. NDE can be used to determine the stillness and strength of a piece of lumber, which reduces dependence on visual grades (which are species dependent) in favor of mechanical grading (which is species independent). Mechanical grading can allow a wider range of species to be substituted for structural applications, as long as certain stiffness and strength requirements are achieved.

Mechanical grading uses static bending techniques, vibration techniques, or stress waves to determine stiffness. Research has demonstrated a direct relationship between the bending stiffness of lumber and its bending strength. The only way to determine the actual bending strength of a board is to break it. Since that is not practical, the next best available method is to measure the board's stiffness, compute the modulus of elasticity, and then predict the bending strength. Such procedures produce a mechanically graded lumber that is accepted by regulatory agencies and all major building codes, provided that production follows approved grading agency certification and quality control procedures.

The volume of mechanically graded lumber produced in the United States has increased by nearly 25% over the past 4 years, especially in the higher grades. A growing demand indicates that this trend will continue. The popularity of mechanically graded lumber stems from its consistent reliability and superior visual and structural qualities. These qualities make this lumber ideal for engineered wood products, such as roof and floor trusses, I-joists, and glue-laminated timbers, which depend on uniform, quantifiable properties to meet specific applications for both residential and nonresidential construction.

Increasing inventories of hardwoods are raising interest in the United States in using hardwood lumber in structural applications. However, efficient use of hardwoods for engineered wood products depends upon grading systems that are comparable to softwood grading systems. Traditional visual grading systems are species-specific and, for hardwoods, are geared for traditional uses such as furniture. Thus, mechanically graded hardwood lumber is gaining acceptance in engineered products.

Mechanically graded lumber is necessary for not only structural uses of hardwood species, but also small-diameter material. Difficulty in obtaining large-diameter logs has led to use of plantation-grown trees and material from thinnings, which require new technologies for efficient use. These technologies have made possible the dramatic increase in the use of engineered wood products. Prefabricated wood I-joists are replacing wide lumber for both floor and ceiling joists in residential applications. These products are made with a web of either plywood or OSB and with flanges of either solid-sawn mechanically graded lumber or laminated veneer lumber.

Laminated veneer lumber (LVL) is one type of structural composite lumber that requires veneers from large- or moderate-sized logs. Veneers for LVL are nondestructively evaluated using stress wave technology. LVL has the potential for very high-strength products and is most economical for high-strength applications. The same processing technologies are used for oriented strand lumber (OSL) as for OSB, but OSL has somewhat lower engineering properties than LVL. These engineering properties will likely improve with new and better technologies.

Extension of the wood resource

Increased efficiency in converting wood to products has traditionally been the cornerstone of the contribution of forest products technology to forest conservation. Since the 1980s, sawmill yields have increased dramatically as a result of improved equipment and sawing techniques. Mills have also converted byproducts such as sawdust and slabs to useful products such as medium-density fiberboard and chips.

Recycling recoverable paper and wood wastes represents a major means of extending the wood resource by reducing the volume of timber harvested for forest products. Recycling can also greatly reduce the amount of wood-based waste sent to landfills. At the same time, it can improve the volume and value of material produced from each tree, create jobs, and increase economic growth. However, realizing these benefits depends on technologies and market conditions that allow and encourage companies to use recovered materials in products. Worldwide, research and development efforts are developing technologies that create new markets and expand existing ones for products made from recovered paper and wood wastes. Research at the Forest Products Laboratory, USDA Forest Service, is aimed at overcoming key technological barriers to utilizing recoverable paper and wood wastes, identifying opportunities to develop new technologies for recycled materials, and matching end-use performance with material properties. Areas for research and development are wastepaper-to-paper recycling, use of wastepaper and wood waste in non-paper items and housing, nonstructural applications, and recycling of treated wood.

Wastepaper-to-paper recycling research is aimed at overcoming problems associated with removing hot-melt and pressure-sensitive adhesive contaminants from packaging materials, sorting fiber, using enzymes to deink printing and writing papers, restoring papermaking properties, brightening fibers for printing paper, and using underutilized wastepaper such as office and mixed paper. Some wastepaper, however, may be too costly to recycle into paper. Technologies are needed to utilize this wastepaper in composite materials, which can be used for structural or nonstructural applications. Technologies for producing these composite materials range from pulp molding to air-forming to extrusion.

