CHAPTER V

Technologies for Growing, Harvesting, and Using Wood

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Summary

The application of existing technologies to the entire cycle of forest products manufacture, from growing and harvesting trees through end use, offers major opportunities to extend domestic wood supplies, Economic considerations, however, will ultimately determine the degree to which they are applied.

Substantial increases in U.S. timber production could result from expanding known silvicultural practices and management technologies on suitable lands. "Economic opportunities" for intensified timber management may exist on 30 to 40 percent of all commercial forestland, according to recent studies by the Forest Industries Council and the Forest Service. ' Net annual growth on these lands could be increased between 11 billion and 13 billion cubic feet (ft^3) per year through application of certain management practices, which could require an investment of $10 billion to $15 billion over 30 to 50 years, Most of the opportunities identified involve planting and management of softwoods, often at a cost of more than $100 per acre. Hardwood management opportunities have yet to be assessed comprehensively.

The area of forestland that is likely to be managed intensively is probably much less than all the land that is economically qualified. Although 30 to 40 percent of the forestland base may be suitable for profitable timber management, bringing these lands under such management may be difficult. Private investments in intensive forest management compete with alternative investment opportunities, many of which have less risk, higher rates of return, and earlier payoffs.

The "economic opportunity" estimates do not reflect site-specific limitations such as conflicting landownership objectives, small parcels, lack of markets, and site conditions that make management difficult. These barriers to intensive management are discussed in detail in chapter VI.

Existing and emerging harvesting technologies and systems could expand timber supplies by enabling recovery of wood now left in the forest and by allowing harvest from tracts now considered inoperable. Conventional harvesting systems now leave substantial quantities of industrially usable material in the forest at harvest because the cost of removal exceeds the value of the product. In 1976, about 1.4 billion ft^3 of growing stock logging residues were left on-site as well as two to four times as much material in tops, branches, rough and rotten trees, and small stems. Salvageable dead timber also contains potentially usable woody material. In addition, some land is excluded from harvest because of such constraints as remoteness, difficult terrain, small tract size, and potential for environmental damage. Development of harvesting technologies and systems to overcome these problems would increase recoverable timber resources.

A major opportunity for increasing harvesting efficiency may be through a systematic, integrated approach to growing, harvesting, and transporting wood for processing. More effective use of equipment, improved harvesting practices, better training of woodsworkers, and more efficient transportation of wood to mills could improve productivity significantly. New harvesting systems also could reduce

'U.S. Department of Agriculture, Forest Service, *An Analysis of the Timber Situation in the U. S., 1952-2030* (Washington, D, C.: Government Printing Office, 1982), p. 248; and Forest Industries Council, *Forest Productivity Report* (Washington, D.C.: National Forest Products Association, 1980), p. 46.

the potential for environmental damage, Over the long term, silvicultural systems for growing wood and technologies for harvesting and processing it could be designed to optimize the use of timber resources on a continuous basis.

Creative "small tract" harvesting technologies and systems could enhance the potential contribution of private nonindustrial forests (PNIF) to national timber supplies. About 20 percent of the private forestland base is composed of parcels of less than 100 acres—tracts too small for efficient use of large harvesting machinery. In addition, improper harvesting operations sometimes discourage landowners from harvesting timber from their land because of damage to remaining trees, impairment of scenic qualities, and injury to the environment. Appropriate technologies and harvesting systems specifically adapted to small tracts and the diverse objectives of small landowners could expand potential harvest levels from the PNIFs. While small-tract systems are well developed in Sweden and other Western European nations where most forestland is in small parcels, they have not been widely adopted in this country.

Public and/or private entities will need to place greater priority on the development and use of improved harvesting systems if their potential is to payoff. Areas deserving attention include harvesting research and development (R&D), alleviation of environmental impacts, proper training of woodsworkers in the use of new systems and machinery, landowner education programs, transfer of proven technologies, and overcoming institutional barriers. Countries like Sweden have improved harvesting productivity significantly through cooperative public and private efforts, but less than 2 percent of the Forest Service's R&D budget in 1976 was applied to harvesting and only about 70 scientist-years of effort were dedicated to it. A similar pattern exists in academic research.

Utilization technologies may expand the use of currently abundant hardwood species and enable the use of low-quality woody material now underutilized or wasted. Several existing technologies permit the manufacture of new high-performance wood products from currently underutilized materials and species that could substitute for goods requiring more expensive and scarcer trees. Softwoods, because of their favorable properties, are now preferred for most high-volume conventional products such as lumber, plywood, and some grades of paper, and manufacturing processes have been tailored to them. Yet, over one-third of the total volume of existing U.S. timber is hardwood, and hardwood inventories are increasing much faster than softwoods. Existing and emerging technologies can overcome many deficiencies in hardwood properties and can enable the manufacture of many products from hardwoods that are now predominantly made from softwood. Saw-Dry-Rip, composite lumbers, and particleboard made from hardwoods could substitute for softwood lumber and plywood. Advances in mechanical and chemomechanical pulping technologies, coupled with newly developed processes for manufacturing press-dried paper, could expand significantly the use of hardwood for making paper and paperboard in time.

The U.S. forest products industry now wastes very little wood in actual manufacturing. As a whole, the industry uses up to 96 percent of its delivered wood, which is either converted into products or burned for process energy. Despite this high average utilization rate, some plants are not able to produce a product mix of the highest value now technologically possible because their equipment is older and less efficient. As new milling facilities replace the old, energy-efficient, higher yield technologies can enhance the industry's productivity and improve product values.

Wider use of currently available technologies, such as computer-assisted milling, could reduce requirements for roundwood per unit of lumber and panels by 20 percent or more. Nearly half of all industrial wood products are lumber and structural panels, so increased yields from these products alone could have a major impact on the domestic wood supply. However, increased yields also would reduce

Photo credit" U.S. forest Service

The forest products industry now uses nearly all wood entering mills for products or energy. These sawmill residues are being loaded for transport to a pulpmill

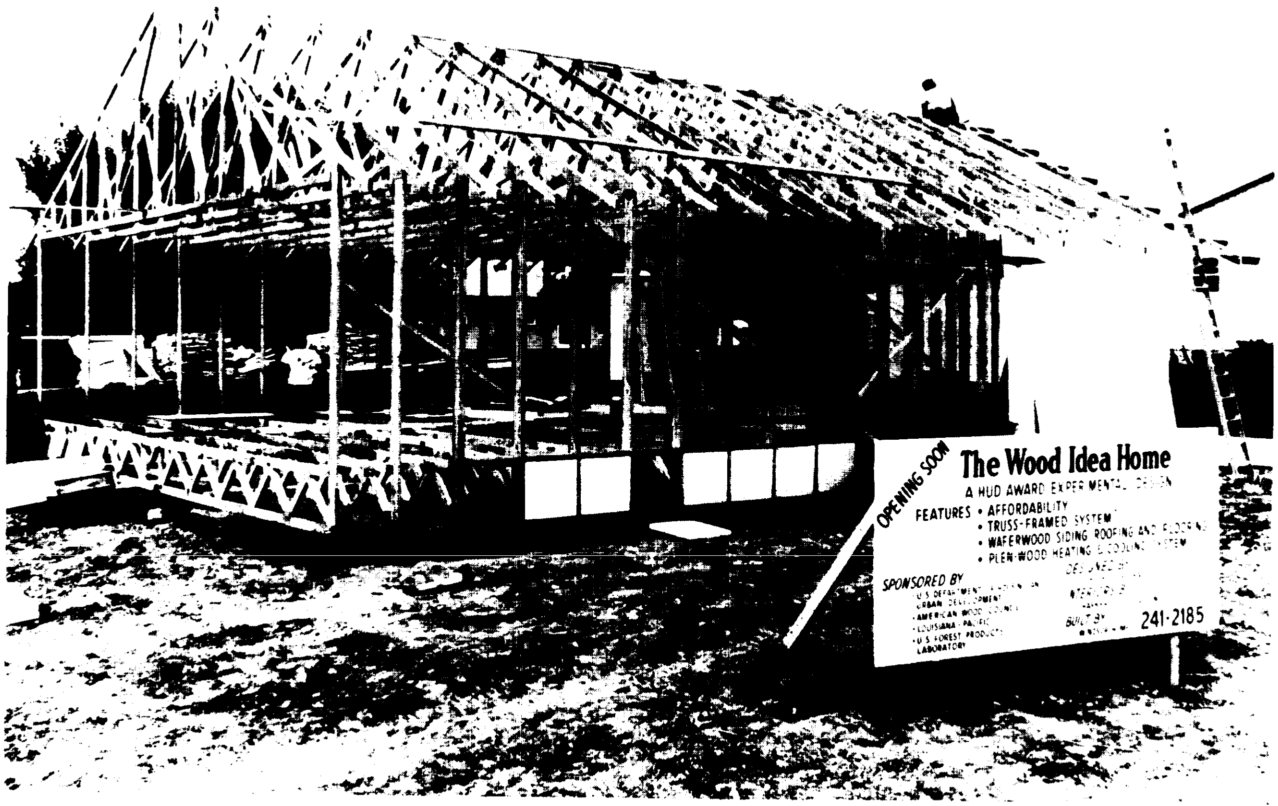
the amount of wood residues available for energy generation in lumber and pulpmills. Replacement of such materials by recovery of additional forest residues and biomass at harvesting may then become more widespread. Tradeoffs between improved wood use efficiency and wood fuel production will change in tandem with relative changes in energy and product prices.

Existing and emerging manufacturing processes could improve energy utilization. The forest products industry now fills a substantial portion of its energy needs from wood. The pulp and paper sector in particular consumes an enormous amount of energy—over 2 quadrillion Btu in 1981—and furnishes about half of it by burning processing residues.

Expanded use of mechanical pulping technologies can conserve both energy and the timber resource by recovering more wood fiber than can chemical pulping. However, longer term improvements in chemical pulping, which now requires large amounts of energy, could reduce energy needs and may even produce additional energy for outside sale. Press-drying paper technologies may also reduce energy requirements when commercialized. Biotechnologies, now in the laboratory stage of development, could be potentially important in pretreatment or digestion of wood prior to pulping, thus improving yields and further cutting energy requirements. In addition, in lumber and panel manufacturing, improvements in drying technologies could reduce energy needs.

Improved end use of wood materials also could conserve timber supplies. For example, a significant reduction in wood needed for residential housing on a per unit basis is possible through the use of innovative construction techniques and designs that are currently available but not widely applied. Two of the major obstacles to adoption of these innovations by builders are outdated building codes and home-buyers' conservative tastes.

About one-fourth of the paper pulp produced in the United States comes from recycled paper. The practical upper limit for the proportion of recycled paper in finished paper is being increased regularly as new technologies are developed. The potential to achieve such increases is affected by the costs added for the removal of glue, ink, and other contaminants and by economic barriers to collecting waste paper outside of metropolitan areas, Paper and paperboards suitable for many uses can be produced from pulp composed almost entirely of recycled fibers.



Phoft credit: U.S. Forest Service

Residential construction is the single largest use for solid wood products. This house is being constructed with a truss frame system developed by the Forest Products Laboratory of the U.S. Forest Service, and a wood foundation which uses the subfloor as a heating and cooling plenum

Increasing Timber Supplies by Intensive Timber Management

Trees now growing will provide most of the timber available for harvest over the next 30 to 50 years. Beyond this, long-term increases in timber supplies will vary considerably among geographic regions and tree species, but will depend mainly on the area of land under management and timber growth rates per unit area. The area of commercial forestland that can respond profitably to investments in intensive management is a function of such factors as climate, soil, topography, and the land's proximity to wood processing facilities,

Unmanaged forests are generally composed of tree communities (stands) best adapted to local ecological conditions. Such stands may produce large quantities of tree biomass, including deformed stems, roots, limbs, and foliage in addition to merchantable stems, but do not necessarily provide industrially useful wood at optimal growth rates. In managed forests, silvicultural technologies—practices that cultivate tree crops by controlling forest composition and growth-are employed to enhance yields of industrially preferred species with usable trunks and stems. Other objectives, such as maintenance of wildlife habitat, watershed management, and esthetics, can be integrated into timber management strategies but are not discussed here.

Distinctions between tree biomass and industrial-quality wood are important in assessing U.S. wood inventories. Such distinctions are not static, however, because changes in manufacturing technologies can broaden utilization standards and the range of sizes and species that are acceptable. Technologies that use material previously considered undesirable could effectively increase existing industrial timber supplies. For example, wood fuel can be obtained from a broader spectrum of tree biomass than roundwood alone, and some silvicultural systems have been developed to maximize biomass production for this purpose.

Ideally, a tree crop is harvested when it reaches the size required by utilization standards and its growth rate has slowed. The series of silvicultural treatments is then repeated for another rotation (or the interval between harvests in a managed system). The optimum number, sequence, and timing of treatments depend on the species, site conditions, and end product, For example, Douglas-fir in the Pacific Northwest and loblolly pine in the Southeast, probably the two most important U.S. timber species, require very different treatment systems.

One or more of eight silvicultural technologies may be used in a single timber rotation:

1. harvesting;
2. site preparation;
3. reforestation;
4. control of fire, competition, and pests;
5. precommercial thinning;
6. fertilization;
7. commercial thinning; and
8. genetic improvement.

Harvesting Methods

Harvesting is often considered the first step of a silvicultural system, because it affects the successful establishment of new stands. The best harvesting method depends on the reproduction requirements of the tree species desired in the next crop. Most softwoods, for example, require full sunlight for optimum growth and regenerate best when an entire stand is harvested all at once. In contrast, many hardwoods are "shade tolerant" and reproduce well when only part of a stand is removed.

