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CHAPTER 10. OPPORTUNITIES TO CHANGE TIMBER DEMAND THROUGH ALTERED TIMBER UTILIZATION

Opportunities to meet rising demands for timber products by increasing net annual timber growth are discussed in the preceding chapter. Utilization improvements can also aid in meeting rising demands by increasing the efficiency of harvesting, processing, and end use of wood and fiber products. But utilization improvements may also increase demand for timber by reducing wood product cost relative to the cost of nonwood products or by developing new products or end uses. These improvements, in general, increase the economic contribution wood-using industries can make to the economy when using a limited timber base.

This chapter discusses opportunities for utilization improvement that will (1) increase efficiency of wood use, (2) reduce the cost of wood products and the cost of using wood in applications, and (3) provide new or improved wood products or wood use applications. A key purpose here is to propose and explain technology-influenced projections of (1) costs for harvesting, softwood lumber processing, plywood processing, nonveneered structural panel processing, and paper/paperboard processing; and (2) product recovery factors for softwood lumber, panels, and paper/paperboard. Projections of processing costs and product recovery are shown in Chapter 6. These projections are used in the various projection systems to project timber consumption and prices shown in Chapter 7. In this chapter, the first section reviews recent trends in improving wood utilization technology. The second discusses and projects the impact of prospective improvements in wood utilization. These technology projections are used in the base timber market projections discussed in Chapter 7. The third section discusses and evaluates the role of research in changing wood utilization technology.

RECENT TRENDS IN IMPROVING WOOD UTILIZATION

Improvements in Timber Stand Utilization

In recent years there has been substantial improvement toward greater utilization of all timber on a harvest site and greater utilization of sources other than growing stock (table 76). This greater utilization of growing stock[43] has been aided by improvements in harvesting, use of a broader range of wood quality in products, and new products that can be made from timber sources other than growing stock. Use of other sources of timber other than growing stock sources has also improved with greater use of whole tree chipping, integrated harvesting, and increases in fuelwood harvesting. Despite the considerable improvement in use of growing stock and other timber sources for products, logging residue left on sites (including growing stock and other logging residue sources[44]) is still one-quarter as large as the amount of roundwood removed. Opportunities for increased utilization of timber on harvest sites still exist.

Improvements in Product Recovery from Roundwood and Residue

Improvement in utilization of timber sources has been accompanied by improvement in product recovery from roundwood and from residue. Between 1952 and 1976 the residue left unused at mills declined from 13% to 4% and declined to 2% in 1986. By 1986 virtually all roundwood was made into products or converted to energy. The percentage of roundwood and mill residue converted to solid products or delivered to pulpmills increased from 68% to 90% between 1952 and 1976 due to increased sawmill and plywood/veneer mill product recoverv, and increased use of mill residue for pulp, and panels. But the proportion declined to 88% in 1986 partially as a consequence of increased demand for fuelwood.

There are three trends that explain the improvement in roundwood conversion. First, product recovery has improved for lumber and plywood processing. Second, products with higher average recovery have replaced those with lower recovery. That is, plywood has replaced lumber in many uses, nonveneered panels are challenging plywood in structural uses, and composite lumber products are replacing lumber in selected applications, Third, there has been progressively more complete use of mill residue for composite products and pulpwood,

The relative importance of recovery improvements is greater for processes that consume more wood material. Sawmills and pulpmills process roughly the same amount of wood material—7. 1 and 7.6 billion cubic feet in 1986 (fig. 77, table 129). Pulpmill furnish includes both roundwood and mill residue. Sawmill input is 24% hardwood. Homes and industries burn 4.5 billion cubic feet of wood for energy. Plywood and veneer mills process 22% as much as sawmills. Their input is 7% hardwood. Particleboard mills, oriented strand board/wafer board mills and miscellaneous industries use about 16% as much wood as sawmills, much of which is residue.

The degree of improvement in these process categories is suggested by specific statistics. Many sawmill studies have shown improved lumber recovery factors (LRF). For example, in the Pacific Northwest-West softwood LRF is estimated to have improved from 6.67 to 7.87 board feet per cubic foot between 1952 and 1985 (table 88), Table 129 suggests that in 1986 sawmills required 2.36 cubic feet of timber to be harvested for each cubic foot

[43] *Other sources includes salvable dead trees, rough and rotten cull trees, trees of noncommercial species, trees less than 5 inches dbh, tops and roundwood harvested from non forest land (e.g., fence rows).*

[44] *Other logging residue sources include material sound enough to chip from downed dead and cull trees, tops above the 4-inch growing stock top and trees smaller than 5 inches. It excludes stumps and limbs.*

of lumber produced—an overall conversion efficiency of 42%. In preparing projections of timber consumption and prices in Chapter 7, the TAMM model used an estimate of 2.04 cubic feet of timber for each cubic foot of lumber produced—an overall conversion efficiency of 49%. The 49% estimate is more in line with estimated sawn wood conversion efficiencies for Canada and European countries (UNECE/FAO 1987).

Softwood plywood recovery factor in the Pacific Northwest-West is estimated to have improved from 12.5 to 14.5 square feet (3/8 inch basis) per cubic foot between 1952 and 1985 (table 89). Table 129 and estimates used in the TAMM model indicate that in 1986 softwood and hardwood plywood/veneer mills converted 50% of veneer log volume to plywood or veneer. Of all roundwood going into lumber and plywood/veneer production the proportion going into plywood production increased from 5% in 1952 to 19% in 1976 and then declined to 18% in 1986.

Nonveneered structural panel production, which currently recovers 55% to 60% of wood input, has grown from 0.8% of structural panel production in 1976 to 15% in 1986. Not only do nonveneered structural panels recover more of wood input, they use a larger proportion of more abundant hardwoods and smaller diameter logs than the average logs required to make lumber or plywood.

This is only a partial list of the process and product trends that are improving the proportion of wood input that ends up in solid-wood products. There are also improvements that increase the quality of lumber and panels from given timber or retain quality when using lower cost timber.

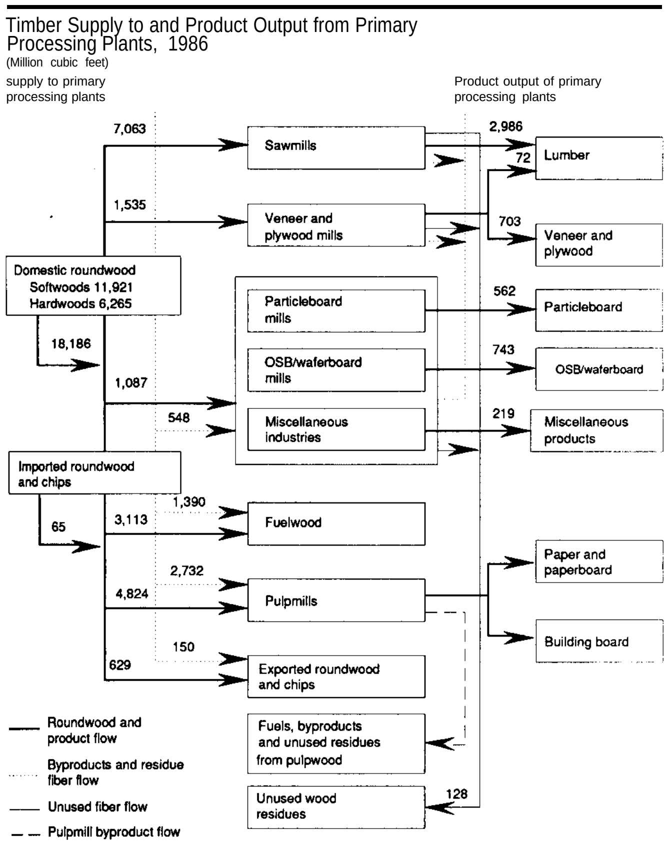


Figure 77.—Timber supply to, and product output from primary processing plants, 1986.

The use of wood (both hardwoods and softwoods) in making all paper, paperboard and related products increased from 1.08 to 1.21 cords per ton of paper between 1952 and 1986. This overall trend masks four important underlying trends. First, use of pulpwood per ton of paper and board has increased largely because of greater use of woodpulp and less use of waste paper attendant with the production of a greater proportion of high strength and lightweight paper and board products. Between 1952 and 1986 woodpulp use per ton of paper and board increased 14% and wastepaper use decreased 36% (table 91). Second, pulpwood use per ton of pulp actually declined between 1952 and 1986 from 1.6 cords to 1.5 cords. Third, use of mill residue as part of the pulpwood mix has increased from 25% in 1962 to 36% in 1986. Fourth, the proportion of hardwood in the pulpwood mix has increased from 14% in 1952 to 25% in 1976 and 31% in 1986. The shift to hardwoods has occurred because of technology developments allowing greater use of shorter hardwood fibers.