Wood waste from construction and demolition sites is in large supply. Such waste can potentially be substituted for expensive virgin construction materials as well as incorporated into molded products. Recovered wood and waste, like paper waste, can also be used to make composite materials. Unlike conventional lumber products, which are constrained by straight line processes, products of composite processes can be molded to finished dimensions, can be curved or edged as needed, and can incorporate performance-enhancing treatments. Composite technologies also allow wastepaper and wood-waste-derived materials to be combined with other fibers or materials such as recovered post-consumer plastics. Wood fiber-plastic composites can be used in a variety of housing and non-housing products, ranging from moldings to tote bins to car door panels.

Wood products treated for insect and decay resistance pose special problems for recycling. Many preservative treatments contain toxic chemical compounds. Public concern about health effects on humans has spurred tightened regulations for disposal of preservative-treated material and has limited development of technology to recycle such materials. Calls for tighter control of this wood waste are colliding with its growing quantity. Utility poles and railroad ties are continually being removed from service, and more than half the Southern Pine lumber produced in the United States is pressure treated with preservatives. Research is exploring options for reusing or recycling these materials, as well as their use as fuels.

Environmental sensitivity of wood products technology

The challenges faced by forest managers are matched by those facing wood product manufacturers. Public concern for air and water quality has paralleled interest in forest management issues. Now, more than ever, the wood products industry needs to avoid generation of pollutants during the manufacturing process and environmental problems during product use. Such “avoidance” technologies will allow forest products to be manufactured with minimal environmental impact and reduce the need for regulation and restoration.

Kraft pulping is the dominant pulping technology used in the United States and worldwide, producing more than 250 million tons of pulp annually. In excess of 60 million tons of kraft pulp is produced in the United States alone. Kraft pulping dominates because it can use a wide variety of hardwoods and softwoods, and it produces paper and paperboard of high strength. It can delignify wood to the point where it can be bleached relatively easily to the high whiteness levels required by the printing industry. However, kraft pulping is extremely capital-intensive—newly sited mills cost in excess of $1 billion (U.S.), and mills must process on the order of 1,000 to 2,000 tons of oven-dry equivalent wood chips per day to be economically viable. Pulp yields are low, around 45% to 55%, and organic sulfur compounds are produced during pulping operations. The low yields, high capital intensity, enormous economy of scale, and production of troublesome organic compounds make it extremely desirable to develop alternatives to kraft pulping. New technologies such as biopulping, which uses white-rot fungi to delignify wood chips, and non-chlorine bleaching are being developed at the Forest Products Laboratory.

White-rot fungi, such as *Phanerochaete chrysosporium* and *Ceriopsus subvermisporia,* are able to remove lignin, the “glue” that holds fibers together. Research is being conducted to pretreat wood chips with *C. subvermisporia* prior to mechanical pulping to reduce energy consumption during pulping and increase papermaking properties compared to those of untreated mechanical pulp. Research work has decreased the time necessary to pretreat wood chips from 6 to 8 weeks to 2 weeks. In addition, fungal pretreatment has been demonstrated to be effective in large (50-ton) chip piles using only 5 grams of fungal inoculum per ton of chips. The treatment can be conducted even in the winter because the metabolic heat of the fungi warms the wood chip pile.

Energy savings of about 30% are realized compared to that from untreated controls.

Research is now focusing on the use of white-rot fungal pretreatments in conjunction with chemical pulping to decrease the amount of chemicals needed and possibly increase pulp yields. In conjunction with this work, researchers at the Forest Products Laboratory are studying cell wall architecture and biosynthesis. Understanding how trees form the cell walls of tracheids can reveal important clues about how to remove lignin and retain cellulose and hemicelluloses.

More than 32 million tons of bleached and semi-bleached pulps are produced annually in the United States. Bleached pulps are used primarily for printing and writing papers. Chlorine and chlorine dioxide were once the most commonly used bleaching agents because they are effective and economical. However, they also produce chlorinated organic compound byproducts, which are environmentally troublesome.