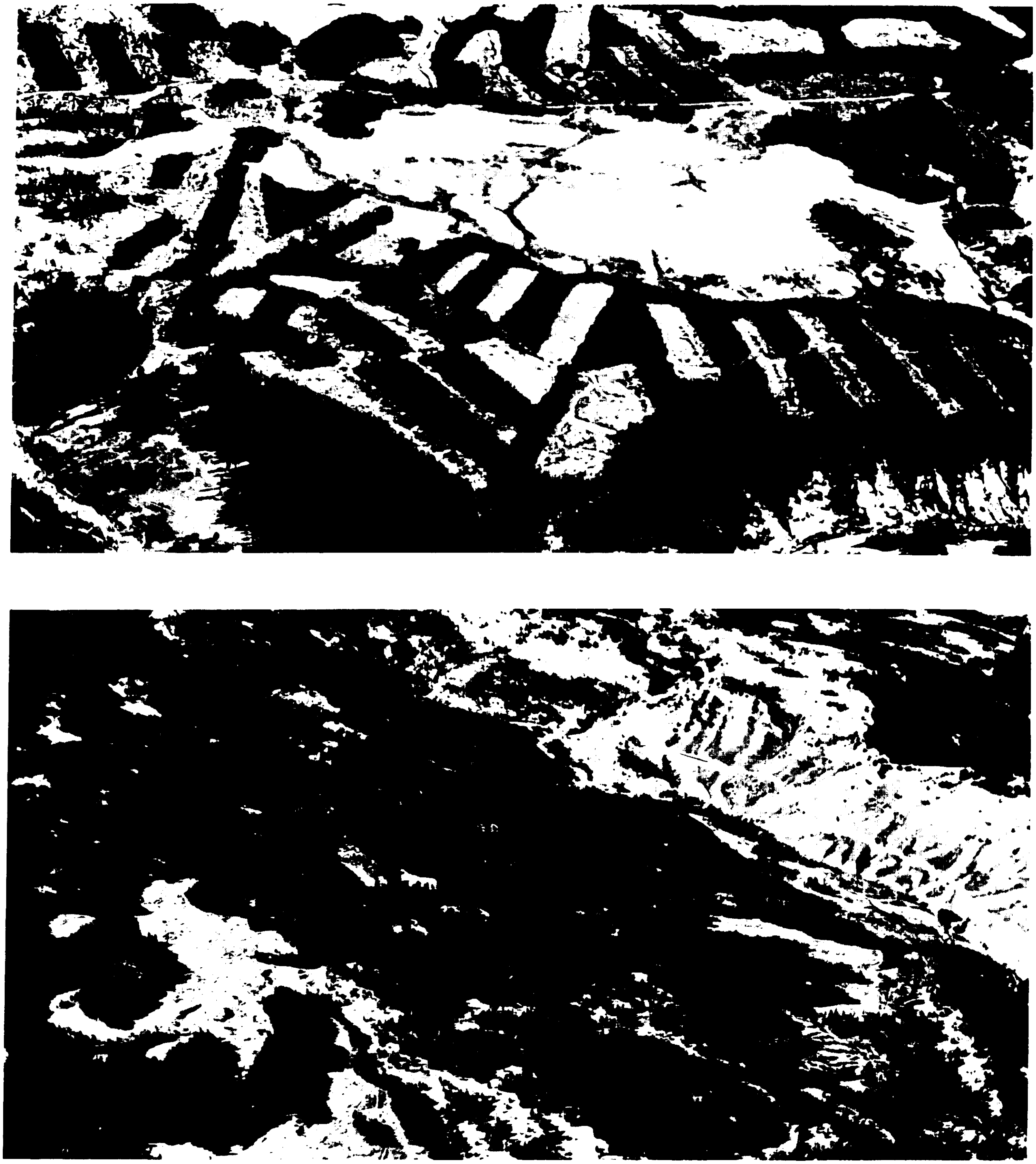
Clearcutting—removal of all commercial trees—is the preferred harvesting method for most commercial softwood species, including Douglas-fir and loblolly pine. It is also commonly applied to even-aged hardwoods such as aspen. When properly conducted, clearcutting has several economic and management advantages:

- it results in even-aged timber stands that are uniform in size and can be used for the same product;
- it allows cost-effective harvesting because maximum volume is removed in one operation; and
- it provides for optimum regeneration of species that grow best in full sunlight.

There are also possible disadvantages to clearcutting:

- regeneration of single-aged, single-species stands (monoculture) can increase their susceptibility to widespread insect or disease damage;
- uniform stands may not provide desired kinds of wildlife habitat;
- total stand removal can be visually unattractive;
- intense logging activity can cause soil erosion and stream sedimentation if improperly conducted; and
- removal of all streamside trees may cause temporary increases in water temperature, possibly affecting aquatic life until stream margins regenerate.

Most of these disadvantages can be mitigated by advanced planning to minimize visual impacts, locating logging roads to minimize soil losses, reservation of "buffer strips" along streams, maintenance of wildlife areas, and limiting the size of the harvest area.



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Partial cutting methods are less common than clearcutting and are less important for industrial timber supplies. Selective cutting (a type of partial cut) involves harvest of a stand's largest crop trees and its "weed" trees to give the residual stand more room to grow. Selective cutting results in an uneven-aged (various-aged) stand and is conducted at intervals on a continuing basis as trees reach crop size, Seed-tree or shelterwood cutting removes all commercial trees except selected "seed trees, " which are left to provide seed for the next stand and sometimes to provide shelter from wind or intense sunlight, Seed trees are often harvested after the new stand is established.

A relatively new application of a centuries-old harvesting method—the coppice system—allows stumps to resprout for successive fast-growing wood crops from the same root system. It is sometimes used for small-diameter hardwoods intended for fuelwood or chips and is expected to become more popular as new manufacturing technologies allow greater use of small hardwoods.

Site Preparation

Site preparation is often required for successful establishment of a new stand. It involves the clearing of unwanted vegetation or debris and in some instances the cultivation of an area prior to regeneration, By exposing bare soil so that seeds or seedlings can become established and by reducing competition from noncrop vegetation, site preparation optimizes conditions for new growth. It is especially valuable in eliminating competing hardwood trees and shrubs when hardwood stands are being converted to softwoods,

There are four site preparation methods that can be used for Douglas-fir and loblolly pine. The methods include mechanical treatment, prescribed burning, herbicide application, and combinations of these,

In mechanical site preparation, competing vegetation is physically uprooted, chopped, and/or removed by heavy equipment. This is sometimes followed by disking, harrowing, or bedding. Mechanically prepared sites can be burned or treated with herbicides to further reduce competition, Because mechanical site preparation removes organic matter and causes significant soil disturbance, concerns have been raised over its potential effects on the long-term productivity of the site. In some cases, mechanical site preparation results in soil losses from erosion.[2] In others cases, the use of heavy equipment may cause soil compaction.[3] The long-term effects of repeated site preparation on productivity will vary considerably depending on the soil, topography, and ground cover,

The use of prescribed burning to expose the soil and control competing vegetation is among the oldest and least expensive site preparation methods. It is widely used in the South for southern pine species and in the West for Douglas-fir. An area maybe burned either before or after harvesting to remove fuels and limit the risk of wildfire or to control unwanted vegetation that often flourishes after crop trees are removed. Under certain atmospheric conditions, prescribed burning can significantly lower local air quality. Forest fires, including both wildfires and controlled burns, constitute a significant source of particulate emissions nationwide and therefore are a major source of air pollution.[4]

Herbicide use has become more common over the last few decades for site preparation on large areas. The most commonly used herbicides are the phenoxies, such as 2,4,5-T; Silvex; 2,4-D; and 2,4-DP. Aerial application generally has replaced hand spraying techniques because in most cases it is less expen-

[2] As discussed in J. Douglass, "Site Preparation Alternatives: Quantifying Their Effects on Soil and Water Resources," in *Proceedings: Site Preparation Workshop, East Southeast* (Raleigh, N. C.: U.S. Department of Agriculture, Forest Service, and North Carolina Department of Natural and Economic Resources, 1977).

[3] However, there may be benefits from reduced competition for seedlings even though compaction occurs. See J. J. Stransky, "Site Preparation Effects on Soil Bulk Density and Pine Seedling Growth, " *Southern Journal of Applied Forestry, vol. .5, 1981,* pp. 176-180, for a discussion,

[4] As discussed in J. Hall, *Forest Fuels, Prescribed Fire and Air Quality* (Portland, Oreg.: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 1972), p. 44.

sive. Some herbicides may be applied either before or after planting, but application of others is more restricted because of potential damage to young seedlings. Herbicides are widely used in the Pacific Northwest in the management of Douglas-fir and to a limited extent in the southern pine region.

The widespread use of phenoxy herbicides has become a major public policy issue, particularly in the Pacific Northwest where public lands predominate. While human health considerations are central to the debate, other public concerns have focused on the relative costs and benefits of herbicide application compared to other site preparation methods. Site preparation studies have tentatively suggested that:

- a ban of phenoxy herbicides in the coastal Douglas-fir region could reduce annual Douglas-fir yields by 7 to 17 percent;
- careful planning and controls could significantly reduce the hazards of human exposure to herbicides;
- nonchemical site preparation methods, such as chopping, clearing or planting cover crops, may be almost as effective as herbicide treatment if properly conducted, but are likely to cost more; and
- many herbicides can replace phenoxies for site preparation, some of which cost more and may be more or less effective. s

Regeneration

Regeneration—the establishment of a new timber crop—is probably the most important phase in a silvicultural cycle. It establishes the stocking (density and volume) and kind of species in the stand and, when conducted promptly, minimizes the length of timber rotations. The three major regeneration methods are planting, seeding, and natural regeneration. The best regeneration method depends largely on species, site, and stand conditions after harvest, Douglas-fir, southern pine, and some eastern hardwoods often are planted after clearcutting.

Planting involves setting seedlings in the soil, either by hand or by machine. Use of containerized stock, i.e., seedlings grown and planted in small containers, is a relatively recent development that may improve seedling survival rates and reduce handling problems. Density, or the number of seedlings per acre, is an important aspect of planting because it influences the rate of growth, total timber volume produced, and individual tree size at the end of the rotation, In general, high-density stands produce smaller trees and higher total volumes, while low-density stands produce larger individual trees and lower total volumes.[6] Planting is generally the best method for establishing rapidly growing, genetically improved trees,

Regeneration by seeding can be accomplished through "seed trees" purposely left on the harvest area (see earlier discussion of harvesting methods) or from seeds that are collected and sown. Seeding is generally less expensive than planting, but the risk is greater that a fully stocked stand will not be established promptly. If supplemental planting or seeding is required and growth of the next tree crop is delayed, seeding can cost more than planting. Seeding can also result in high-density stands requiring precommercial thinning (see below), which significantly increases costs.

Natural regeneration is the renewal of tree crops from seeds or sprouts, In many instances, it simply amounts to letting nature take its course. In other instances, it may be part of a management strategy. Management actions, such as proper harvesting and site preparation, may be required to ensure successful reseeding, Seed tree and selection harvesting systems rely on natural regeneration to produce the next crop of trees.

5 A case study of herbicide issues in forestry can be found in K. Green, *An Evaluation of Herbicides, Forestry and People: A Western Oregon Case Study* (New York: Council on Economic Priorities, 1982).

6 W. Harms and F. Lloyd, "Stand Structure and Yield Relationships in a 20-Year-Old Loblolly Pine Spacing Study, " *Southern Journal of Applied Forestry*, vol. 5, 1981, pp. 162-165,

Competition, Fire, and Pest Control

While site preparation can control competing vegetation that invades an area immediately after harvest or planting, unwanted brush and grasses can redevelop and crowd out new trees before a stand becomes sufficiently established to compete effectively for growing space. Control of competition within 3 years after planting loblolly pine can result in growth increases of up to 300 percent.[7] Alternative competition control methods include herbicide application, hand cutting, and mechanical cultivation between trees.

Wildfire, insect, and disease control are important in maintaining a healthy and vigorous stand of timber. Insect control increasingly involves integrated pest management systems that can reduce losses from insects and disease through silvicultural methods, selective chemical pesticides, and improved detection and forecasting. Most U.S. forestland is now under organized wildfire control conducted on a cooperative basis by Federal, State, local, and private entities. Cooperative efforts also have played important roles in insect and disease control,

Precommercial Thinning

There is some evidence that thinning plantations precommercially (before they reach a marketable size) can increase wood production. Growth of loblolly pine and Douglas-fir has been improved by precommercial thinning.[8,9] A disadvantage of precommercial thinning is that it requires expenditures without immediate cost recovery from wood sales, in contrast to thinning delayed until stands reach pulpwood size. Expanded use of fuelwood could make precommercial thinning more economical in the future.

Fertilization

Fertilization can increase wood production substantially for certain species and soil types. Fertilizer is most commonly applied aerially, often to large areas. Since the cost of fertilizer is tied closely to the cost of energy, the future extent of forest fertilization may depend on energy costs in relation to timber values.[10]

Nitrogen fertilization of Douglas-fir has become more widespread in the Pacific Northwest, and growth response varies with the rate of application and with site quality. Incremental growth increases from fertilization tend to peak 3 to 5 years after application, and detectable effects disappear completely after 10 or 15 years.[11] Research results suggest that maximum economic benefit is achieved when nitrogen is applied both 3 to 5 years before thinnings and before final harvest and that lower quality Douglas-fir sites may benefit more from fertilization than higher quality sites.

Loblolly pine may benefit from phosphorus and nitrogen fertilization, although some studies indicate a less consistent response. Fertilization of southern pines is not currently a common technique,[12] yet some firms have adopted it as a routine practice on responsive sites.