Changes in the End Use of Wood Products

Improvements in recovery of products from roundwood and residue have been accompanied by improvements in the efficiency of wood use in construction, manufacturing and shipping, as well as development of new wood products or applications for wood that have replaced nonwood products (Bowyer et al. 1987). Examples of end-use efficiency improvements include prefabricated roof trusses which save up to 30% of wood requirements over conventional roof systems. Roof trusses have expanded from less than 1% of residential roofing in 1952 to 77% in 1976 and more than 90% in 1986. Long spans are possible and reduce the need for interior load bearing walls, costs can be held down on assembly lines in manufacturing plants, and erection time is reduced at construction sites. An example of one wooden product being used to replace another wooden product has been the use of medium density hardboard siding in place of softwood lumber. This product has also replaced plywood and aluminum siding. The market share of hardboard siding peaked in 1983 at 31% and has declined to 25% in 1985. Finally, vinyl siding is an example of a nonwood product competing with a wood product. Vinyl siding was first introduced in 1957 but did not exceed 1% of the siding production until 1963. By 1985, improvements in quality, particularly regarding the fading of the finish, and reduction in cost increased its market share to 16% of siding production.

An example of a new use for wood has been the development and use of residential wood foundations. Since the building of a number of demonstration homes in 1969–71 the number of new homes using wood foundations increased to about 20,000 per year in 1984 or about 1% of new homes.

Table 129.—Source and utilization of roundwood in primary processing plants in the United States, by softwoods and hardwoods, 1988.

Product	Total	Residue[1] from solid products	Sawlogs	Veneer bolts and logs	Pulpwood, roundwood and whole-tree chips	Pulpwood chip imports	Miscella-neous industrial	Fuelwood
	Million cubic feet, solid-wood basis, excluding bark							
Supply to primary processing plants								
Roundwood products from U.S. forests								
Softwoods	11,921	—	5,980	1,433	3,095	—	868	545
Hardwoods	6,265	—	1,668	127	1,683	—	219	2,568
Total	18,186	—	7,648	1,560	4,7786	—	1,087	3,113
Imported roundwood and chips								
Softwoods	58	—	10	0	12	36	—	—
Hardwoods	7	—	0	5	2	1	—	—
Total	65	—	10	5	14	37[2]	—	—
Exported roundwood								
Softwoods	599	—	595	0	4	—	—	—
Hardwoods	30	—	0	30	0	—	—	—
Total	629	—	595	30	4	—	—	—
Total supply to domestic mills								
Softwoods	11,380	—	5,395	1,433	3,103	36	868	545
Hardwoods	6,242	—	1,668	102	1,685	1	219	2,568
Total	17,622	—	7,063	1,535	4,788	37	1,087	3,113
Output from primary processing plants								
Lumber								
Softwoods	2,238	—	2,167[3]	72[4]	—	—	—	—
Hardwoods	819	—	819[5]	0	—	—	—	—
Total	3,038	—	2,986	72	—	—	—	—
Plywood and veneer								
Softwoods	677	—	—	677[6]	—	—	—	—
Hardwoods	26	—	—	26[6]	—	—	—	—
Total	703	—	—	703	—	—	—	—
Pulpwood delivered to U.S. mills								
Softwoods	5,408	2,270[8]	NA	NA	3,103	36	NA	—
Hardwoods	2,147	462[9]	NA	NA	1,685	1	NA	—
Total	7,556	2,732	NA	NA	4,788	37	NA	—
Pulpwood chip exports								
Softwoods	150	150	150	—	—	—	—	—
Hardwoods	0	0	0	—	—	—	—	—
Total	150	150	150	—	—	—	—	—
Particleboard and OSB/waferboard								
Softwoods	566[9]	NA	NA	NA	—	—	NA	—
Hardwoods	216	NA	NA	NA	—	—	NA	—
Total	781[10]	NA	NA	NA	—	—	NA	—
Miscellaneous industrial								
Softwoods	618	NA	NA	NA	—	—	NA	—
Hardwoods	125	NA	NA	NA	—	—	NA	—
Total	743	NA	NA	NA	—	—	NA	—
Total particleboard, OSB/waferboard and miscellaneous industrial								
Softwoods	1,183	396[7]	NA	NA	—	—	787	—
Hardwoods	343	151[8]	NA	NA	—	—	190	—
Total	1,524	548	NA	NA	—	—	976	—
Fuelwood								
Softwoods	1,648	1,103[7]	NA	NA	—	—	NA	545
Hardwoods	2,855	287[8]	NA	NA	—	—	NA	2,568
Total	4,503	1,390	NA	NA	—	—	NA	3,113
Total of all products								
Softwoods	11,305	—	NA	NA	3,103	36	NA	545
Hardwoods	6,189	—	NA	NA	1,685	1	NA	2,568
Total	17,494	—	NA	NA	4,788	37	NA	3,113

Table 129.—Continued.

Product	Total	Residue[1] from solid products	Sawlogs	Veneer bolts and logs	Pulpwood, round wood and whole-tree chips	Pulpwood chip imports	Miscella-neous industrial	Fuelwood
Unused manufacturing residues								
Softwoods	75	75[7]	NA	NA	0	0	NA	—
Hardwoods	54	54[8]	NA	NA	0	0	NA	—
Total	128	128	NA	NA	0	0	NA	—
Total output								
Softwoods	11,380	—	5,395	1,433	3,103	38	868	545
Hardwoods	6,242	—	1,668	102	1,685	1	219	2,568
Total	17,622	—	7,063	1,535	4,788	37	1,087	3,113

NA—indicates detailed data on residue or roundwood use for this column is not available.

[1]The residue column shows total residue used in a product which came from sawmills, veneer/plywood mills or miscellaneous industries, except that for particleboard, OSB/waferboard and miscellaneous industrial products this column is total residue from sawmills and veneer/plywood mills only. The sawlog column contains residue from sawmills except for the lumber products row where it contains roundwood contents in lumber. The veneer log column contains residue from veneer/plywood mills except for the plywood/veneer product row where it contains roundwood contents in plywood/veneer. The miscellaneous industrial column contains residue from miscellaneous industrial mills except for the particleboard, OSB/waferboard, and miscellaneous industrial products rows were it contains amounts of roundwood contained in byproducts.

[2]Total roundwood and chip imports (630,000) times 79.2 cubic feet Per cord.

[3]Lumber volume in 1,000 board feet times 64.50 cubic feet per 1,000 board feet.

[4]Lumber volume from cores of peeled veneer logs is estimated at 5% of veneer log volume.

[5]Lumber volume in 1,000 board feet times 79.47 cubic feet per 1,000 board feet.

[6]Plywood/veneer volume in 1,000 square feet 3/8-inch basis times 31.25 cubic feet per 1,000 square feet.

[7]Residue use in bone dry tons times (2,000 pounds/27.35 pounds per cubic foot).

[8]Residue use in bone dry tons times (2,000 pounds/34.34 pounds per cubic foot).

[9]Softwood furnish estimated at 72.4% of total.

[10]Volume of particleboard and OSB/waferboard in 1,000 square feet 3/4-inch basis times 62.5 cubic feet per 1,000 square feet.

Note: Numbers may not add to totals due to rounding.

Sources: Roundwood products from U.S. Forests: Waddell et al. 1989: table 30. Imported and exported sawlogs and veneer logs and pulpwood chip exports: USDA FS 1988e: tables 4-7. Imported and exported roundwood and whole tree chips: USDA FS 1988e: tables 5, 6, and 27. Residues from solid wood products for making pulp products, fuelwood, and other products (particleboard, OSB/waferboard and miscellaneous industrial): Waddell et al. 1989: table 31.

PROSPECTIVE IMPROVEMENTS IN WOOD UTILIZATION TECHNOLOGY

There are at least three techniques and associated rationales to use in preparing forecasts of technological capabilities (Bright 1978): (1) extrapolate trends—assume a steady pace of technological change; (2) project change based on change in technological determinants; and (3) project change based on identifying emerging innovations, their capabilities and possible pace of adoption—assuming a certain pace of adoption for promising innovations. The evaluation method here rests primarily on the third technique and to a lesser degree on the second technique.