Alternatives to the use of chlorine to whiten pulps include the use of chlorine dioxide, oxygen, ozone, and peroxides. In addition, extended delignification during kraft pulping can reduce the amount of lignin in kraft pulps that needs to be removed during bleaching operations. However, these alternatives are generally more costly than and not as effective as chlorine-based bleaching. Oxygen, ozone, and peroxide are not as specific for lignin in bleaching operations as is chlorine, and they generally attack cellulose and hemicelluloses as well as lignin. Therefore, their use must be carefully controlled.

The Forest Products Laboratory has taken two novel approaches to develop non-chlorine bleaching technologies that are specific to lignin and do not produce troublesome byproducts. The first involves the use of enzymes produced by white-rot fungi, such as *P. chrysosporium,* in metabolizing wood. Research has revealed that *P. chrysospurium* produces enzymes that use lignin-specific oxidative reactions to break down lignin. By treating pulp with combinations of enzymes, it appears possible to produce pulps that are more easily brightened with peroxides.

The second approach involves the use of polyoxometalate (POM) chemistry. The POMs are a class of chemical compounds that react very specifically with lignin. They are nontoxic and reusable, and they can bleach pulp without attacking cellulose and hemicelluloses or weakening fiber structure. As a result, they do not reduce paper strength properties. POMs also oxidize the organic byproduct compounds produced during bleaching operations, making possible effluent-free (closed-mill) bleaching. The only byproducts from POM bleaching are water and carbon dioxide. POMs greatly reduce the environmental impacts of pulp bleaching and its associated economic costs.

In the early 1970s, the use of pressed wood products such as particleboard and hardwood plywood created indoor air quality problems, principally as a result of formaldehyde emissions from adhesives used to bond the wood products. Changes in adhesive formulations and processing modifications have greatly decreased formaldehyde emission problems. More recently, the concern about volatile organic compound (VOC) emissions resurfaced for wood products, both in use and during processing. Emissions from wood and wood-based materials may result from adhesives, natural components of wood, and byproducts of thermal degradation during wood processing, such as the drying of lumber in kilns or pressing of reconstituted board products in heated platen presses. Some compounds reported in wood or adhesive emissions are known to be hazardous to human health. Confirming the presence of such compounds is essential to evaluating risks and devising cost-effective and efficient risk management strategies. The Forest Products Laboratory is developing new and novel methods to determine how many and what kind of VOCs are emitted from wood-based materials and how processing affects their production. In this way, effective,, efficient, and economical control strategies can be developed that both protect the consumer and mitigate or prevent adverse environmental effects.

In their final end-use, VOCs can be emitted from not only the wood but also the finishes and coatings used to protect and preserve the wood. The Forest Products Laboratory is also involved in developing new technologies that will help eliminate the use of VOC-based solvent systems for finishing and protecting wood from weathering and decay. Research is investigating new water-based solvent systems as well as determining the surface degradation mechanisms by which wood and wood-based materials weather. By understanding the mechanisms involved and combining this with knowledge of the performance of water-based solvent finishing systems, new aqueous and dry-powder finishing systems can be devised that do not negatively impact the environment or adversely affect human health.

CONCLUSIONS

Sustainable development must be based on the interdependence of the environment and the economy. Wood technology is essential to this integration. Key areas for research and development include the following:

- Determining new and better ways to extract, reduce and convert virgin wood raw materials to useful products.
- Developing technology to allow the re-use of materials and products to the maximum extent possible.
- Making sure that the latest technologies for extracting, reducing, converting, using and re-using wood raw materials are transferred to developing nations as quickly as possible.
- Developing methods to ensure that renewable resources of all kinds, e.g., wood and agricultural crop residues, are converted to value-added uses like advanced consumer and engineered wood products.
- Developing technologies to reduce the emission of VOCs during the manufacture of wood products.

This list represents but a few of the areas that hold promise for advancing wood utilization activities to meet the needs of society while keeping a well-tuned balance among the ecological, economic, and social aspects of sustainable forest management.

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