Following fertilization, nitrogen concentration in nearby streams can reach high levels, in some cases increasing growth of aquatic plants downstream from the fertilized area. Peak concentrations of nitrogen, however, seldom persist for more than a few hours and usu-

[7] L. Nelson, C. Pederson, L. Autry, S. Dudley, and J. Walstand, "impacts of Herbaceous Weeds in Young Loblolly Pine Plantations," *Southern Journal of Applied Forestry,* vol. 5, 1981, pp. 153-158.

[8] D. Reukema and D. Bruce, *Effects of Thinning on Yield of Douglas-Fir: Concepts and Some Estimates Obtained by Simulation,* General Technical Report PNW-58 (Portland, Oreg.: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 1977), p. 33.

[9] R. Lohrey, "Growth Responses of Loblolly Pine to Pre-Commercial Thinning, " *Southern Journal of Applied Forestry,* vol. 1, 1977, pp. 19-21.

[10] S. Gessel, R. Kenedy, and W, Atkinson, *Proceedings of Forest Fertilization Conference* (Seattle, Wash.: University of Washington, College of Forest Resources, 1981).

[11] See R. Miller and R. Fight, *Fertilizing Douglas-Fir Forests,* General Technical Report PNW-83 (Portland, Oreg.: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 1979), p. 29.

[12] H. W. Dugan, and H. L. Allen, "Estimating fertilizer response in site-prepared pine plantations using basal area and site index, " in *Proceedings of the First Southern Silviculture Resource Conference* (Washington, D. C.: U.S. Government Printing Office, 1981,) p. 219-232, USDA Forest Service General Technical Report 50-34.

ally return to pretreatment levels within 3 to 5 days.[13] Environmental damage can be reduced if untreated buffer areas are left along streams, if fertilization is timed to avoid heavy storms or snow melt, and if fertilizer is applied during periods of low wind and good visibility so that placement can be well controlled.[14]

Recent investigations have tested the potential for increasing nitrogen on poor sites by growing Douglas-fir in association with red alder, which adds nitrogen to the soil through the action of bacteria occurring naturally on its roots. Preliminary results suggest that the largest total volume of both species maybe produced by growing red alder for 13 years, removing it, and growing Douglas-fir for 45 years.[15] However, maximum economic return still comes from growing Douglas-fir without the alder rotation, because the current value of red alder is relatively low.

Commercial Thinning

Commercial thinnings—removals of usable trees to give the residual stand more room to grow—ideally are made on a 5- to 7-year basis in both Douglas-fir and southern pine. The first commercial thinning in Douglas-fir is usually applied between ages 25 and 30 and in the southern pines between ages 15 and 20. Commercial thinning maintains optimum spacing to ensure desired tree size at harvest and provides intermediate investment returns.

Heavy thinning may shorten the time required for final crop trees to reach a specific size. However, the maximum amount of wood from both thinnings and mature trees probably can be produced by removing only the number of trees that are likely to die naturally during the rotation. Manufacturing technologies that allow use of smaller trees could make tree size less important and lead to longer intervals between thinning or to shorter rotations,

Genetic Tree Improvement

Planting of genetically improved seedlings ultimately may increase future timber yields greatly. Since the early l950's, programs to develop genetically superior trees have been undertaken by industry, government, and academic institutions. Most of these efforts have focused upon Douglas-fir and loblolly pine, First generation tree breeding efforts were aimed at producing progeny from trees of superior form and growth (superior trees). Second generation efforts have cross-pollinated or cloned superior trees to produce improved planting stock.

increases of 10 to 45 percent in the annual growth of Douglas-fir plantations have been reported from the use of improved planting stock,[16] Increases of 40 to 80 percent in southern pine growth rates also have been reported.[17] Genetic improvement appears to be more advanced in the South than in other timber producing regions, although all regions are working on its development.

Optimal growth levels are achieved when plantations of genetically improved trees are intensively managed under a silvicultural regime. Such management approaches dramatically boost productivity over what could be expected on natural sites, According to one estimate, improved planting stocks and existing technology could improve Douglas-fir production by 70 percent and loblolly pine by 300 percent, but these gains are still less than half of theoretical maximum productivity levels (fig. 19), Further gains could be made through additional advancement in tree genetics and refinement of management technologies.

[13] D. Moore, *Effects of Fertilization with Urea on Stream Water Quality,* Research Note PNW-241 (Portland, Oreg.: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 1975), p. 9.

[14] L. Norris and D. Moore, "The Entry and Fate of Forest Chemicals in Streams, " in J. Krygier and J. Hall (eds.), *Proceedings of the Symposium on Land Uses and Stream Environment* (Corvallis, Oreg.: Oregon State University, 1971), pp. 138-158.

[15] W. Atkinson, B. Bormann, and D. DeBell, "Crop Rotation of Douglas-Fir and Red Alder: A Preliminary Biological and Economic Assessment, " *Botanical Gazette,* vol. 140 (Supplement), 1979, pp. 5102-5107.

[16] WI. H Ya,e, *Timber Supply, Land Allocation and Economic Efficiency* (Washington, D. C.: Resources for the Future, 1980), p. 223.

[17] W. Dorman and B. Zobel, *Genetics of Loblolly Pine,* Research Paper WD-19, (Washington, D. C,: U.S. Department of Agriculture, Forest Service, 1973],

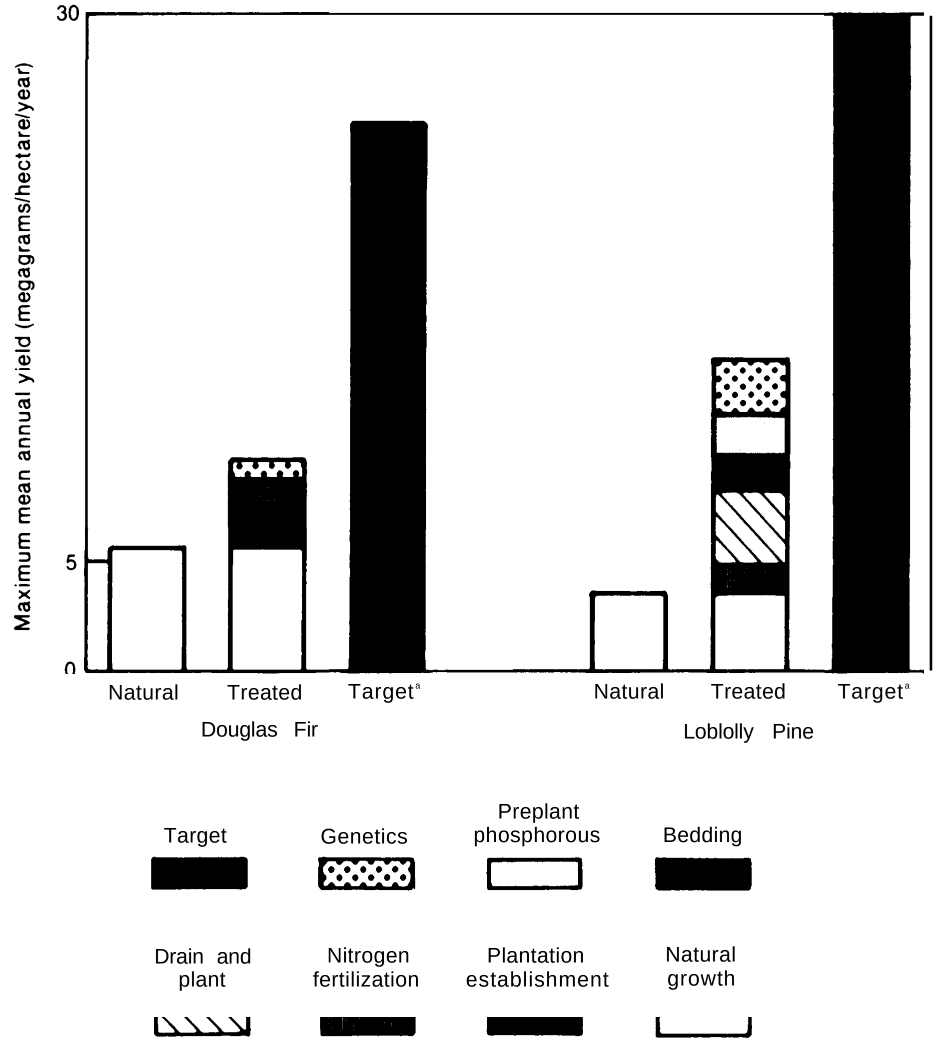
Photo credit USDA Soil Conservation Service

Commercial thinning is used to achieve desirable spacing of trees, and also provides landowners with income

Occasionally, the crossing of tree strains produces hybrids that grow faster, produce higher quality wood or have better form than either parent tree. Such hybrids can be reproduced from cuttings (cloned) to supply large quantities of superior planting stock. Poplars probably have been the most successful tree hybrids. Clones developed from cuttings from conifer species show gains in productivity, but several problems have been identified, including difficulties in propagating cuttings from trees old enough to show superior characteristics. Clones developed for superior growth often have less capacity to accommodate environmental variations and may be more subject to damage from disease and climatic extremes than trees produced from wild seeds.

The potential of genetics to improve growing stocks has not been realized as quickly in silviculture as it has in agriculture because of the long growing cycle of trees, Genetic improvement of tree species requires far longer testing periods than for agricultural crops, and the establishment of improved trees in plantations is an incremental process. The long time period (5 to 20 years] before trees reach seed-

Figure 19.— Productivity Increases Attributable to Intensive Management



[a] "Target" values for maximum mean annual yield were defined through a theoretical model and observations from existing stands. The targets are estimates of mean annual yields potentially achievable on plantations established at the end of the century, assuming advancements In cultural and genetic technologies.

SOURCE: Adapted from Peter Farnum, et al., "Biotechnology of Forest Yield," Science, 2/1 1/63, p. 697,

bearing age has slowed progress in tree breeding using traditional techniques. The corresponding commercial application of these advances has taken 50 years or more in the past because of the repeated breedings necessary to establish useful strains.

Advances in biotechnology may accelerate this process greatly.[18] For example, mass propagation of superior clones through tissue culturing is a potentially important development in forest genetics. Tissue culturing entails in vitro propagation of living cells in a supportive medium that maintains their viability. Some forest products firms now are field testing mass propagation of clones produced through tissue cultures that have been planted in natural conditions.

[18] *Impacts of Applied Genetics: Microorganisms, Plants, and Animals* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, OTA-HR-132, April 1981), describes new plant breeding technologies in detail.

Photo credit: Simpson Timber Co.

Tissue culturing has important implications for forest genetics. Tissue cultured clones (such as the redwood plantlets shown above) are now being field tested by some forest products firms

Short Rotation Hardwood Culture

Improved techniques for hardwood management have received comparatively less attention than management of softwood species. An important exception is short rotation intensive hardwood culture aimed at production of biomass for energy.

The oil shortages of the early 1970's drew attention to the wood fuel potential of fast-growing trees produced in intensive agricultural-like systems, While both softwoods and hardwoods have been tested, fast-growing hardwoods such as hybrid poplar, cottonwood, willow, and sycamore appear to be the most promising. These species are less expensive to regenerate because they can be propagated from cuttings and can reproduce from stump sprouts after successive harvests (coppice systems).

Combinations of genetic improvement,[19] site preparation, cover crops which reduce competition, cultivation,[20] fertilization,[21] and irrigation[22] may be used to increase biomass production, Biomass yields from intensively cultivated 4- to 5-year-old hardwoods may yield 25 to 30 short tons per acre per year on the first rotation and volumes 30-percent greater on successive crops from the resprouted root systems.[23]

While early research has focused on biomass for energy, changes in wood utilization standards to allow the use of small timber and modifications in intensive hardwood culture to grow larger trees could lead to other products.[24]

Potential Gains From Intensive Timber Management

The Forest Service has compared current average net annual wood growth with potential growth that might occur in fully stocked natural stands, i.e., natural stands with optimal density and spacing (table 17), Net annual

[19] See, for example, J. Ranney, J. Cushman, and J. Trimble, *The Short Rotation Wood Crops Program: A Summary of Research Sponsored by the Biomass Energy Technology' Division*, draft report (Oak Ridge, Term.: Oak Ridge National Laboratory, 1982).

[20] See, for example, H. Kennedy, Jr., " Foliar Nutrient Concentrations and Hardwood Growth Influenced by Cultural Treatments, " *Plant and Soil*, vol. 63, 1981, pp. 307-316.

[21] See, for example, T. Bowersox and W. Ward, "Economic Analysis of a Short Rotation Fiber Production System for Hybrid Poplar, " *Journal of Forestry*, vol. 74, 1976, pp. 750-753,

[22] See, for example, D. H. Uric, A. R. Harris, and J. H. Cooley, "Irrigation of Forest Plantations with Sewage Lagoon Effluents, " in *State of Knowledge in Land Treatment of Wastewa ter*, vol. 11 of proceedings from 1978 Conference at U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, N, H., pp. 207-213.

[23] M. Cannell and R. Smith, "Yields of Minirotation Closely Spaced Hardwoods in Temperate Regions," *Forest Science*, vol. 26, 1980, pp. 415-428.

[24] P. Larson, R. Dickson, and J. Isebrands, "Some Physiological Applications for Intensive Culture, " *Intensive Plantation Culture*, General Technical Report NC-21 (St. Paul, Minn.: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, 1976), pp. 10-18.