Technological innovations will change the competitiveness of wood sources and products by (1) increasing the recovery and decreasing costs for making lumber, panels, paper and paperboard; (2) developing processes/products that expand the use of underutilized species, mill residue and residue left on harvest sites; (3) decreasing the cost of harvesting; (4) increasing the efficiency of end use of wood products; and (5) developing new/improved products and end-use application methods to expand markets for wood, This section identifies many of these technological developments and focuses on projecting costs and/or product recovery for harvesting operations, lumber processing, plywood and nonveneered structural panel processing, and pulp and paper processing. This section also discusses prospective technological changes in construction and manufacturing and the resultant projections of wood product use rates in various end uses.

The next several subsections present an assessment of the effects of technological change in harvesting and processing of softwood lumber/composite lumber, softwood plywood, nonveneered structural panels and paper/paperboard. Each begins with a discussion of possible technological developments in processing. The assessment includes the following steps: (1) identifying likely changes in technology, (2) formulating current and future mill designs which incorporate innovations and have specific recovery and cost characteristics, (3) developing projections of the mix of mill designs used for production through 2040, and (4) calculating recovery and costs resulting from the projected mix of mill designs.

In addition to the assessment of harvesting and softwood lumber, panel and paper/paperboard processing, we present more general assessments of technology change in hardwood lumber processing, wood use in construction, wood use in manufacturing, and wood use for energy. Included in these assessments are an explanation of the technology assumptions used to make the timber consumption and price projections that are shown in Chapter 7.

Harvesting

Timber harvest and transport includes machines and processes whose application varies widely by region, season, terrain, tree species, tree size, stand density, portion of the stand removed, and distance to market. Timber harvesting involves a wide range of equipment tailored to the unique problems posed by each stand. The characteristics of the harvest system used are determined by the major product of each stand (pulpwood, saw logs, veneer logs, tree length logs, whole trees, or chips), stand and species characteristics, expected weather conditions, and the terrain (flat, mountainous, or swamps). Many stands include several product/terrain combinations. To cover the range of conditions encountered, each timber producing region has developed several distinct sets of equipment and procedures. These "solutions" may not necessarily result from a least-cost calculation but from practical adjustments to the highly seasonal and otherwise unpredictable nature of the business, local labor shortages or surpluses, industry purchase policies, and agency landowner harvest schedules.

In general, for a given harvesting system, costs per unit volume are inversely related to the square of average tree diameter and inversely related to trees per acre. This is because stands are harvested one tree at a time and tree volumes increase with the square of diameter.

Technology Developments

Future timber harvest equipment will closely resemble today's. Tomorrow's logging machines, regardless of improved efficiency, will still have to move over rough surfaces, sever and maneuver heavy trees or logs, and carry them considerable distances in all kinds of weather. Within these constraints, equipment and system designers seek to improve: (1) load capacity, (2) travel and process speed, (3) reliability and longevity, (4) species and product versatility, (5) terrain capability, (6) operator comfort, and (7) safety. Flexibility, rather than maximizing efficiency for a specific kind of stand, is often a more important goal in developing harvest machines and processes.

Table 130 describes specific changes now in development or contemplated for the felling-bunching, skidding-forwarding, processing, loading, and transport functions. These are stimulated by the following problems which current systems do not adequately address:

1. Operating on steep terrain and on sensitive soils;
2. Operating in stands which contain significant portions of unmerchantable species, or multiple products;
3. Operating in low density stands or stands with many small trees;
4. Operating on small tracts required by regulations or fragmented land ownership;
5. Increasingly expensive road construction and long distance hauling; and
6. Improving utilization of branches, tops, bark and previously unmerchantable material.

Other pressures for change include the need to conserve energy and labor and to protect the long-term productivity of forest lands.

There are major opportunities to reduce costs in ground skidding, cable yarding, and log transportation. These functions are the most capital and energy intensive and the most dangerous. Lighter weight machines and engines, improved tires and suspension systems along with much improved fuel efficiency, will reduce costs significantly. As a result of these changes, longer economical skidding or yarding distances will reduce the need for expensive roads.

Current and Projected Harvest System Characteristics

In order to calculate current and projected harvesting and transport cost per thousand board feet for wood harvested in each U.S. region, the production costs were identified for a range of current harvesting systems in each region. These systems are shown in table 131 by the key equipment used. Harvest and transport costs for each system are affected by average tree diameter and volume per acre.

Each harvest system was developed to be close to the "optimum" for the typical diameter/volume/terrain conditions encountered in that region and typical conditions in one region may be extreme conditions in another. Generally, the regional ranking from lowest cost per unit volume to highest is as follows: South, Pacific Northwest-East, Pacific Southwest, Pacific Northwest-West and Rocky Mountains (table 81).

Projected Mix of Harvesting Systems

Substantial shifts in system mix are expected in various regions (table 131), On the flat terrain in the East, and in the North and South, loggers will rely increasingly on mechanized feller-bunching and grapple skidding to central landings for processing and loading. Chainsaw felling is generally being replaced by feller-bunchers in pulpwood operations but will continue to be widely used on saw log and veneer operations to protect valuable butt logs. It is difficult, however, to attract workers to do this hard, dangerous chainsaw work. Grapple skidders are expected to replace most cable skidders by 2040 for safety reasons. Grapple skidders will increase their share of production from 43% to 63% in the South and 5% to 24% in the North. In the South, use of the unique and very labor intensive bobtail truck and farm tractor systems are expected to decline, but will still produce about one-eighth of roundwood output in the South by 2040. These labor intensive systems persist, despite the availability of more efficient equipment, because of a traditional need for off-season farm employment. These systems often produce the least expensive wood, primarily due to the lack of employment altmma-

Table 130.—Technology developments in timber harvesting.

Process	Description	Impact
Felling and bunching		
Lighter weight and/or lower ground pressure machines	For flat terrain, feller-bunchers either smaller, mounted on lighter chassis, or equipped with larger tires, high speed tracks, or air cushions.	Less soil erosion or compaction, maintains productivity, enables harvests on previously "unsuitable" land; fewer roads required.
Walking or self-leveling feller-bunchers or felling-directors	Feller-bunchers able to negotiate slopes over 50%. In larger diameter western stands, more portable machines that direct felling with hydraulic jacks,	Less soil erosion or compaction, maintains productivity, enables harvests on previously "unsuitable" land; fewer roads required.
Multistem carriers attached to feller-bunchers	For smaller diameter stands and plantations, the ability to accumulate several stems before dropping.	Will make plantation management and pole timber thinning economic.
Saw felling heads	In lieu of shears, saw heads eliminate butt splitting.	Improves lumber and veneer recovery from butt log.
Skidding and yarding		
For ground-based skidding and forwarding:		
Lighter weight and/or lower ground pressure machines	Skidders and forwarders, either smaller or mounted on lighter chassis, or equipped with larger tires, high speed tracks, or air cushions.	Less soil erosion or soil compaction, therefore maintaining productivity or enabling harvests on previously "unsuitable" land: fewer roads required.
For aerial cable yarding systems:		
Grapple yarders	Cable yarders that can bunch and grapple by remote control.	Reduces crew size, inefficiency, and danger in hand choker setting
Self releasing chokers or grapples	Load can be released automatically at landing.	Reduces crew size, inefficiency, and danger with hand choker setting.
Synthetic ropes and rigging	Replaces expensive heavy wire cable and massive steel running gear.	Reduces equipment cost, more usable load.
Remote log and tree weight estimation	Enables yarder operator (with or without computer assistance) to judge tree or log weight and thereby plan each load.	Improves system production, safety, and reduces equipment breakage.
Cable tension monitors	Enables yarder to electronically monitor load during retrieval.	Improves system production, safety, and reduces equipment breakage.
More mobile tail block systems	Depending on slope, cable yarding systems require ends of cable system to be moved frequently.	Reduces crew requirements, and increases production.
Cheaper more reliable anchors	Previously, very large stumps were used for cable anchors but these are now seldom available.	Will enable harvests on small timber in steep terrain, extending the area of "suitable" lands.
Smaller systems for smaller timber primarily in the east	Cable yarders for western U.S. conditions are for large logs and long steep slopes. Eastern mountains are less demanding but need cable yarding to avoid soil erosion and residual stand damage caused by partial harvests.	Extends the area of "suitable" land in the east. Reduces need for expensive road construction.