Table 17.—Average Net Annual and Potential Growth Per Acre in the United States by Ownership and Section, 1976[a]

Item	Unit of measure	All ownerships	National forest	Other public	Forest industry	Farmer and other private
North:						
Current	Cubic feet	35	43	36	44	33
Potential	Cubic feet	66	63	59	74	66
Current/potential	Percent	53	68	61	59	50
South:						
Current	Cubic feet	57	57	54	60	56
Potential	Cubic feet	77	71	71	83	77
Current/potential	Percent	74	80	76	72	73
Rocky Mountains and Great Plains:						
Current	Cubic feet	29	30	25	50	25
Potential	Cubic feet	60	64	55	74	51
Current/potential	Percent	48	47	45	67	49
Pacific coast:						
Current	Cubic feet	49	30	53	80	62
Potential	Cubic feet	97	91	88	119	99
Current/potential	Percent	51	33	60	67	63
Total:						
Current	Cubic feet	45	35	42	59	45
Potential	Cubic feet	74	74	68	87	72
Current/potential	Percent	61	47	62	68	62

[a]Potential growth is defined as the average net growth attainable in fully stocked natural stands. Much higher growth rates can be attained in intensively managed stands.

SOURCE: Adapted from *An Analysis of The Timber Situation In the United States, 1952-2030* (Washington, D.C.: U.S. Department of Agriculture, Forest Service, 1982), p 137.

growth on all commercial forestland in the United States in 1976 was estimated to be about 60 percent of potential if all forests were well-stocked natural stands. The Pacific coast had the highest potential production at 97 ft^3 per acre per year, but growth in 1976 was only about half of what it could have been.

Differences among timber species, site quality, available management techniques, and landowner objectives make it difficult to reliably estimate the absolute potential for increased timber production through intensive silviculture, but substantial increases in per-acre productivity clearly are possible if adequate investments are made.

Several factors determine whether a tract of land might be intensively managed for timber. These include its biological suitability as well as its economic suitability. Another factor is whether or not its owner is willing to make the investment and has the financial capacity to do so (see ch. VI for further discussion).

Both the Forest Industries Council (FIC), a trade group sponsored by the National Forest Products Association, and the Forest Service recently published estimates of acreage affording economic opportunities for management in 25 States.[25 26] Both studies used standard discounted cash flow techniques. The financial feasibility of timber management was based on estimates of potential wood yields, management costs, and timber values that would produce a positive net present value at specified interest rates. The FIC study used a 10 percent rate of return criteria in calculating economic opportunities, while the Forest Service used a 4-percent rate of return, The Forest Service excluded national forests from its survey, while the FIC survey did not,

The 25 individual States that FIC analyzed contain together about 83 percent of the com-

[25]Forest Industries Council, *Forest Productivity Report* (Washington, D. C.: National Forest Products Association, 1980), p. 46.
[26]*An Analysis of the Timber Situation*, Op. Cit., p. 248.

mercial forestland in the United States. Fifty-three percent of the land considered was determined to be silviculturally suitable for intensive management, and 34 percent was determined to be economically suitable (see table 18).

Both studies concluded that the greatest potential for increasing timber production through intensive management is in the South, followed by the Pacific coast and the North. To achieve the projected potential gains, large amounts of capital would be required—an estimated total investment over a rotation cycle of $10 billion under the FIC study to $15 billion under the Forest Service study.

The FIC and Forest Service estimates of economic opportunities for management provide useful information given the limited data available. The projected economic opportunities, however, are probably higher than will actually be realized. Landowner objectives, for example, which on private nonindustrial forests (PNIF) lands are diverse and seldom include intensive timber management, were not considered, even though most of the projected potential increase was on PNIF properties (see ch. VI for discussion of PNIF ownership objectives). In addition, the studies considered all commercial forest tracts 1 acre in size and larger, but the possible effects of tract size on the economics of intensive forest management were not addressed.

Table 18.—Area of Commercial Forestland and Areas Suitable for Intensive Management in 25 FIC Study States (million acres)

	Commercial forest land	Silviculturally suitable land	Economically suitable land
Mississippi	16.9	11.5	11.2
Oregon	24.4	12.5	10.0
Arkansas	18.2	11.6	9.9
Louisiana	14.5	9.0	9.0
Georgia	24.8	12.8	9.0
Washington	17.9	9.4	7.6
Alabama	21.3	15.1	7.4
Texas	12.5	8.9	6.5
Florida	15.3	7.5	6,3
Virginia	15.9	7.1	6.3
California	16.3	10.0	6.2
Tennessee	12.8	6.6	6.0
Idaho	13.5	7.8	5.3
Michigan	18.8	7.4	5.0
West Virginia	11.5	7.2	4.9
Montana	14,4	8.1	4.9
North Carolina	19.6	13.6	4.5
South Carolina	12.2	7.3	3.6
Wisconsin	14.5	4.9	3.3
Missouri	12.3	9.2	3.1
Pennsylvania	17.5	2.8	2.4
Kentucky	11.9	8.3	2.1
Minnesota	16.1	4.5	1.7
Maine	16.9	6.8	1,4
New York	14.5	3.6	1.4
Total	404,5	213.3	139.0

SOURCE Individual State Productivity reports prepared for the Forest Productivity Project of the Forest Industries Council, 1978-80

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Increasing Timber Supplies by Improving Harvest Technology

Improved harvesting systems could effectively increase timber supplies by removing more wood from harvest sites and by opening up areas that currently are too costly or environmentally sensitive to log. Key areas where improvement can be made include harvesting machinery, harvesting methods, woodsworker training, and improved integration of all aspects of harvesting into an organized system.

Developing new, innovative mechanical systems takes 7 to 10 years. Because of this timeframe, current timber characteristics and available technologies for timber extraction and processing will define harvesting systems in the next 30 years, In the longer term, it is possible to improve utilization and increase available wood fiber by designing integrated systems for growing, harvesting, and processing to achieve near-optimal results.[27]

Several factors affect the feasibility of increasing timber supplies through improved harvesting technology:

- characteristics of the forests to be harvested;
- opportunities for utilizing materials that harvest makes available; and
- environmental constraints.

Characteristics of U.S. Forests

Over the next 20 to 30 years, harvesting systems will reflect the quality and quantity of trees now growing. These characteristics vary significantly by region. In the East, average tree diameters are not expected to change much, while in the West a decline of 27 percent by 2000 has been projected.[28] Hardwood inventories are expected to accumulate in the North and the South; in the South, softwood production may increase on a per acre basis due to intensive management.

Ownership factors and the economics of extracting timber will also affect harvesting efficiency. For example, private nonindustrial lands are expected to account for an increasing portion of timber supplies. PNIF tracts are typically small in size, however, while most harvesting machinery is designed for large operations.

Beyond 2010, current and prospective intensive management practices could increase timber supplies and change the character of timber stands. Replacement of unmanaged stands with rapidly growing, genetically improved trees could result in smaller, less defective, and more uniform trees for harvest.

Utilization Opportunities

Recent technological advances in forest products manufacturing have increased substantially the opportunities for utilization of small logs, hardwoods, residues, and defective or rough timber. Some of the more important developments include:

- the use of low-quality wood as filler for panels and as center portions of laminated beams and studs,
- machines that peel smaller logs for plywood,
- processes that make panels from low-grade hardwood chips and flakes that can substitute for plywood in some applications, and
- new systems for efficient combustion of wood wastes.

Wider adoption of such processes could expand the use of materials now considered too costly to remove from the forest for use. According to the Forest Service,[29] 1.4 billion ft^3 of growing stock residues were left on harvest sites in 1976, along with two to four times as

[27] As discussed in G. W. Brown, W. R. Bentley, and J. C. Gordon, "Developing Harvesting Systems for the Future: Linking Strategies, Biology, and Design," *Forest Products Journal*, vol. 32, 1982, pp. 35-38.

[28] R. Haynes, D. Adams, and E. Bell. Manuscript on file at U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

[29] *An Analysis of the Timber Situation*, op. cit., pp. 264-266.

much material in the form of tops, branches, small stems, and other materials. About 14 billion ft' of potentially salvable accumulated dead timber existed in 1977, mostly western softwood. Commercial timberland also contains tens of billions of cubic feet of defective trees from commercial species. A greater portion of these materials may have economic potential for use in fuel and industrial applications in the future.

Environmental Limitations

Improper harvesting practices can cause serious environmental damage. New harvesting technologies and systems could exacerbate such impacts unless special care is taken in their design and operation. Harvesting systems that remove rough and rotten trees and dead timber over a large geographic area could affect adversely those wildlife species dependent on such trees for habitat. Also, operations that totally remove all the fiber produced on sites may further deplete nutrients in shallow, low nutrient soils, especially under short rotation systems. Some States have adopted forest practices laws designed to mitigate damage to soil, water quality, wildlife, and esthetic resources caused by harvesting.

New technologies and systems could be developed to overcome some of the constraints that presently prevent harvest of some forests. For example, about 185,000 acres of national forest timberland in the Pacific Northwest are excluded from the allowable cut base because of potential environmental problems associated with harvesting; systems that entail less damage could expand the acreage available. For many small landowners, small-scale systems that are well adapted to scenic and esthetic concerns could broaden the appeal of timber harvesting. Training of woodsworkers is also important for reducing environmental effects during harvest operations.

Technology Development Process

The development of harvesting technology in the United States has not been an integral part of the overall timber production system. For the most part, coordination of efforts among equipment manufacturers, timber producers, and processors has been limited, even on a regional basis .30 Development of harvesting systems has not been supported as intensively by either private or public research in the United States as in Western Europe (see box B),

In the absence of a strong coordinated R&D process, the focus has been largely on individual machines rather than integrated systems. In this country, harvesting machinery is developed primarily in three ways:

- Trial and error—often by loggers. While innovation has sprung from this method, it usually produces designs that meet unique rather than general needs.
- Development in small job shops—sometimes in response to needs expressed by a logger client. These advancements often are not fully exploited because of limitations in the size of the production line, investment capital, and the engineering staff.
- Development by major equipment manufacturers, Contributions by large firms, while important, have been small in relation to their potential, partly because the construction and agriculture industries are their primary markets.

Current U.S. Harvesting Technology and Systems

In general, U.S. harvesting equipment is classified as either ground-based or aerial. Usually, this equipment is designed to "yard" or transport timber felled and limbed by chainsaw from stump to landing where it is loaded as a log onto a truck for transportation to the mill, Probably 90 percent of the wood fiber in the United States is processed in this manner. In the eastern half of the country, pulpwood is the main product, cut into 100-inch" or 63-inch lengths. Small diameter trees are frequently sheared rather than cut by chainsaw and are often delimbed by pushing the stem through a gate. Trees are either yarded to the landing by skidders or are cut into pieces and loaded directly onto flatbed trucks. In the West,

[30] As discussed in Brown, Bentley, and Gordon, "Developing Harvesting Systems for the Future, " op. cit., pp. 35-36.

because logs are used predominantly for lumber or plywood, they usually are yarded in 25-ft lengths or longer.

A description of yarding equipment and the performance characteristics of each type is presented in table 19.[31] Horses, tractors, wheeled skidders, and feller-buncher tree processors move logs across the ground surface. Aerial harvesting equipment (cables, skylines, balloons, and helicopters) provide lift to logs as they are delivered from stump to landing.

The cost of harvesting by these means varies widely depending upon the skill of the crew, the terrain, the timber size, and the size of the tract harvested. In general, ground-based operation cost less than aerial systems. For ground-based equipment, which is best suited to gentle terrain, costs are usually half those of aerial machinery. As a result, most industrial

[31] See J. J. Garland, *Timber Harvesting Options,* Oregon State University, Extension Service Extension Circular 858 (Corvallis, Oreg.: Oregon State University, 1980), for a discussion.

Table 19.—Performance of Timber Harvesting Equipment

Horse	Tractors and wheeled skidders	Feller-bunchers tree processors	Cable and skyline	Balloon	Helicopter
Timber size capability					
Small timber generally less than 24" Dbh[a]	Capable of handling all sizes in design range of machine	Small to medium timber less than 24" Dbh[a]	Medium to big timber; small timber in thinnings	Timber weight limit	Timber weight limit
Production potential					
Low production	High production	High production possible	Medium to high production	Medium to high production; winds over 25 knots limit operability	Very high production but weather restricts operability
Costs of production					
Low	Low	Low to medium	Medium to high	High	Very high
Limits on silvicultural system					
None	None	Thinning in rows or strips possible	Generally clearcuts; partial cuts possible	Suited to clearcuts; experimental in partial cuts	No limitations
Topography limits					
Gentle; occasional short, steep pitches over 500/o; downhill yarding preferred	Up to 35 to 450/o; downhill yarding preferred	Up to 30%	Deflection necessary but suited to steep slopes	Adaptable to topography within limits	No limits
Road access requirements					
Haul road close-to skid road (300' to 500' desirable)	Long skid distances feasible but not economical	Medium distances from haul road up to 1,500'	High lead logging 1,500' approaching maximum yarding distance—some skyline operational at 5,000'	About 5,000 limit	No limit except by economy
Stream protection					
Generally excellent with proper practices	Can be excellent depending on proximity to stream and practices; crossings need preparation	Good with proper practices; stream crossings need preparation	High lead poor if logging across streams, otherwise good; skylines can lift log free of streams	Capable of lifting logs free of streams; large landings near streams are problems	Excellent protection
Site disturbance					
Minimum disturbance; little slash handling capability; small landings 50' diameter	Medium to high disturbance; soil compaction potential; damage to residual stand possible; slash handling possible; medium landings approximately 75' diameter	Medium to high disturbance; soil compaction potential; damage to residual stand possible; slash handling possible; medium landings approximately 75' diameter	Minimum to medium disturbance possible with proper practices; slash handling possible; may damage residual stand in partial cuts; medium landings about 75' diameter	Minimum disturbance; slash handling a problem; requires 100' diameter landing + 200' diameter tie down area	Minimum disturbance; slash handling a problem; requires 100' diameter landing + 50' x 100' setdown maintenance area

[a] Diameter at breast height

SOURCE J. J. Garland, 'Timber Harvesting Options, Extension Service Circular 858 (Corvallis, Oreg : Oregon State University, 1980) and nonindustrial forestlands are harvested by ground-based methods. Costs may range from a low of $15 per thousand board ft of timber logged with skidders in favorable operating conditions to a high of over $200 per thousand board ft logged with helicopters.

Costs increase rapidly as tree size declines (fig, 20). Workers must handle more pieces to produce the same volume of wood, so that as tree size declines from 10 to 4 inches in diameter at breast height (4.5 ft above ground), costs increase by 70 to 80 percent.[32] Tract size also affects harvesting expenses because of the fixed cost of moving equipment. One researcher, using simulation techniques to estimate the effect of tract size on harvest cost, found that highly mechanized equipment presently available becomes inefficient as tracts drop below 100 acres.[33] This has significant implications for the future as more wood is obtained from small private nonindustrial tracts.

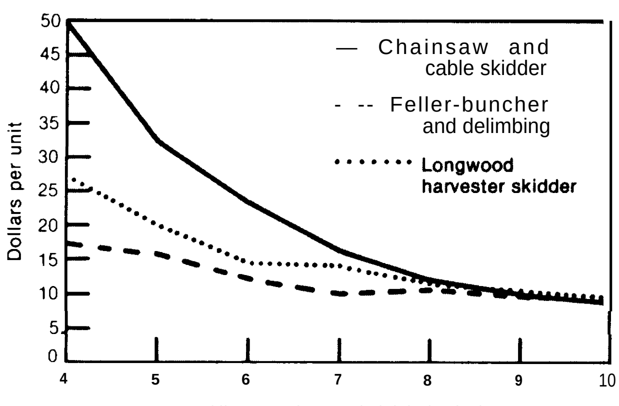
[32] J. R. Erickson, "Changing Resource Quality: Its Impact in Harvesting and Transportation, " in *Impacts of the Changing Quality of Timber Resources,* Forest Products Research Society, Proceedings No. P-78-21, 1978.

[33] F. W. Cubbage, "Economies of Forest Tract Size in Southern Pine Harvesting, " unpublished paper on file at the U.S. Department of Agriculture, Southern Forest Experiment Station, 1982.

The skill of equipment operators and other crew members also is critical in determining production costs. As in any industrial enterprise, production rates can vary from 65 to 135 percent of normal depending on worker expertise and work habits.

Aerial equipment, while more costly, is better suited to steep terrain than is ground-based equipment. In the West, aerial equipment is commonly used on slopes greater than 35 percent. Regulations for State forest practices in Oregon, Washington, and California, for instance, require its use on steep slopes. Within the last 5 years, a few small U.S. manufacturers have placed light, highly mobile and inexpensive cable machines on the market that may be

Figure 20.—Cost Comparison for Cutting and Skidding by Diameter Breast Height for Three Logging Systems



SOURCE: Adapted from J R Erickson, "Changing Resource Quality: Its impact in Harvesting and Transpiration, " in *Impacts of the Changing Quality of Timber Resources,* Forest Products Research Society Proceedings No P-78-21 , 1978

Photo *credit U.S. Forest Service*

Helicopter yarding of logs is expensive, but can open up areas to logging that are too inaccessible or environmentally sensitive for ground-based yarding systems useful for harvesting small timber in private nonindustrial forests in steep areas,

The structure of the logging industry also is an important consideration affecting the current and prospective design of harvesting systems, Some forest products firms maintain their own logging crews, but independent contract loggers are responsible for a large portion of U.S. harvesting operations, Most such logging operations are small in scale, In 1977, there were over 15,000 independent logging establishments, employing about 83,000 workers, an average of less than 6 employees per firm. This figure does not include crews hired by sawmills and pulpmills, farmers or part-time loggers. According to a 1982 report on Canadian companies' equipment marketing prospects in the Southeast, forest products firms have largely disbanded their logging crews in the region except for areas or conditions where specialized machines are called for.[34] The small-scale nature of southern logging contractors, averaging about $250,000 invested in equipment, is a key determinant of equipment needs.

Harvesting Machinery

Priorities for new developments in harvesting machinery differ by region. To fully utilize available forest resources in the East, harvesting machines need to be highly mobile, with low environmental impact, and able to harvest, handle, and process large numbers of small irregular pieces. Prospects for companies that develop such machines appear favorable, according to a recent Canadian assessment of the potential for Canadian firms to penetrate U.S. equipment markets (see box B).

In the West, including Alaska, harvesting systems for steep terrain are needed that produce little environmental impact and that can economically deliver timber from thinnings and wood residue to roadside. Other systems capable of reaching long distances could provide access to some presently inaccessible areas,

A systems approach to developing machines for growing, managing, and harvesting trees of given specifications for delivery to processing centers[35] has not yet been undertaken in the United States. Most big manufacturers produce machinery primarily for agricultural or construction markets and only secondarily for harvesting timber, Much of the harvesting equipment now available is simply modified agricultural or construction vehicles. In addition, small, independent contract loggers, who play a major role in harvesting even in the Pacific Northwest where there are large consolidated tracts of industrial land, are not organized in a fashion that leads to the communication of desired specification for harvesting systems to machinery designers.

Harvest Methods

Harvesting machinery must be used properly if it is to be economically and environmentally acceptable. In many cases, machinery currently available can be more effective if new methods for its operation are devised. For example, small, low-cost skyline yarders designed for harvesting timber within 300 ft of roads can be used to reach timber 1,000 ft from roads using a method called "multispan logging, " This system, designed in Western Europe, extends the reach of small yarders by suspending the cable from supports hung between two trees and operates much like a ski lift. In many regions, this method could provide access to timber too small to be yarded by large expensive systems with long-reach capabilities or to environmentally sensitive terrain where few logging roads can be used.

Soil disturbance has become a major environmental concern in many forests. Tractors have been prohibited from harvesting timber on sensitive soils on some Federal lands because of the potential for site damage from normal tractor operations. Harvesting by cable

[34] Department of Canadian External Affairs, *Market Studies of United States: Canadian Forestry Machinery and Equipment in the Southeastern United States,* prepared by Sandwell International, Inc. (Ottawa, Canada: Canadian Department of External Affairs, August 1982), p. 12.

[35] See "Developing Harvesting Systems for the Future, " op. cit., for a discussion.

Box B.—Harvesting Technology in Western Europe

The development of harvesting machinery in Western Europe began in much the same way as it did in the United States. Most equipment was fabricated by individuals or small shops. In the last 15 years, however, Western European manufacturers have begun to design more complete systems for harvesting, preprocessing, and transporting wood from stump to mill. Scandinavian countries have led this transition from a machine to system focus. These countries were forced to better integrate harvesting with tree growing and processing because of increasing labor costs and a growing proportion of their timber supplies taken from small, nonindustrial private forestlands—factors that also affect the forest products industry in the United States. In Sweden, where there are some 247,000 small forest owners, 56 percent of the forestland tracts are less than 62 acres in size. In Austria, over 80 percent of the forest is privately owned and nearly all is in tracts of less than 500 acres.[36]

Rapidly rising labor costs threatened to price Swedish wood products out of the world market in the early 1960's. Reducing those costs became a national objective and the government, organized labor, forest owners, and machinery manufacturers banded together to forma cooperative research organization whose main charge was mechanization of timber harvesting. In 20 years, harvesting in Sweden was transformed from a high-cost, labor-intensive operation to a low-cost, mechanized activity.[37]

The payoff from such R&D can be very high. In Sweden, productivity was roughly 46 ft^3 per worker-day in 1950. By 1975, it had increased about 7.5 times to 350 ft^3 per day. The net result of improved productivity was that Sweden remained a competitor in world markets. Its present research thrust is the development of highly mobile, low-cost machines for use on small, scattered, nonindustrial forests.

The importance of small, privately held forests has led Western European manufacturers to produce a wide variety of small, inexpensive, highly mobile machines that can be used individually or as part of an integrated system. Such machines make it easy for landowners to harvest their own timber and encourage them to manage their forests as part of their agricultural enterprise. Many machines are designed to operate from the power takeoff of common farm tractors.

Data is not available to assess the role that development of harvesting machinery for private nonindustrial owners has played in increasing supplies of wood to Western European mills. It is likely, however, to be significant, especially in Scandinavia. Sweden, for example, relies on nonindustrial forests for about 70 percent of its wood. Forest products continue to be the nation's leading export commodity, evidence that output from nonindustrial lands remains high and that small private owners continue to contribute to the country's wood supply.

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[36]Western European landownership trends are discussed in Swedish Institute, *Forestry in Sweden* (Stockholm, Sweden: Swedish Institute, 1976); and G. W. Brown, "INTERFOREST 82—Technology and Science of Managing Small, Young Forests," *Journal of Forestry*, vol. 80, 1982, pp. 702-703.

[37]G. W. Brown "Harvesting Research and Development in Sweden," *Journal of Forestry*, vol. 80, 1982, Pp. 793-794, 800.

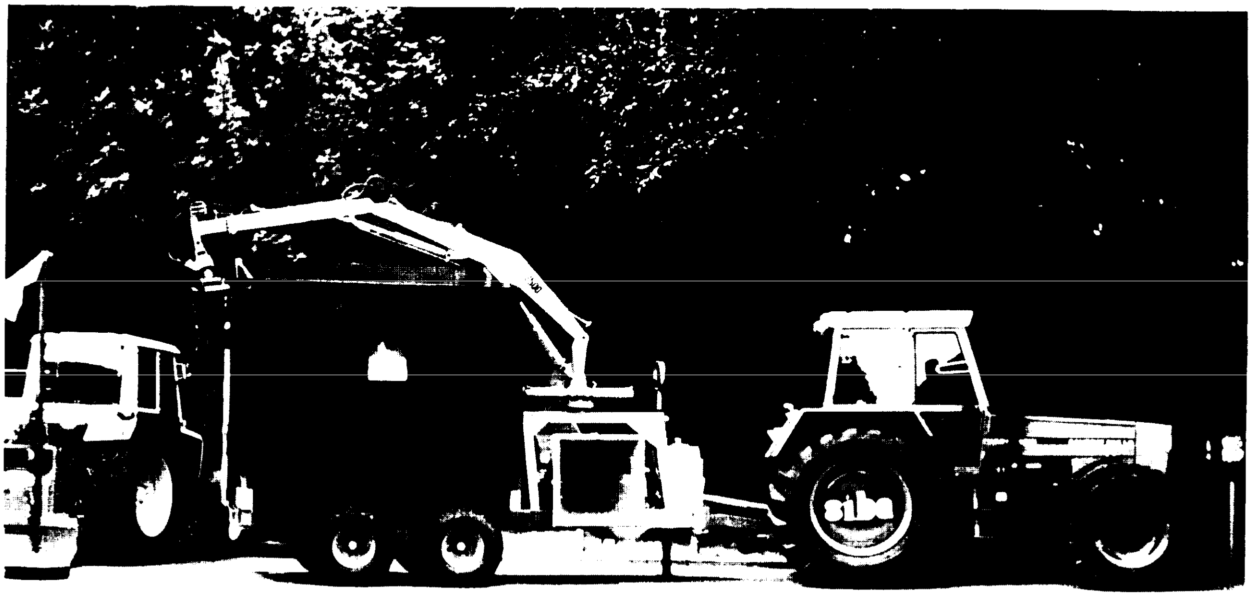

Photo credit George Brown

Development of small harvesting equipment for use on private nonindustrial forestland has been a priority in Western Europe and Scandinavia. The photo shows a tractor-powered chipper and detachable chip bin

systems is permitted, but costs over twice as much. As a result, much of the timber effectively is excluded from harvest because it cannot be extracted economically. Recent research on new methods of harvesting within acceptable levels of soil disturbance and cost may change this situation.[38]

Transportation Systems

Once harvested, timber must be transported from the forest to processing centers. For processing centers that convert wood to fiber or composition products, a broader array of options is available to transport wood besides the standard log common today. These options include whole trees, tree-length logs, chips, chunks, and compacted bales of residue. An advantage of using chunks or compacted bales, for instance, is that more wood fiber can be packed into a load than with logs, especially if they are crooked and limby. Transportation costs thereby are reduced and more timber can be harvested economically.

Broader transportation questions are raised with the development of new harvesting systems. These questions include the adequacy of existing highways and the design of vehicles capable of dealing with diverse conditions. For example, most forest roads are designed for log trucks that bend in the middle. Vans to haul

[38]As discussed in H. A. Froehlich, D. E. Aulerich, and R. Curtis, *Designing Skid Trail Systems to Reduce Soil Impacts from Tractive Logging Machines,* Forest Research Laboratory Research Paper 44 (Corvallis, Oreg.: Oregon State University, 1981).

chips or chunks are designed primarily for highway use and have a different configuration, This means they can neither turn around nor negotiate curves on standard logging roads as easily as most logging trucks. In some cases, bridges and overpasses limit the size of trucks to be used and would need to be redesigned or strengthened to accommodate heavier loads or wider carriers. Highway problems and likely solutions differ by region. The West has long haul distances on secondary or low-volume gravel roads; the East has a more extensively developed, paved public road network where load limits and aging bridges are disadvantages.

Training for Woodsworkers

New machines and new methods require trained crews to use them. As machines become more sophisticated, they usually become more expensive; abusive treatment or inefficient operation can affect costs significantly, Unfortunately, woodsworker training has been given low priority in North America. In Scandinavia, operator training has received equal emphasis with machine development because researchers and managers recognize that the two are closely linked (see box C). Probably half of the increased productivity experienced in Sweden can be attributed to operator training programs. In central Europe, productivity for a well-trained crew averaged 19.3 minutes per cubic meter harvested; an untrained crew required 43.5 minutes.[39] If similar gains in productivity can be achieved in the United States, timber now considered too costly to harvest could be added to the supply base.