Table 130.—Continued.

Process	Description	Impact
Processing		
Mechanized delimbers	Hardwood sawlogs are expensive and dangerous to delimb. Softwood log form is better and delimbing is less of a problem.	Reduces labor requirements, improves production and safety.
Debarkers	Removing bark on the landing before chipping or hauling.	Reduces hauling cost, increases utilization if clean chips can be produced, leaves more nutrients on site,
Smaller, lighter chippers and/or chunkers	Chips or chunks offer the opportunity to recover vast amounts of wood previously wasted, Chunks are very large chips which require less energy to produce.	Improves utilization, extends timber supply, removes unwanted stocking hindering regeneration.
Merchandisers	Combined chipping/chunking and roundwood processor in the woods that produce and direct species and tree components to their highest value use.	Maximizes return to land. owners, extending area of “suitable” lands,
Transportation		
Log weight estimation	Knowing log weights beforehand can increase average load size without overloading.	Reduces overload fines, equipment breakage, improves safety,
Automatic truck weighing	Sensors installed on each truck reporting actual weight.	Reduces overload fines, equipment breakage, i reproves safety.
Central tire inflation	Compressor and piping on each truck could inflate or deflate tires. Dirt roads last longer when tires have low pressure but highways require high pressure for high speeds.	Extends forest road life.
General developments		
Lightweight machine construction	Development of metal alloys, ceramics, plastic composites for chassis, engine and components will alter machine design, construction and performance.	Lower fuel cost, more power available for useful work, machines can range farther, reducing road requirements, less soil compaction and/or erosion.
Improved fuel economy	New engine designs such as fuel efficient 2-cycle engines, air cooled diesels, gas turbines, and fluidics will decrease fuel consumption and the way power is transmitted for traction or processing.	Lower fuel cost, more power available for useful work.
Improved engine, chassis, suspension, and maintenance	Computer monitoring of machine loading and maintenance needs will increase machine life.	Lower fixed machine costs per unit volume. Lifetime maintenance costs may exceed purchase price.
Ergonomic design (human factor engineering)	Designing machines and their controls to suit the tolerances of humans is a largely untouched but crucial area in harvest equipment design.	Increased production and reduced accidents. Decreased cost for workman’s compensation insurance.
Computer aided systems analysis and operation	On-board computer, as well as off-machine systems analysis and operations research technique can make market sensitive real-time decisions and train employees.	Increased productivity, reduced wood losses or grade reduction, more rapid training.

Table 131.—Proportion of timber harvested by various systems by region in 1985, with projections to 2040.

Section and region	1985	Projections 2000	2010	2020	2030	2040
				Percent		
South—flat terrain						
Roundwood						
Cable skidders	35.0	30.0	25.0	20.0	15.0	10.0
Grapple skidders	43.0	47.0	51.0	55.0	59.0	63.0
Bobtail trucks and farm tractors	17.0	16.0	15.0	14.0	13.0	12.0
Whole tree chippers	5.0	7.0	9.0	11.0	13.0	15.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
North[1]—flat terrain						
Roundwood						
Cable skidders	61.0	50.0	40.0	31.0	22.0	14.0
Grapple skidders	26.0	29.0	33.0	36.0	39.0	41.0
Forwarders	5.0	9.0	13.0	17.0	20.0	24.0
Whole tree chippers	9.0	11.0	14.0	16.0	19.0	21.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
North[1] and South—steep terrain						
Cable yarders	10.0	16.0	22.0	28.0	34.0	40.0
Skidders and forwarders	90.0	84.0	78.0	72.0	66.0	60.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Rocky Mountains[2]						
Tractors—jammers	86.1	83.9	61.7	79.5	77.2	75.0
Cable yarders	13.9	16.1	18.3	20.5	22.8	25.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Pacific Coast						
Pacific Southwest[3]						
Highlead	6.4	6.1	5.8	5.6	5.3	5.0
Skyline—short	23.2	24.0	24.8	25.4	26.2	27.0
—medium	7.4	8.3	9.2	10.2	11.1	12.0
—long	0.0	0.2	0.4	0.6	0.8	1.0
Tractors	63.0	61.4	59.8	58.2	56.6	55.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Pacific Northwest						
Pacific Northwest-West						
Highlead	20.0	18.0	16.0	14.0	12.0	10.0
Skyline—short	37.5	38.0	38.5	39.0	39.5	40.0
—medium	7.5	6.0	8.5	9.0	9.5	10.0
—long	2.5	2.6	2.7	2.8	2.9	3.0
Tractors	32.5	33.4	34.3	35.2	36.1	37.0
Total	100.0	100.0	100.0	100.0	100.0	100.0
Pacific Northwest-East						
Highlead	3.0	3.4	3.8	4.2	4.6	5.0
Skyline—short	12.0	12.6	13.2	13.8	14.4	15.0
—medium	6.0	6.4	6.8	7.2	7.6	8.0
—long	0.0	0.4	0.8	1.2	1.6	2.0
Tractors	79.0	77.2	75.4	73.6	71.8	70.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1]*Includes North Dakota, Nebraska, and Kansas.*
[2]*Excludes North Dakota, Nebraska, and Kansas.*
[3]*Excludes Hawaii.*

tives. In the North, forwarders are expected to expand from about 26% to 41% by 2040 and whole tree chipping is expected to increase from 9% to 21% by 2040.

The East also possesses considerable "mountainous" terrain. About 55%, 6%, 13%, and 11% of the Northeast, North Central, Southeast, and South Central regions, respectively, are considered mountainous. While not as rugged as the Rockies or Pacific Coast, the proximity of a large concerned population, very erodible soils, and generally less productive sites, heighten the need for cost-effective and environmentally sound harvesting equipment and methods. To date, several small scale cable yarding systems adapted from European and West Coast equipment have been applied with some success. We assume cable systems could increase from 10% of the harvest from mountainous terrain to 40% between 1985 and 2040.

On the Pacific Coast the rugged terrain and extremely large trees frequently require expensive and complex cable yarding systems. Despite their cost, these systems are effective in reducing soil erosion. Highlead systems are expected to decline and to be replaced by more versatile skyline systems. Both use portable guyed steel towers but skyline running gear is more complex. Almost all trees are hand felled in the West because of large diameters and steep slopes. Ground skidding using rubber-tired or crawler tractors on less steep slopes is expected to remain about the same in all Pacific regions. Tractors now account for 33%, 79%, and 63% of production in the Pacific Northwest-West, Pacific Northwest-East, and Pacific Southwest subregions, respectively.

In the Rockies, movable skyline systems are widely used but are expected to be replaced somewhat by smaller cable yarders adapted from the Pacific regions.

Generally, shifts in system mix in all regions are expected to be from less efficient to more efficient systems, and from more labor intensive to less labor intensive systems.

Projecting Harvesting Costs as Stand Characteristics and System Mix Change

Four factors were used to make initial harvest cost projections in each region to 2040: (1) the harvest and transport costs for systems used in each region, (2) the proportion of wood harvested with each system (table 131), (3) the average tree diameter and volume per acre, and (4) the assumed rate of productivity improvement for each harvesting system. The initial harvest cost projections were further modified as noted below.

Tables of harvesting costs (for a range of tree diameters and stand volumes) were computed for each region and decade by weighing harvest cost for individual systems by the proportion of wood harvested by that system (table 131). A single average cost was selected from these tables using projected tree diameter and volume per acre for that region and decade.[45] These projections assume that productivity of individual harvesting systems will not increase between 1985 to 2040. They also assume constant wage rates and energy prices. The initial projected harvest costs change only as a result of changes in stand characteristics and system mix (Bradley 1989). The initial projections were modified in certain regions.[46]

45 Tree diameter (DBH) and stand volume per acre Were projected to change as follows between 1985 and 2040:

	DBH	Vol/A
North	+ 2%	+ 45%
South	-7%	+31%
RM	-27%	+26%
PNW-W	-49%	0%
PNW-E	-27%	0%
PSW	-49%	0%

46 For the Rocky Mountain region, initial logging cost growth rates were raised to equal those of the Pacific Northwest-East. This retains the past position of the Rocky Mounains as the highest cost western U.S. region. Environmental limitations on logging are likely to remain at least as stringent in the Rocky Mountains as elsewhere in the West, thus maintaining higher costs. For the South, logging cost growth rates were raised to maintain the current relative regional cost structure—the revised growth rate for the South, overall, is slightly greater than for the Rocky Mountains and Pacific Northwest-East. Higher cost growth rates in the South could result in part from more rapidly rising labor costs than in other regions (Adams 1989).