Woodsworker training could improve the logging industry's safety record and reduce harvesting costs associated with workers' compensation payments (table 20). Among industries in 1976, logging had the second highest injury and illness rate and thus had high compensation rates. Logging is already a dangerous occupation but may become more so as workers are required to handle more pieces and as operations move into more difficult terrain.

[39] A. Trzesniowski, Logging *in the Mountains of Central Europe* [Rome, Italy: United Nations FAO, 1976).

Table 20.—Summary of Workers' Compensation Insurance Rates by State for Logging and Lumbering Workers (cost per $100 of payroll)

State	1974	1978	1980
Alabama	$9.37	$10.52	$12.52
Arkansas	15.26	18.26	22.00
Florida	13.60	32.59	27.69
Georgia	13.52	16.10	22.16
Louisiana	29.90	39.68	52.10
Mississippi	23.24	34.59	44.36
North Carolina	10.47	16.54	28.59
Oklahoma	26.34	32.26	53,35
South Carolina	9.23	16.03	22.29
Tennessee	14.08	19.61	17,43
Texas [a]	27.06	41.90	14,98
Virginia	8.86	15.37	23.69

[a] Texas rates were lowered in 1980 to encourage @mployment

SOURCE *Market Studies of the United States Canadian* Forestry *Machinery and Equipment in the Southeastern United States* (Ottawa Canadian Department of External Affairs, 1982), p 12

Workers' compensation rates paid by employees for their crews are very high, and contribute significantly to the costs of logging. Injuries and associated costs may continue to rise unless training programs can improve the safety record.

Training workers also could reduce environmental impacts of harvesting and improve timber management. Since most PNIF lands are not harvested under a management plan prepared by a professional forester, special woodsworker education could be directed at owners of private nonindustrial forests. Some owners personally harvest their own timber, a choice common in Europe and among some U.S. farmers. In other cases, owners who do not perform the harvest themselves may benefit from learning more about harvesting timber and be better prepared to make decisions about harvest programs. Such education may be an important key to the availability of timber on private nonindustrial forestlands.

Research and Technology Transfer

If timber supplies are to increase from improved harvesting and land management technologies, additional improvements may be needed in the present system of forestry-related research and technology transfer. The United States does not have a research organization like the Forest Engineering Research Institute

Box C.—Marketing Canadian Equipment in the Southeastern United States

Development of small, multipurpose harvesting equipment for use on nonindustrial tracts could aid in increasing timber supplies from PNIF lands. Such equipment is widely available in Scandinavia and Western Europe, where small tract ownerships are common, but less so in the United States. Sensing an opportunity for Canadian manufacturers, the Canadian Government recently undertook a study of the potential market for Canadian-manufactured harvesting equipment in the Southeastern United States.[40]

The Sandwell International study, commissioned by the Canadian Department of External Affairs, found "no reasons . . . why Canadian-manufactured forestry machines and equipment could not obtain an increased market share in the Southeastern United States." Although some import duties could affect Canadian competitiveness, favorable exchange rates between Canadian and U.S. currency would probably balance duties.

From interviews with logging contractors and corporate executives, the study concluded that "existing equipment design will not meet future requirements for log harvesting." More intensive silviculture with associated commercial and precommercial thinning will establish a need for smaller, highly mobile skidders and harvesting equipment able to be used for several purposes. Machines designed to meet noise reduction standards, reduce damage to plants, and minimize stream water pollution would also be desirable.

The potential for Canadian penetration of the skidder market was found to be especially high, due to a continuing need for replacements (2,500 to 3,500 per year in the United States). Attachment devices able to run off tractors also were given high potential, due to unique designs by some Canadian manufacturers. Reforestation equipment was also found to be a promising market if Canadian manufacturers adapted their designs to Southeastern U.S. environmental and topographic conditions.

The study also assessed marketing strategies. Because many forest products firms have cut back their own logging operations, the most successful strategy, according to the study, would be aimed at independent contractors, followed by farmers and other part-time loggers with a need for attachments running off farm equipment. Dealerships were found to be crucial for successful marketing, since few loggers were willing to travel more than 30 miles for services. Trade fairs were found to be less effective because loggers want to see equipment in actual operation. Therefore, demonstrations at harvest sites by forestry schools and State agencies were thought to be more promising. In addition, cooperative efforts with vocational schools would help train woodsworkers to use the new machinery and facilitate market penetration by giving operators a chance to test equipment.

[40]Canadian Department of External Affairs, *Market Studies.*

of Canada, which carries out coordinated research on harvesting. Furthermore, public resources currently directed to harvesting systems research are quite small. In 1976, only 70 scientist-years of effort were devoted to it, and it comprised less than 2 percent of the Forest Service research budget.[41] Greater emphasis on R&D may be needed if harvesting systems that extend timber supplies are to be forthcoming.

[41]C. W. Boyd, W. W. Carson, and J. E. Jorgensen, "Harvesting the Forest Resource—Are We Prepared?" *Journal of Forestry,* vol. 75, 1977, pp. 401-403.

Traditionally, the formal framework for forestry-related technology and information transfer has been weak in the United States. This situation may improve over time, however, if the Renewable Resources Extension Act of 1978 (Public Law 95-306) bringing forestry more fully into the agricultural extension system, is adequately implemented.

The 1978 act gives forestry a greater priority in the Cooperative Extension System, which for nearly 70 years has served as a vehicle to help farmers in on-the-ground application of agricultural research findings, The act called for periodic development of a National Renewable Resources Extension Plan, along with complementing State plans, to identify renewable resource priorities in the extension system. The initial program was submitted to Congress in 1980. Earmarked funding for renewable resources extension was not provided until fiscal year 1982, and it has been proposed for deletion in fiscal year 1984, As a result, most forestry-related work is conducted with discretionary funds allocated chiefly to agricultural activities (see box D).

Box D.—Forestry in the Cooperative Extension System

The National Cooperative Extension System is the primary means by which government speeds agricultural research findings on technology and management to landowners and other members of the public. Established in 1914 by the so-called Smith Lever Act, the system is comprised of USDA, land-grant universities, and State and county government extension agencies. Nearly all of the over 3,000 counties in the United States have extension offices which conduct information, education, and demonstration programs related to activities as diverse as forestry, home economics, marketing, and agricultural production.

Federal cost-sharing of forestry-related extension activities has occurred at a modest level for many years ($1.6 million in 1979) under general-purpose appropriations or separate appropriations for specific projects. Most of these activities are aimed at encouraging land management by private nonindustrial owners, although wood utilization activities also have been authorized. Federal funds account for 30 percent of project costs. A State's cost-share is 70 percent. Extension forestry activities typically are undertaken in conjunction with other agencies, including the Forest Service, State forestry offices, the Soil Conservation Service, local conservation districts, and county agricultural conservation program committees.

Examples of cooperative extension forestry-related activities include:

- provision of stumpage price information in some county extension offices in the South,
- operation of metropolitan area workshops on timber management investment opportunities for absentee forestland owners,
- initiation of a Northeastern project for improving timber stand management through income-producing fuelwood thinning, and
- establishment of County Forest Resources Associations in several States.

An organizational framework for increased involvement of the extension system in forestry was provided by the Renewable Resources Extension Act of 1978. The act called for development of a National Renewable Resources Extension Plan on a 5-year basis.

In the initial renewable resources extension plan submitted to Congress in 1980, States identified educational and informational "opportunities" associated with extension forestry which would require 493 staff-years to implement. This compared with 160 staff-years of forestry extension activities in 1980.

Although the 1978 act specifically authorized earmarked Federal appropriations, up to $15 million annually, for renewable resource extension purposes, Federal funding continues at a modest level. Actual funding ($2 million) was not provided until fiscal year 1982 and has been proposed for deletion in the fiscal year 1984 budget request. Smith Lever general funding thus may continue to be the primary source of forestry funds, with forestry competing with other activities for Federal support.

At present, however, fewer than 10 people are actively involved in formal harvesting extension programs, and all forestry-related extension activities entail only about 160 staff-years or effort annually, If the increased productivity witnessed in agriculture that is attributable to extension education could be duplicated for forest resources, the timber supply would likely be markedly improved.

Increasing Timber Supplies Through the Manufacture and End Use of Wood Products[42]

More efficient use of wood in the manufacture of forest products could be achieved in several ways by:

- the expanded use of underutilized tree species, wood residues, and defective materials that are now left in the woods after harvest;
- the increased recovery of high-value primary products, such as lumber and plywood, from roundwood logs;
- the increased use of manufacturing residues for particleboard and fiberboard;
- increased efficiency in end use of wood products, such as in the design of houses; and
- increased recycling of paper.

A variety of products can be made from underutilized trees. Such products may substitute increasingly for wood products derived from more costly and scarce raw materials. Application of advanced engineering techniques to end uses of wood, such as in design and construction, also could improve efficiency by economizing on the use of the resource while maintaining structural quality.

There are additional opportunities to improve raw material use in the mill, In 1976, over 96 percent of the wood entering mills for primary processing was either converted into wood products, such as lumber, veneer, plywood, composite panels, and pulp and paper, or burned to supply the energy needs of the industry. Although most material is used, product yields can be improved as new mills, able to process wood more effectively, come on line.

Technological Adjustments to Changes in Growing Stock

Historically, the U.S. forest products industry has adapted well to changes in species availability and growing stock.[43] As preferred species, sizes, and qualities of wood have become depleted due to increased demand, processing technologies have been adjusted to work with more abundant species and materials previously thought to be unusable.

There are several examples of the industry's accommodation to raw materials availability. Originally, the pulp and paper sector depended on northern spruce and fir for papermaking. As inventories of spruce and fir declined in the early 1900's, widespread concern arose over possible shortages, since other species such as southern pine were thought to be unsuited for paper. However, the sector, aided by research laboratories, quickly adapted the kraft sulfate papermaking process to southern pine, which now is a major contributor to paper production.[44] In addition, research was initiated on the use of lesser quality hardwoods in paper, so that suitable low-grade hardwoods are now added to the raw materials mix.

[42]See volume II of this report for detailed discussion of wood utilization and manufacturing technologies from which this section is derived.

[43]See, for example, Egon Glesinger, *The Coming Age of Wood* (New York: Simon & Schuster, 1949), in passing, for discussion of changes in raw materials utilization by the forest products industry.

[44]As discussed in Ibid., pp. 169-172.

Similarly, plywood producers initially depended on large-diameter, straight western softwood, As a result of increasing prices for such timber and uncertainties about future supplies, manufacturers learned to use previously untried southern pine in the early 1960's. By 1980, the South produced nearly as much plywood as the West, generally using smaller logs,

Implications of New Wood Products for Fuller Use of Resources

Today, softwoods are preferred for lumber, plywood, and certain papers. As currently preferred softwood grades become scarcer and more expensive, the forest products industry continues to seek ways to use different portions of the timber resource through the expanded utilization of hardwood species and the expanded recovery of wood left in the forest after "merchantable" material is removed.

Hardwood species present major opportunities for greater use. Hardwood inventories, found mostly in the East, comprise more than one-third of the Nation's growing stock and are multiplying fast, In 1976, hardwoods accounted for 36 percent of the standing timber, but only 26 percent of roundwood supplies.[45] Existing and emerging technologies can produce materials from hardwoods of similar performance to many products now produced mainly from softwoods.

In the pulp and paper sector, the increased substitution of abundant hardwoods in the production of papers suitable for a variety of uses could relieve resource problems caused by the economic scarcity of softwoods. While several technologies could permit greater hardwood utilization, only about one-fourth of the pulpwood used in the United States presently is derived from hardwoods.

Current pulping processes can use a broad range of woody materials, such as wood residues and chips, Over 35 percent of the total wood used for kraft paper comes from residues. In the Pacific Northwest, nearly 90 percent of the wood used for pulp originates from sawmill or veneer mill residues.[46] The suitability of whole tree chips, including bark and branches, is now under study; when efficient segregation methods are developed, these chips could greatly enlarge the wood resource available for pulp products. In addition, waste paper now accounts for about one-fourth of the fiber used in the industry; increased recycling is also feasible (see box E).

The lumber and panel sector has adjusted its processes to use smaller logs, as second-growth timber replaced old-growth and as tree utilization standards changed. This trend will probably continue. The potential of hardwoods in structural plywood production is being explored, Some studies have concluded that construction-grade hardwood plywood made from a mixture of high- and low-density species could be economically competitive with softwood construction plywood.[47] Improved methods of drying and seasoning hardwoods[48] could provide additional impetus for their use in plywood,

Several composite panel products have been developed for structural application, including waferboard, oriented strand board, and Com-Ply in which a particle core is overlaid with a veneer surface. Nearly all the new panel products developed in the last 30 years can use hardwoods and some wood defective for other uses, thus extending the timber resource.

Waferboard and flakeboard panels (made of wood wafers or large flat flakes) can be made from any hardwood species, but the less dense species are best. Waferboard is unsuitable for some structural applications but may substitute for plywood for sheathing. Waferboard has

[45] Derived from An *Analysis of the Timber Situation*, op. cit., 1982, p. 158.

[46] D. A. Tillman, A. J. Rossi, and S. O. Simmons, *Wood: Its Present and Potential Uses* (OTA contract report prepared by the Envirosphere Co., April 1982), p. 4-25.

[47] R.W. Jokerst and J. F. Lutz, "Oak-Cottonwoood Plywood: No Delamination After Five Years, " Plywood *and Panel Magazine*, June 1981, p. 18.