Based on these assumptions and methods, logging costs are projected to increase at a slower rate than that experienced from 1952 to 1985 in all regions except the South. The rate of increase between 1985 and 2040 is greatest in the South—57% (table 81). The slowest growth is 49% in the Pacific Southwest.

Softwood Lumber and Composite Lumber Processing

Conventional softwood lumber is made by breaking down logs, while composite lumber is made by recombining wood flakes and / or veneer into products which perform like lumber in selected applications. Softwood lumber is made from many species for use in construction and remanufacture. It is made in length multiples of 1 or 2 feet as specified by various grading rules. Width commonly varies from 2 to 16 inches nominal (actual width is less). Lumber is categorized by thickness: boards—less than 2 inches nominal; dimension—2 to just less than 5 inches nominal; and timbers—5 inches or more nominal. Lumber for making products is graded under the American Lumber Standard. Lumber for construction may be stress-graded, nonstress-graded, or appearance-graded. Lumber for remanufacture may be factory (shop) grades; industrial clears; molding, ladder, pole timber, or pencil stock; or structural laminations (USDA FS 1987b).

Conventional lumber processing includes yard handling of logs, bucking, debarking, log breakdown by primary and secondary sawing, planing, drying, grading and preparation for shipping. Timber characteristics that influence the recovery of lumber from roundwood and the processing costs include log diameter, length, shape, and defects. Timber characteristics have less influence on the rate of recovery of composite lumber from roundwood. Hardwood lumber processing is discussed in a later section.

Technology Developments

The softwood lumber industry adopts technological improvements to produce lumber in order to (1) reduce costs of wood, (2) reduce processing costs, and (3) maintain and enhance quality for evolving end uses—all while facing a timber resource that is declining in size and quality. Many improvements seek to reduce wood costs and processing costs in response to competition from lumber imports, decline in timber diameter, lower cost for hardwoods compared to softwoods, and the small but growing proportion of plantation timber which has a higher proportion of juvenile wood. Other technological developments seek to minimize processing costs by reducing the need for costly capital, labor, and energy.

Two general trends in sawmill technology are expected. First, more sawmills will be part of integrated wood processing systems rather than independent profit centers. These systems may include logging, wood merchandising, sawmills, plywood mills, particleboard mills, pulpmills, and wood use for energy. These integrated wood processing systems will work to allocate each tree stem to its most profitable use. Second, equipment within a sawmill will continue to change from a collection of independent machines connected by a material transport system to an electronically integrated collection of machines linked by conveyors. For production of traditional lumber products, techniques that increase wood recovery and thus reduce cost include improved scanning to measure log shape; computer control for optimal log breakdown based on the best-opening-face (BOF) concept to provide improved bucking, primary and secondary breakdown, edging and trimming; thinner saw blades, longer wearing teeth and better saw guides to reduce saw kerf and sawing variation; and more closely controlled drying using improved moisture sensing and removal to reduce energy use and degrade (table 132).

Although we do not evaluate their potential impact here, several new lumber type products can further increase wood recovery. These include laminated veneer lumber, composite lumber, composite wood I-beams and hardwood structural lumber made by the Saw-Dry-Rip

Table 132.—Technological developments in softwood lumber, hardwood structural lumber and composite lumber processing.

Product type and development	Description	Impact
Softwood lumber		
Log and board scanners linked with process optimizers	Improved scanning of log and board shape coupled with increasingly sophisticated computer software and log/board positioning equipment provide improved log bucking, primary breakdown, secondary breakdown, edging and trimming	Improves recovery of lumber
Sawline loss reduction	Kerf can be reduced with thinner saws and sawing variation can be reduced with developments of low expansivity alloys for saw blades, improved saw guides and lower wearing narrower saw teeth.	Improves recovery of lumber
Abrasive planing	Abrasive planing, which removes much less wood than knife planing, can be used more as surface irregularities decrease with use of more stable saws.	Improves recovery of lumber
Improved control of drying	Sensing of temperature drop across the load in all zones of a dryer decreases degrade of pieces.	Holds down cost of drying, improves lumber recovery
Tomography for log defect detection	Experiments indicate computer aided tomography using x-rays can recognize internal log defects which could supply computer programs with information to improve grade recovery of lumber.	Improves recovery of lumber
Hardwood lumber—structural		
Saw-dry-rip processing[1] for hardwood structural lumber	The saw-dry-rip-sequence for processing warp prone medium density hardwoods sharply increases the yield of STUD grade structural hardwood lumber.	Production of structural lumber from plentiful medium density hardwoods
Composite lumber		
Laminated veneer[1] lumber	Wide dimension lumber made from laminated sheets of veneer efficiently uses smaller diameter logs to replace long length larger structural lumber (2 by 8, 10, 12) made from larger diameter logs.	High recovery from smaller logs to make deep dimension structural lumber
Parallel strand[1] lumber	Long strands of veneer residue are used to make deep long structural lumber.	Recovery of veneer residue to make structural lumber
Com-ply lumber[1]	Corn-ply lumber is formed of a flakeboard center with several laminations of veneer at the edges. Hardwood and softwood may both be used with high recovery from smaller logs to make structural lumber for housing.	High recovery and joint use of smaller diameter softwoods and hardwood to make lumber

[1]*The effects of potential expanded use of these processes is not included in the technology projection model or the timber supply/demand projections.*

(SDR) process. Laminated veneer lumber has gained acceptance where uniform strength, greater depth and long-span support is needed. Composite wood I-beams with laminated flanges (top and bottom edges) and plywood or flake board webs (centers) have also gained acceptance where long-span support is needed. Composite lumber for construction has been produced in the form of Corn-ply (lumber with a core made from hardwood and softwood flakes and edges made from veneer) but the prospects for its wide use are not clear. Although there has been little commercial application, structural lumber may be made from medium density hardwoods, such as yellow poplar and cottonwood, using SDR (Maeglin et al. 1981, Maeglin 1985, Allison et al. 1987). The SDR process reduces the tendency of these same species to warp due to growth stresses and it can also be used to reduce warping in lumber made from logs with a high proportion of juvenile wood.

Current and Projected Characteristics of Lumber Processing

A range of sawmill designs that include many of the innovations noted in the previous sections were prepared as part of calculating future lumber recovery factors (LRF) and lumber processing costs (Williston 1987). Mill designs for laminated veneer lumber, composite wood I-beams, composite lumber, or SDR lumber processing were not included. Some designs that were used include considerable improvement over traditional sawmills, including reduction in kerfs and dressing allowance, closer approach to theoretical highest yield (table 133), an increase in log throughput rate and a decrease in labor requirements.

For five regions, mill designs for three mill types at four technology levels were prepared. Mill types were (1) stud mills, (2) random length dimension mills, and (3) board mills. Technology levels were (1) current average mill producing less than 5 million board feet per year, (2) current average mill producing more than 5 million board feet per year, (3) mid-1980s best mill, and (4) future mill.

The chief features of current average mills producing less than 5 million board feet per year were use of a carriage to transport logs with circular saw breakdown, kerf in excess of .250 inch, little or no computer control of breakdown, air drying of lumber and knife planing. The remaining types of mills all produce more than 5 million board feet per year and use kilns for drying lumber,

The current average mills producing more than 5 million board feet per year vary by product produced, The stud mill uses canter log transport and a quad band headrig, kerf less than .200 inch, computer controlled breakdown, but no optimizing edger or trimmer. The random length dimension mill uses full taper canter log transport and a quad band headrig, kerf less than .200 inch, and computer controlled breakdown and edging, The board mill uses carriage log transport with a single band headrig, kerf of about .250 inch, computer assisted log offsets, and an edger optimizer.

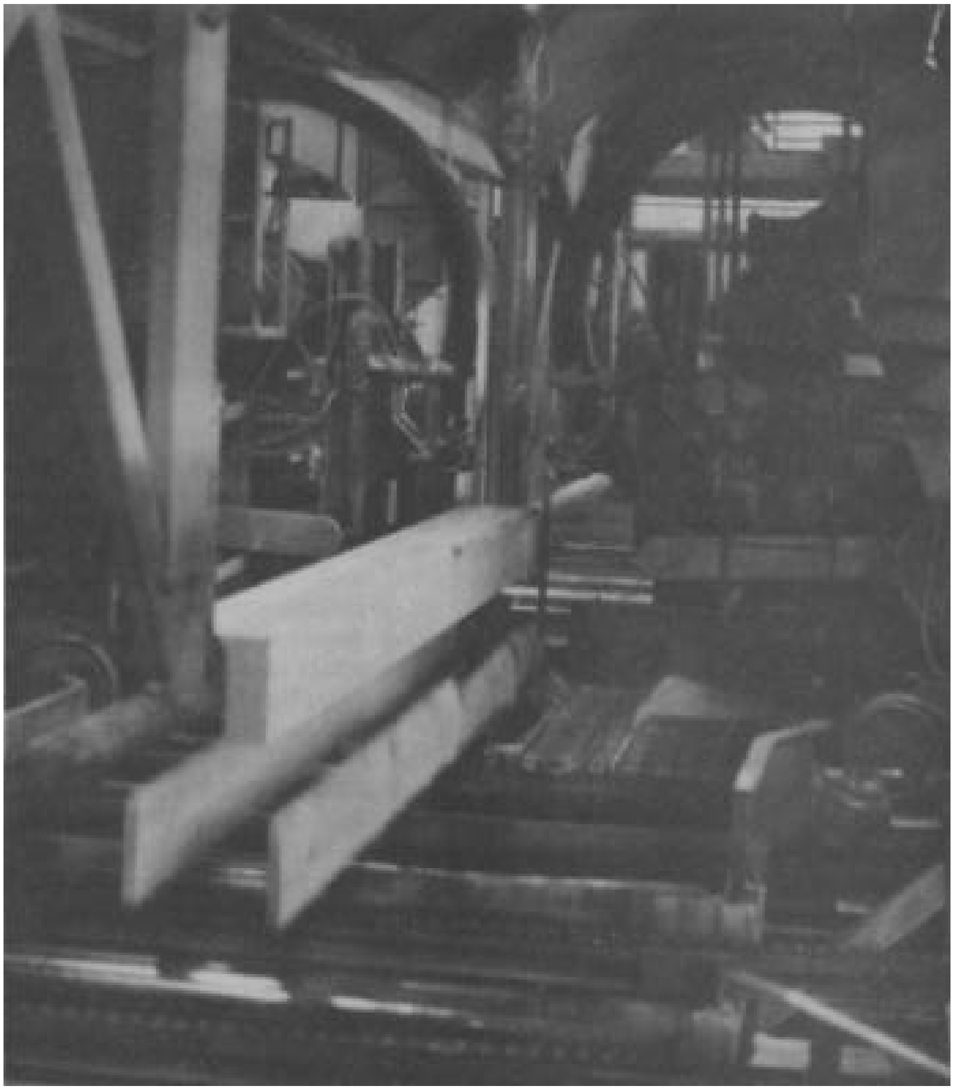
Table 133.—Current and projected designs of softwood sawmill systems.

Age of technology[1], size of mill and type of mill	Log transport system/ headrig type	Sawing parameter: Kerf — Headsaw	Kerf — Resaw	Dressing allowance	Percent[2] of BOF yield attained
		Inches			
Current less than 5 MMBF					
Stud	Carriage/Circular saw	.284	.284	.119	72
Random length dimension	Carriage/Circular saw	.284	.284	.119	72
Board	Carriage/Circular saw	.284	.284	.118	72
Current more than 5 MMBF					
Stud	Canter/Quad band—ex. North	.202	.173	.119	72
	Carriage/Circular saw–North	.205	.179	.119	72
Random length dimension	Full taper canter/Quad band — except North	.202	.173	.119	72
	Carriage/Circular saw—North	.205	.179	.119	72
Board	Carriage/Single band	.252	.183	.118	72
Mid-1980s best					
Stud	Overhead end dog/Quad band	.121	.119	.107	74
Random length dimension	Side dog sharp chain/Quad band	.121	.119	.107	74
Board	Overhead end dog/Quad band	.121	.119	.107	74
Future					
Stud	Magazine/Precision canter	.110	.100	.015	76
Random length dimension	Integral/Precision canter	.110	.100	.015	76
Board	Overhead end dog/Quad band	.110	.100	.015	76

[1]*Mid-1980's best technology and future systems are mills producing more than 5 million board feet per year.*

[2]*Percent of theoretical lumber recovery attained, where theoretical recovery is computed using the Best-Opening-Face computer Program with sawing parameters shown in the table.*

Source: Headrig type: Williston 1987. Kerfs and Dressing allowance: Steele et. al. 1987, Steele et al. 1988a. Estimates for mid 1980s best and future mills are from Lunstrum and Danielson 1987.



This double-bandsaw headrig with an end-dogging carriage is one example of innovative technology used in western sawmills.

The mid 1980s best mills also vary by product. All are assumed to have headsaw and resaw kerf just over .125 inch. The stud mill uses overhead end dog log transport and a quad band headrig, computer controlled breakdown, and an optimizing edger. The random length dimension mill uses side clamp sharp chain log transport with a quad band headrig, computer controlled breakdown, and an optimizing edger. The board mill uses overhead end dog log transport with two reducer heads and a quad band headrig, computer assisted log offsets, and an edger optimizer.

The future sawmills are assumed to come into use in the mid 1990s. In the future stud mill, long logs are scanned, bucked and sorted by diameter, length and shape. Input may include plywood cores. Logs are sorted by diameter and irregularities removed to permit high speed magazine feed (30 logs/minute). Logs are cut by precision machinery canters with offset capability which produce smooth 2x4's from the sides and 2x6's from the cant. Stacking is done by an automatic crib-stacker. Lumber is dried under restraint at high temperature and high speed. Dressing removes .015 inch by touch sanding. Grading is done by noncontact scanning at 650 feet per minute followed by sorting and packaging.

In the future random length dimension mill, long logs are scanned and bucked for optimum length and shape. Logs are sorted by diameter, length and grade before storage in the log yard. Log infeed is by diameter class permitting infeed at 8.5 logs/minute. Log transport is by flat chain feed with side and top rollers for positioning. The headrig has log offset and taper sawing capability and contains four reducer heads, a gang saw and built-in edgers., Stacking is automatic. Lumber is dried at high temperature. Dressing removes .015 inch by touch sanding. Grading is done by noncontact scanning followed by sorting and packaging.

In the future board mill, logs are sorted into two grade categories and several diameter classes. Computer aided tomography type scanning is used to sense interior defects. Logs are fed into the mill by class in relatively long runs at 3.5 logs per minute per headrig. Coded grade marks on logs indicate the position of sweep and crook, the location of clear and common faces, and the depth of cut to maximize value recovery. Smaller diameter logs with only one or two opposing clear faces go to a side with overhead end dog transport and a reducer quad band headrig. Larger diameter logs with two or more clear faces go to a side with overhead carriage transport and 90° turning capability and a reducer quad band headrig. Common lumber cants go through an optimizing gang saw. Upper grades pass through an optimizing edger that scans and cuts to optimize value based on appearance grade. A computer controls drying to 12% moisture content. Dressing removes .015 inch by abrasive planing. Boards are then scanned for appearance grade and trimmed and sorted automatically.

Projected Mix of Lumber Processing Systems

Average LRF and processing costs were computed for each region by taking a production-weighted average over all mill types and technology types (table 134). The averages change over time as the proportion of production moves from current technology to the best technology of the mid-1980s to future technology and as average log diameter declines (table 135).[47]

New sawmill capacity is introduced in two ways: remodeling or new construction.[48] Between 1982 and 2040, new or remodeled capacity that is small mill technology[49] is assumed to decline nationwide from 16% to 8%. In 1982 the percentage of mill capacity using this small mill technology varied from 21% in the South to 0.1% in the Pacific Southwest (McKeever 1987b). Between 1982 and 1990, the large mill technology will initially be replaced by current average technology for mills greater than 5 million board feet per year, but will gradually change so that by 1995 large mills will be replaced only by mid-1980s best technology. Between 1995 and 2040, the proportion of new or remodeled capacity that is mid-1980s best technology will gradually decline to zero, while the proportion with the future technology will increase (table 134).