[48] See Walter R, Smith, "New Horizons in Hardwood Utilibation, " manuscript presented at Forest Products Utilization Research Conference, Forest Products Laboratory, Madison, Wis., Oct. 19-21, 1982, pp. 8-9 for a discussion of hardwood seasoning research.

Box E.-Potential for Increased Recycling of Waste Paper

About 23 percent of the fiber used by U.S. papermakers in 1980 came from wastepaper according to a recent report prepared for the Solid Waste Council of the Paper Industry.* Paper recycling declined in the 1950's and most of the 1960's, but has been increasing since 1968.

Most waste paper is not recycled. In 1980,67.8 million tons of paper were consumed and about 42.7 million tons of paper were disposed of in landfills or were otherwise not recovered. An estimated 6.2 million tons were diverted, destroyed, or lost in use and therefore were not recoverable for recycling, and 0.8 million tons were burned to produce energy. About 18.1 million tons were recovered for recycling, up from 12.9 million tons in 1971.

A portion of the paper recovered for reuse—2.7 million tons—was exported. The remaining 15.4 million tons were used as raw material in the production of new domestic paper.

Of the 18.1 million tons of paper recovered for recycling, 8 million tons consisted of corrugated paper (i.e., box plant cuttings and corrugated containers) obtained primarily from commercial enterprises. The balance consisted of a mix of paper types, the most important of which was newsprint obtained chiefly from residential users.

Collection of waste paper is difficult, especially outside of urban centers. Furthermore, waste paper is not always easily separatad from nonfiber contaminants. Eliminating contaminants is often laborious and inconvenient and is frequently not fully accomplished. Contaminant problems arise in part from lack of coordination among the industries making, using, and recycling paper. Cooperation among them could be benificial and could greatly reduce obstacles to recycling. If paper converters used water soluble inks and glues, for example, subsequent recycling would be easier.

Municipal burning of wastepaper for energy has been singled out by the paper manufacturers as potentially competitive. According to industry estimates, waste paper burned for energy production could increase from less than a million tons in 1980 to nearly 9 million tons in 2000. For this reason, the industry is concerned that municipal efforts to address solid waste disposal problems through waste-to-energy systems could create supply problems for paper recyclers.

*Franklin Associates, Ltd., *Waste Paper: The Future of a Resource 1980-2000*, report to the Solid Waste Council of the Paper Industry (New York: American Paper Institute, 1982).

been widely accepted in Canada where it was first introduced. Several waferboard plants now operate in the United States, most of which are in the Great Lakes States and New England.[50]

Product Recovery in the Solid Wood Products Sector

From roundwood, the solid wood products sector produces a variety of goods, including dimension lumber, plywood, laminated lumber, molding, and furniture stock. Leftover materials generally are shipped to pulpmills and particleboard plants or turned into other composite materials. Remaining materials, such as bark and sawdust, are burned as fuel, so virtually all of the roundwood—more than 95 percent—is used in some way.

Improving Yields in Lumber Manufacture

Lumber products include dimension lumber, boards, finish lumber, and timbers. Of all lumber and panel products produced in the United States in 1979, almost 70 percent (by weight) was lumber.[51] Available technologies

[50]Initial waferboard plants were established in the Great Lake States; subsequently, several others were established in New England. Trends are discussed in Lloyd C. Irland, *Wildlands and Woodlots: The Story of New England Forests* (Hanover and London: University Press of New England, 1982), p. 160; and Henry M. Montrey, III, *Current Status and Future of Structural Panels in the Wood Products Industry*, M.S. thesis, Massachusetts Institute of Technology, June 1982, pp. 110-115.

[51]U.S. Department of Agriculture, Forest Service, *U.S. Timber Production, Trade, Consumption, and Price Statistics, 1950-1980*, miscellaneous publication No. 1408 (Washington, D. C.: U.S. Government Printing Office, 1981), p. 10.

Photo credit: U.S. Forest Service

A variety of solid wood products are now used, but lumber continues to be the largest use by weight

could increase lumber yields per unit of roundwood, but these technologies would reduce the wood left over for nonlumber wood products.

About 40 percent of a log entering a typical sawmill is converted into dimension lumber. Most of the rest becomes sawdust, shavings, and edging used to manufacture particleboard, fiberboard, and paper or is used for fuel. With new technologies and processes, lumber recovery in mills could reach between 60 and 88 percent for medium-sized logs.[52] Material tradeoffs are important, however, in balancing lumber recovery efficiency with the production of other goods and energy,

Several processes could increase lumber recovery without major sawmill modifications:

- The best opening face process produces higher grades and increases recovery of lumber through computer-assisted selection of sawlines during milling. Laboratory tests indicate that this process could increase lumber yields by 20 percent and some in-service tests have confirmed this,
- The saw-dry-rip process enables fuller use of hardwoods by reducing their tendency to warp and deform and also permits use

[52] Jerome Saeman, "Solving Resource and Environment Problems by More Efficient Utilization of Timber, " in *The Report of the President's Advisory Panel on Timber and the Environment* (Washington, D. C.: U.S. Government Printing Office, April 1973), app. F, p. 361.

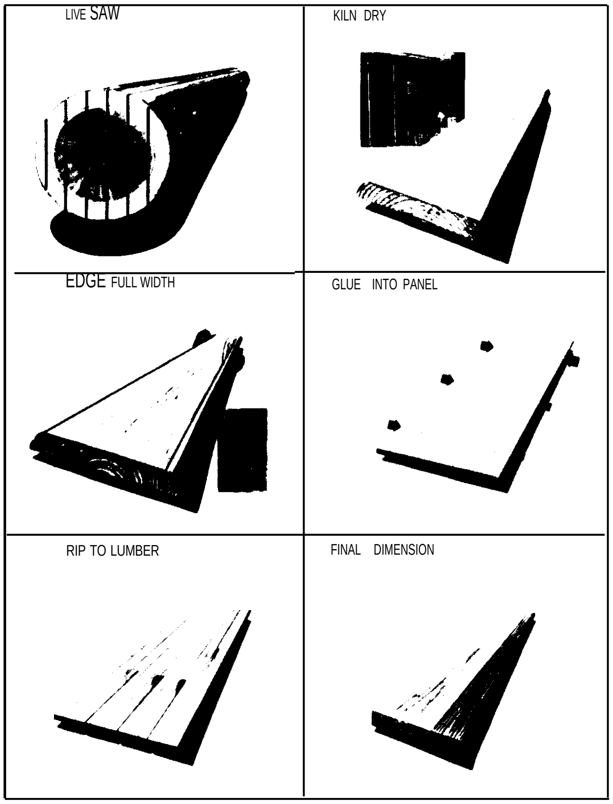

Photo *credit: U.S. Forest Service*

The Saw-Dry-Rip process enables fuller utilization of logs, particularly hardwoods

of defective timber and wood residues that were once considered unmerchantable.

- The **edge-glue and rip process** is an innovative sawing and gluing technique which reduces wood loss and permits use of low-quality raw materials to produce high-quality lumber-like products.

Other available processes could improve product recovery, but would require costly investment by mill owners. Technologies for composite products, such as Parallel-Laminated Veneer (PLV) and Corn-Ply, can produce high-quality, lumber-like products from low-quality materials and hardwoods. The dimensions of PLV and Corn-Ply products are not limited by log size and can produce stronger lumber than conventional manufacturing.

Despite the advantages, the substitution of composites for dimension lumber may proceed slowly. Composite lumber manufacture requires expensive equipment, which therefore

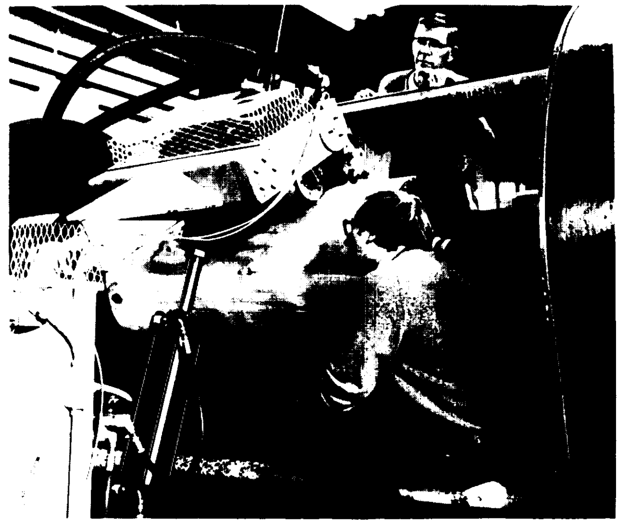

Photo credit: U.S. Forest Service

The power backup roller can improve veneer log yields in plywood manufacture

is more likely to be installed in new mills than retrofitted in old ones. As existing sawmills are depreciated, PLV facilities may be built as replacements, particularly if stumpage values increase and building codes are modified to permit the use of PLV lumber.

Potential Improvements in Plywood Manufacture

At present, plywood recovery runs between 47 and 53 percent.[53] Less than 1 percent of all roundwood used in plywood manufacture is waste, because residues from plywood mills are used for lumber, particleboard, pulp, paper, fiberboard, and fuel.

Mills now accept smaller logs than in the past, and there is an increasing effort to use hardwood for structural plywood. Many innovations in structural panel manufacturing have focused on expanded use of hardwoods and lower grade wood.

Currently, 25 percent of the veneer logs brought in from the forests are considered unsuitable for peeling .54 Because of the high value

[53] Kidder, Peabody & CO., Inc., *A Critical Issue Report: Com-Ply Waferboard, Oriented Strand Board: Revolution in the Structural Panel Market* (Kidder, Peabody & Co., Dec. 24, 1980), p. 14.

[54] Frank J. Fronczek, "Preventing Veneer Bolt Spinout," reprinted from *Modern Plywood Techniques,* proceedings of the Seventh Plywood Clinic, Portland, Oreg., 1979, p. 22.

of veneer logs, reducing the amount of unusable material can improve the productivity and profitability of the mill, and some promising technologies for accomplishing this have been developed.

Product Recovery by the Pulp and Paper Sector

The increased cost of energy, the rising cost of both roundwood and sawmill residues, market emphasis on printability and other nonstrength factors, and the abundance of less expensive hardwood timber have all prompted the pulp and paper sector to consider more energy-efficient and materials-efficient manufacturing technologies. Now pulp and paper manufacturers are turning out higher quality pulps that require less wood per ton of pulp produced.

In 1978, the pulp and paper sector consumed approximately 77 million short tons of ovendry pulpwood. Forty-four percent came from chips and sawmill residues. About 26 percent was hardwood. Trends in wood use in the past 40 years have moved toward the increased utilization of hardwood species and increased reliance on chips and sawmill residues. In addition to mill residues and chips, pulp and paper manufacturers used approximately 15 million short tons of recycled waste paper for pulp and paper production.[55]

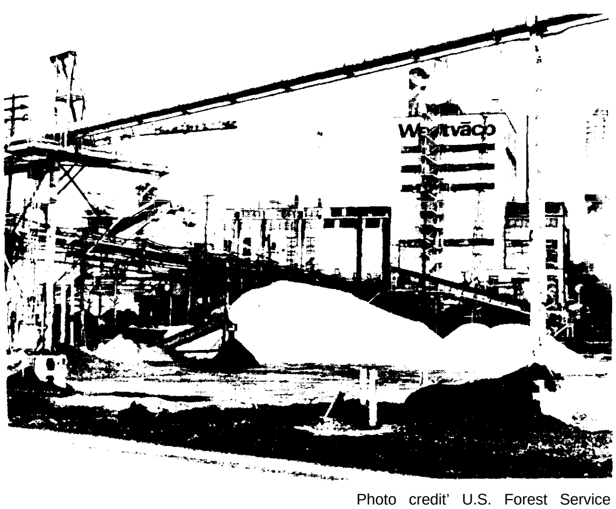

Photo credit' U.S. Forest Service

Modern papermills can achieve fuller wood utilization and decreased requirements for purchased energy

More widespread adoption of mechanical pulping technologies could further reduce fiber requirements, For example, it takes an estimated 2.5 short tons of wood to produce 1 ton of paper through the kraft chemical pulping process. Only 1,05 short tons of wood is required to produce 1 ton of paper in thermomechanical pulping. With this potential reduction, each 2-percent increase in pulping capacity would require only a 1.7-percent increase in wood fiber.[58]

While incremental improvements in current processes may be important in raising the efficiency of existing mills, the greatest potential for dramatic advances in pulp and paper manufacture lies in new technologies. Such innovations could enable the use of large quantities of currently underutilized hardwood species and may even present prospects for developing superior new papers for specialized needs. At the same time, new concepts in energy use and cogeneration could achieve new levels of energy efficiency, thus freeing up additional fiber for paper.

Press-drying technology, developed at the U.S. Forest Products Laboratory, holds promise both for reducing the amount of energy required in papermaking and for enabling the use of dense hardwood species, such as sweetgum and red oak, which are not currently used in large quantities for pulp. Press-drying uses high-yield hardwood or softwood kraft pulp to produce linerboard with strength superior to conventional softwood kraft paper in every respect except tear strength. At the same time, press-drying can reduce the amount of energy needed in the drying process by applying pressure to the fiber (pulp) mat as it is dried, in contrast to conventional drying that applies pressure and heat separately.

[55] Joan E. Huber, *The Kline Guide to the Paper Industry* (Fairfield, N. J.: Charles H. Kline & Co., 1980), pp. 66-67.

[56] G. Styon, "Impact of North American Timber Supply on Innovations in Paper Technology, " *Paper Trade Journal,* May 30, 1980, p. 28.