[47] *A computer model was used to compute lumber recovery factor (LRF) and processing costs for 3 mill types at each of 4 technology levels for 6 regions. Many mills have the same basic design across regions. Each design has (1) a basic equipment layout; (2) estimated costs for equipment, maintenance, labor, energy, and administration; (3) estimated log throughput rate by log diameter (Williston 1987); and (4) an equation to estimate LRF by log diameter that was prepared using best-opening-face (BOF) computer software (Lewis 1985). Associated with each design and LRF equation are specific sawing characteristics, such as split-taper or full-taper sawing, headsaw kerf, resaw kerf, dressing allowance (table 133), trimming procedures, and proportion of theoretical yield obtained. Sawing parameters for "current average" technologies are from the Sawmill Improvement Program (SIP) (Steele et al. 1987, Steele et al. 1988a) and estimates by Lunstrum and Danielson (1987). Sawing parameters for "mid-1980s best" and "future" mills were estimated by Lunstrum and Danielson (1987). Proportion of theoretical yield attained was estimated by reducing BOF estimated LRF's to match estimated 1985 "real world" recoveries in the Timber Assessment Market Model data set (Haynes 1987). LRF and costs were calculated for each mill type/technology level in each region for the average log diameter processed (table 135). Processing costs exclude wood cost and revenue from sale of mill residue. For our projections to 2040, it is assumed that real wage and energy costs are held constant at 1986 levels. The model's first year is 1982. Log diameters for 1982 are from SIP data (Steele et al. 1988b). The initial proportion of lumber made in mills producing less than 5 MMBF per year is from state and national mill directories (McKeever 1987). The proportion of capacity in stud mills (10%), random length dimension mills (65%) and board mills (25%) is based on data from the USDC Bureau of Census (1982).*

[48] *A mill is assumed to be remodeled or shut down after 10 Years. In 1982, capacity is assumed to be uniformly distributed among 10 1-year age classes. Beginning in 1983, a mill in the 10-year-old age class is assumed to be remodeled or shut down. The mill is assumed to be shut down if there is an externally specified decrease in total capacity. Entirely new capacity is added to fulfill a need for an increase in total capacity.*

[49] *Current average technology producing less than 5 MMBF.*

Projected Recovery and Costs as Log Diameter and Mix of Systems Change

Average softwood lumber recovery in the United States is currently about 49% of the cubic volume processed, and the lumber recovery factor (LRF) is 6.8 board feet lumber tally per cubic foot log scale. Overall recovery is projected to improve by 15% between 1985 and 2040, to 57%. Projections of LRF average 7.8 by 2040 and exceed more than 8.4 in the Pacific Northwest-West (table 88). These projections reflect a decline in diameter of logs processed (table 135). The national averages are weighted by regional production and are influenced by the regional production shift from the West to the South.

Projected increases in lumber recovery vary by region. Between 1985 and 2040, recovery will increase by 19% to 24% in the South and Pacific Northwest-East regions (table 88) where decreases in log diameter are limited. Recovery improvement will be least in the Pacific Northwest-West (80%) and Pacific Southwest (11%) due to a projected 24% decline in average log diameter. The wide range in regional recoveries in 1985 (6.02 to 7.87) will narrow by 2040 (7.18 to 8.47). The Pacific Northwest-West and the Pacific Southwest will retain the highest recovery factors because the South is projected to retain a significant number of small, less efficient mills.

Softwood lumber processing costs are projected to decrease in all regions by 2040 (table 82). Processing costs exclude wood costs and revenue from sale of residue. This departure from the upward cost trend in the 1970s is attributable to continued improvements in sawing technology; less capital, labor and energy per unit; and projected constant wage rates and energy prices. The cost decline between 1985 and 2040 will be the greatest in Pacific Northwest-East (24%), lowest in the Pacific Southwest and Rocky Mountains (16-21%), and 22% in the South and Pacific Northwest-West. Newer mills will be able to keep costs per unit output down, even in regions where diameters decline, by increasing their log throughput rate.

The Impact of Technology Change on Lumber Manufacturing Costs

Lumber manufacturing costs include costs for stumpage, harvesting and hauling, and processing. The technology changes discussed previously hold down the cost

Table 134.—Proportion of various softwood sawmill systems by region in 1985, with projections to 2040.

Section and region	1985	Projections 2000	2010	2020	2030	2040
		Percentage of production				
North[1]						
Old less than 5 MMBF	81	54	49	43	38	33
Old more than 5 MMBF	37	3	0	0	0	0
Mid-1980s best	2	41	39	31	20	7
Future	0	2	12	26	42	61
South						
Old less than 5 MMBF	21	19	17	15	13	11
Old more than 5 MMBF	75	8	0	0	0	0
Mid-1980s best	4	73	64	46	28	9
Future	0	3	20	39	59	80
Rocky Mountains[2]						
Old less than 5 MMBF	12	11	10	9	7	6
Old more than 5 MMBF	84	7	0	0	0	0
Mid-1980s best	4	80	69	50	30	9
Future	0	3	21	42	63	84
Pacific Coast						
Pacific Southwest[3]						
Old less than 5 MMBF	0	0	0	0	0	0
Old more than 5 MMBF	95	8	0	0	0	0
Mid-1980s best	5	89	77	54	32	10
Future	0	3	23	46	68	90
Pacific Northwest						
Old less than 5 MMBF	1	1	1	1	1	0
Old more than 5 MMBF	94	8	0	0	0	0
Mid-1980s best	5	88	76	54	32	10
Future	0	3	23	45	67	90

[1]*Includes North Dakota, Nebraska, and Kansas.*
[2]*Excludes North Dakota, Nebraska, and Kansas.*
[3]*Excludes Hawaii.*

Table 135.—Trend in diameter of softwood logs processed by sawmills, by region, 1985, with projections to 2040.

Section and region	1985	Projections 2000	2010	2020	2030	2040
		Inches				
North[1]	10.1	10.1	10.1	10.1	10.2	10.2
South	10.3	10.3	10.1	10.0	9.9	9.8
Rocky Mountains[2]	10.6	10.2	9.8	9.6	9.4	9.2
Pacific Coast						
Pacific Southwest[3]	13.6	12.4	11.9	11.4	11.0	10.4
Pacific Northwest						
Pacific Northwest-West	12.5	11.4	11.0	10.5	10.1	9.6
Pacific Northwest-East	10.6	10.2	9.8	9.6	9.4	9.2

[1]*Includes North Dakota, Nebraska, and Kansas.*
[2]*Excludes North Dakota, Nebraska, and Kansas.*
[3]*Excludes Hawaii.*
Source: Estimates for 1985 are based on data from the Sawmill Improvement Program, see Steele et al. 1988b.

of making lumber by decreasing the delivered cost of logs per unit of lumber output and by holding down sawmill processing costs.

Projected improvements in lumber recovery will hold down the cost of logs as a component of lumber costs. Even though delivered log costs for the Pacific Northwest-West and South are projected to increase by 10.2% and 13.0%, respectively, per decade through 2040, the cost per unit of lumber output increases only 9.9% and 10.0% per decade, respectively (fig. 78). Technological change is projected to be more effective in holding down log costs as a component of lumber costs in the South due to smaller projected declines in log diameters.

Other improvements in lumber processing, in addition to LRF improvement, will also shield the cost of making lumber from projected increases in log costs. Even though delivered log costs for the Pacific Northwest-West and South increase by 10.2% and 13.0% per decade through 2040, total lumber manufacturing costs increase only 4.9% and 5% per decade on average (fig. 79). Most of the projected increase occurs by 2010 to 2020. Technological change is more effective in holding down overall lumber manufacturing costs in the South. As a result, the South is projected to widen its comparative advantage in lumber manufacturing costs relative to the Pacific Northwest-West over the projection period (fig. 79).

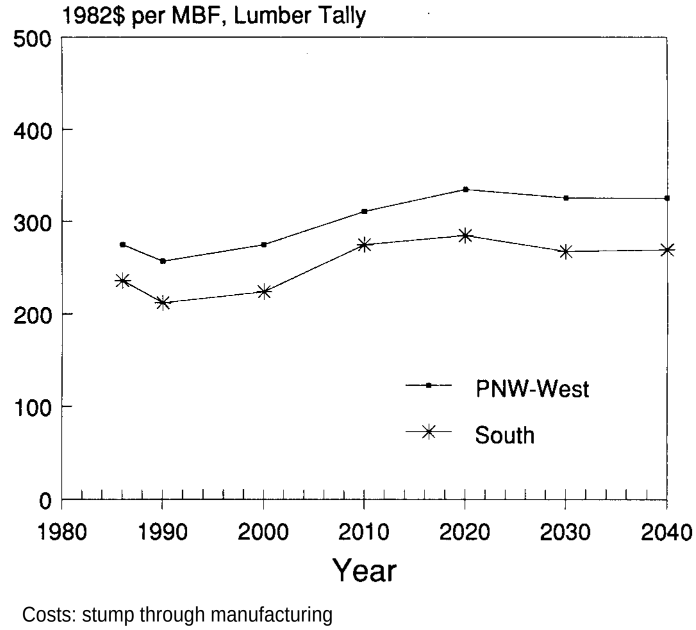


Figure 79.—Total softwood lumber-making costs, PNW-West and South.