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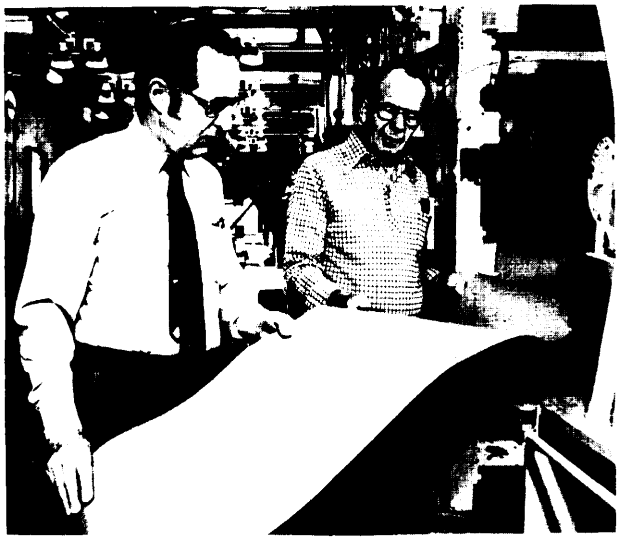

Photo credit: U.S. Forest Service

USDA Forest Products Laboratory scientists have developed a prototype press-dried paper technology

Paper produced from press-drying kraft red oak pulp has been shown to have a burst and tensile strength approximately 13 percent greater than conventionally dried pine kraft paper. Compression strength of the press-dried red oak paper was 50 percent better than the pine. The lower tear strength of press-dried hardwood paper may limit its use for wrapping or sack paper; however, its higher burst and tensile strength make it suitable for linerboard.

An estimated 19 percent in net energy savings could be gained from the use of press-drying technology.[57] press-drying also may reduce equipment requirements in both the drying section and the pulping process because of its capability for using unrefined pulp although this is uncertain because a commercial-scale press-dry paper machine has not yet been built and operated.[58] The major limitation of press-drying to be overcome before the technology can be used commercially, is the low speed of the Forest Products Laboratory's pilot-scale paper machine and the resulting slow production rate.

Decreasing Energy Requirements

The forest products industry now burns about half the wood entering its mills to meet internal energy needs. Generally, only low-value wastes and residues are used for fuel, but some residues now used for fuel could be utilized instead in the manufacture of products. Development of energy-efficient wood processing systems could improve the balance between wood energy and fiber recovery.

The major long-term opportunities for energy savings are in the energy-intensive pulp and paper sector. Pulp and paper producers consume about 7 percent of U.S. industrial energy and about 3 percent of the total energy consumed nationwide. 'g About half of the sector's energy requirements currently are met internally by burning wood residues, pulping liquors, and other waste products,

In the near term, the best prospects for reducing the pulp and paper sector's energy requirements may be through increasing the use of mechanical pulping, which uses less energy than chemical pulping methods and recovers a higher proportion of the fiber. Another way may be through expanding the use of recycled paper.

Over the long term, commercialization of some experimental pulping technologies, could help the industry reduce energy needs. One experimental process, an organic solvent extraction process called Organosolv, may permit the industry to become a net energy producer in the future. The Organosolv process also may be capable of using hardwood species and obtaining high fiber yields with little sacrifice in product strength. The process is still in the developmental stage, but it may be commercially available in 25 years or so.

There are also opportunities for the more efficient use of wood fuels in the solid wood products sector. In plywood manufacturing, higher fuel costs have prompted increased interest in the improvement of veneer drying,

[57] V. Setterholm and Peter Ince, "The Press-Drying Concept for Papermaking," *Southern Lumberman,* December 1980.
[58] P. J. Ince, "FPL Press Drying Process: Wood Savings in Linerboard Manufacture, " *TAPPI,* vol. 64, 1981, p. 109,

[59] Total U.S. energy consumption in 1981 was 74.1 quadrillion (Quads] Btu of energy.

recycling waste heat, and heat conservation. Use of mill residue, wood dust, and bark for power generation is a common practice in many plywood mills. One manufacturer reports replacement of propane with plywood trimmings and scrap in two dryers at a savings of over 70 percent in fuel costs. Another manufacturer is converting almost all of its wood sanding dust to energy, producing 40 million Btu per hour in auxiliary power,

Veneer drying accounts for 70 percent of the process steam needs of plywood manufacturers. Improved drying processes, aimed at reducing energy consumption and increasing operating speeds, are being developed. One such process, platen drying, increases recovery by 5 to 15 percent, shortens drying time, reduces the need for additional drying, and reduces process steam needs by up to 50 percent.

In lumber production, up to 90 percent of the heat energy consumed in processing is for drying lumber, usually in a steam kiln that circulates air. Kilns may use natural gas or propane directly or, more often, are heated by steam coils. Several new drying technologies, including continuous feed solar, vacuum, and vapor recompression drying, may gain some commercial acceptance by 2000, although none seems likely to completely replace conventional steam kilns.[60]

Increased Efficiency of Wood Products in End Use

Design improvements in construction offer a significant chance to increase efficiency in wood use. Current techniques could reduce substantially the quantity of wood used for home construction, particularly in single-family detached dwellings, without reducing the quality of the structure. Two developments are particularly noteworthy—truss framing and engineered panel assemblies that combine sheathing and framing. The use of trusses is becoming more common for roof and floor systems. Truss framing uses single trusses to frame floors, walls, ceilings, and roofs together. Some analysts estimate that it could achieve as much as 30-percent reduction in lumber use over conventional construction practices, Engineered panel assemblies or stressed-skin panels used for floors, walls or ceilings which combine sheathing and framing in sandwich panels, may also conserve wood. Such assemblies are factory—built, as are trusses, and their use could reduce the wood wastes on construction sites from cutting and custom fitting, while still providing structural strength and stiffness,[61]

Since lumber production is linked closely to the housing industry, an upturn in homebuilding could drive softwood log prices up, thus increasing the incentives for lumber manufacturers to streamline operations and increase product yields to remain competitive. Low rates of residential construction could force many small lumber mills out of business, thus concentrating production in the larger mills that tend to be more efficient, Other developments in the homebuilding industry could also affect the lumber sector, such as moves toward smaller houses and multifamily dwellings.

In the pulp and paper sector, increased paper recycling could reduce demands on the resource base (see box E). Approximately one-fourth of the paper pulp produced each year is from recycled paper, with the practical upper limit for using recycled fiber in the pulp mix increasing as new technologies are developed. The suitability and use of recycled fiber for current paper products varies significantly. Some products [i.e., bleached paperboard) are made with little or no recycled fiber, but in some others one-third or more of the fiber requirement come from recycled materials (table 21). In Europe, paper suitable for many uses is produced from pulp containing as much as $10 percent recycled fiber. However, the potential for further increases in recycled paper use must be weighed against two barriers—the expense of removing glue, ink, and other materials that normally are present in

[60] Tillman, Rossi, and Simmons, *Wood: Its Present and Potential Uses,* op. cit., p. 3-25.

61 Trends in wood utilization in construction are discussed in University of Wisconsin Extension, Environmental Awareness Center, *Housing and Wood Products Assessment* (OTA contract report, Dec. 10, 1982).

Table 21.–Utilization of Waste Paper by Sector and Major Grade Category, 1980

Industry/grade category	Total production	Quantity of waste paper used in production	Utilization rate[a]
Paper:			
Newsprint	4,672	898	19.2
Tissue	4,375	1,698	38.8
Other grades	21,144	1,125	5.3
Subtotal	30,191	3,721	12.3
Paperboard:			
Unbleached kraft	15,295	912	6.0
Semichemical	4,724	1,206	25.5
Recycled	7,071	7,710	109.0
Bleached	3,862	2	0
Subtotal	30,952	9,830	31.8
Construction	2,558	1,543	60.3
Grand total	63,701	15,094	23.7

[a]Ratio of the weight of waste paper used in production to the weight of the new paper produced

SOURCE Franklin Associates, *Waste Paper, The Future of a Resource 19802000 (New* York American Paper Institute, 1982), p 22

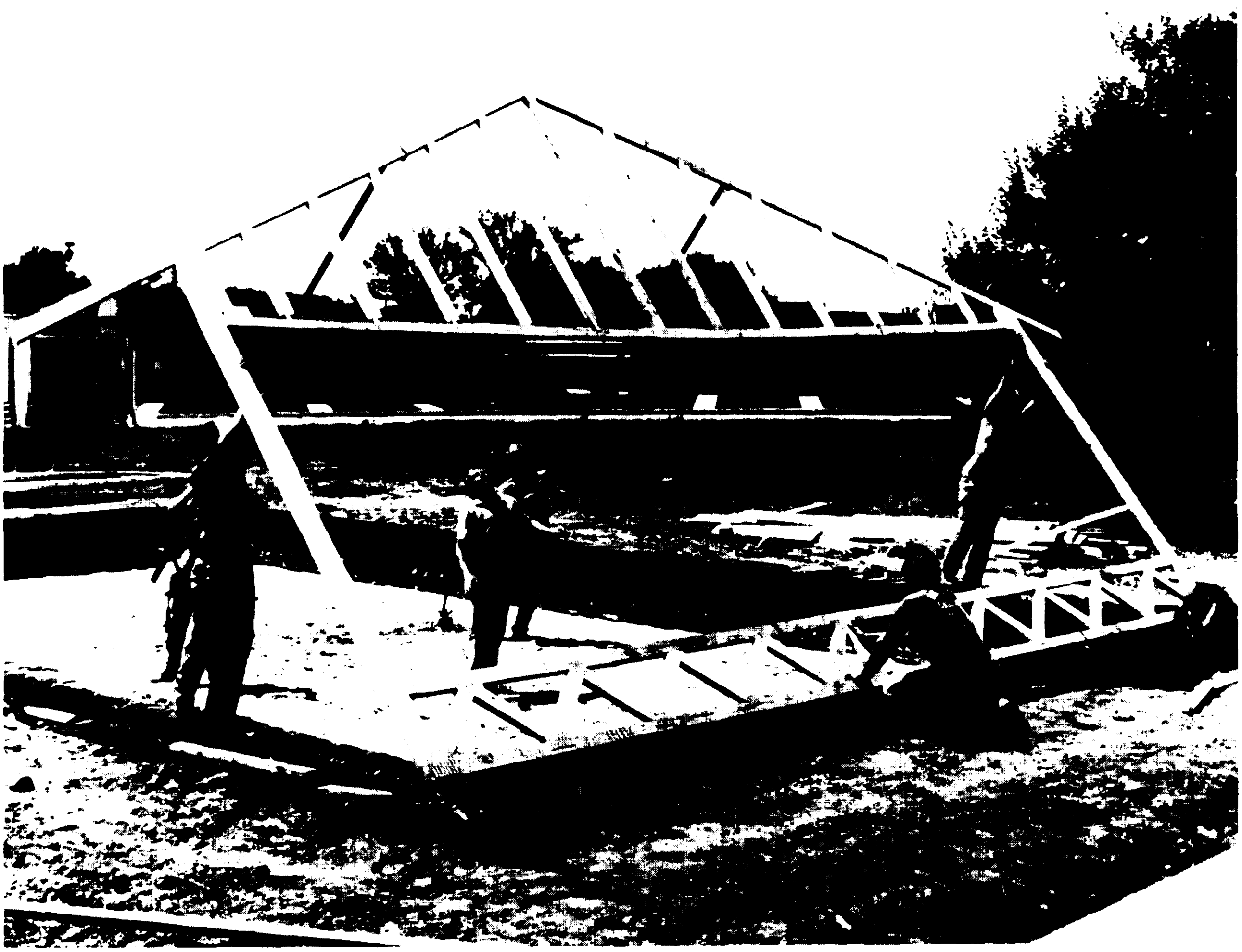

Photo *credit: US. Forest Service*

Truss framing can significantly reduce lumber requirements in light frame construction waste paper and the economics of collection and transportation that limit recycling primarily to metropolitan areas. Recycling reduces the energy requirements of papermaking significantly. It also reduces municipal solid waste disposal problems.[62 63]

The efficiency of residential and commercial fuelwood burners is another area where significant advances could be made. Approximately one-third of the wood fuel burned in the United States is for home heating.[64] This is about equal to the amount of wood that ends up in paper and paperboard products each year when wood fuel consumption by the forest products industry is subtracted. Firms outside the forest products industry that use fuelwood commercially now constitute a small but very rapidly growing group. The potential for residential/commercial fuelwood demands to conflict with forest industry demands for roundwood may be lessened by more efficient woodstoves, boilers, and furnances.

The number of efficient small capacity burners—stoves in particular—are growing steadily. Many improvements, such as more air-tight designs, have increased burning efficiency by an estimated 1.5 percent annually.[65] Technologies capable of even more efficient wood combustion also may reduce air pollution emissions. One example is wood burning stoves with catalytic converters. As the demand for wood burning devices spreads, further improvements in efficiency, wood handling, and fuel uniformity may follow.

[62] W. E. Franklin, *Paper Recycling: The Impacts of Contaminants. 1973-1985, Summary and Overview* (Kansas City, Mo.: Midwest Research Institute, 1975).

[63] P. Sizifert, R. Sector, and P, C rirea, "Waste Paper Pulping With Maximum Energy," *TAPPI*, vol. 59, 1981, pp. 111-113,

[64] U.S. Department of Energy, *Estimates of U.S. Wood Energy Consumption From 1949 to* 1981 (Washington, D, C.: U.S. Government Printing Office), p. 74,

[65] As cited in Applied Management Sciences, *Methodology for Residential Wood Energy Consumption, Letter Report No. 2: Recommended Methodology* (Silver Spring, Md.: Applied Management Sciences, June 30, 1981).