Hardwood Lumber Processing

The principle use of hardwood lumber is for remanufacture into furniture, cabinet work and pallets, or directly into flooring, paneling, molding and millwork. It is mainly graded and sold as factory lumber, or processed into dimension parts and finished products. Factory lumber comes in random widths and is graded by the number and size of clear cuttings that maybe obtained. It is intended to be cut into smaller pieces after kiln drying (dimension parts) that will be used to make furniture or other fabricated products. Pallet parts are cut from green lumber or cants. Dimension parts are normally kiln dried parts with specific thicknesses, lengths and widths. They may be sold rough or surfaced, and semi-fabricated or fabricated for further use in making products such as furniture. Finished products are sold in finished form. The highest volume example is flooring. Others include lath, siding, ties, planks, car stock, construction boards, timbers, trim, molding, stair treads and risers.

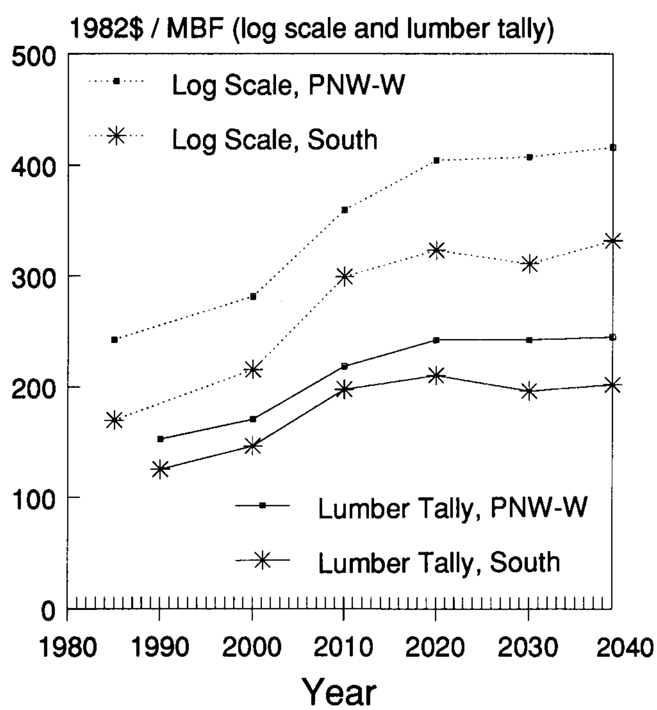
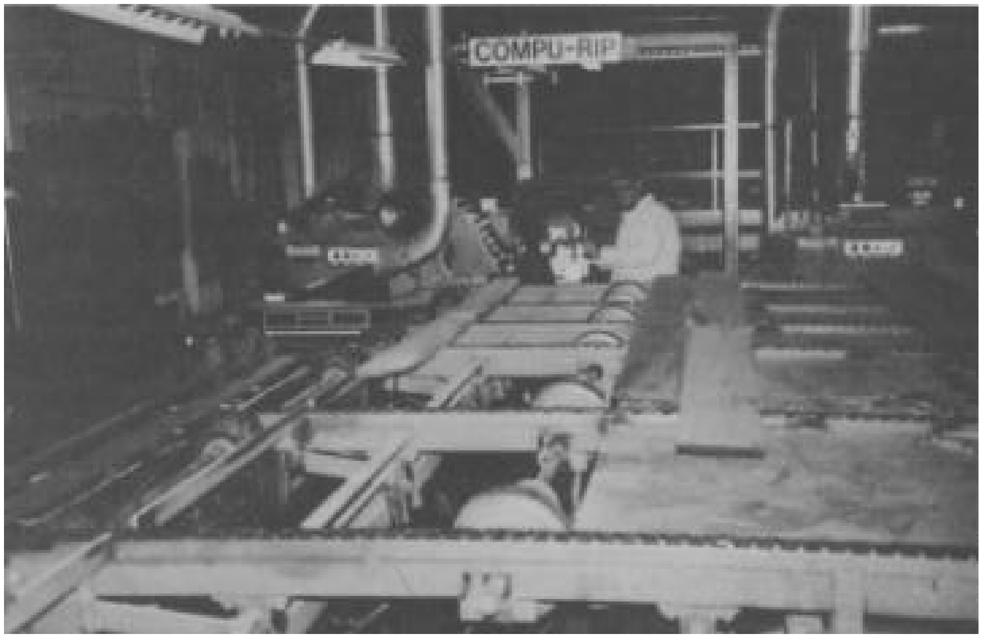


Figure 78.—Delivered log cost for softwood lumber, PNW-West and South.

The production of hardwood lumber in general is less automated and less sophisticated than softwood lumber processing. A majority of the mills have wide-kerf circular headrigs instead of narrow-kerf band headrigs and the production capacities are much smaller in hardwood mills. Sophisticated log scanning, computer assisted log processing, and computer controlled edging and trimming are technologies developed for softwood sawmills and are seldom used in the hardwood industry. In general, the technology is too expensive for most options or does not apply to the production of hardwood lumber. Most hardwood logs are processed to produce the highest appearance grade lumber possible. Processing for higher grade lumber normally stops when low grade faces appear on the remaining center cants. Cants are subsequently processed for lower grade lumber or pallet parts at the same mill or a pallet plant.

In general, top grade first-and-second and select (FAS & Sel) lumber is used for moldings, millwork, export, and other uses that require clear or almost clear lumber.



In this cabinet parts rough mill, lumber is ripped into strips (far left) after an operator marks edges to be trimmed with two laser lines, and a computer determines the size of strips to fill mill needs. (Credit: Phil Araman, USDA Forest Service)

Secondary quality lumber, graded number 1 common (1C) and number 2 common (2C), is used primarily for wood furniture, upholstered furniture, cabinets, flooring, and other products that do not require clear lumber. Material below 2C grade is used in railroad ties, mine timbers, pallets, and flooring.

Hardwood lumber drying is more critical than softwood drying for two reasons. First, hardwood lumber must be dried down to 6-8% moisture content for furniture instead of the 15% moisture for most softwood lumber that is kiln dried and used in construction. Second, hardwood lumber must be dried more slowly to avoid drying degrade such as splits, checks, warping, staining, and internal honeycombing. These defects reduce the value and usefulness of the lumber.

After drying, hardwood lumber is converted into cuttings for furniture, cabinets, moldings, flooring, stair treads and risers, and other product parts in processing facilities called rough mills. The lumber is planed, crosscut and ripped, or ripped and crosscut into parts or cuttings. Many of the cuttings are edge glued, planed and then re-ripped to parts. In some systems finger jointing is used to make long parts out of short cuttings. In the future, we may see more rough mill type processing tied directly to sawmill and drying operations. For secondary quality lumber (1C and 2C) we could see production of green dimension cuttings followed by drying. With this system, dry kilns would not have to dry all the waste lumber that is discarded when lumber is cut into dimension parts. This system would increase the capacity of existing kilns to produce dry dimension parts.

Possible Changes in Hardwood Lumber Production

The main pressures to improve or change hardwood lumber processing techniques stem from the need to manufacture enough better grade material for important export and domestic markets. Processors need to improve yields, but they must improve quality and contain costs to maintain markets and reduce the potential competition from substitute wood or nonwood products. Modernization with computer aided manufacturing and computer controlled processing are keys. But, once again this equipment will be used to increase the recovery of higher grade material and not necessarily to cause major increases in overall yields or reductions in wood consumption.

Technology improvements such as computerized log shape scanning and computerized sawing decisions are available and are being adopted by some large mills. These systems provide better sawing consistency, closer tolerances and therefore reduced lumber target sizes, increased lumber yields and increased higher grade lumber output from lower quality logs.

A hardwood computer aided edging system has been developed to properly edge random width hardwood lumber and a more sophisticated system is being investigated that would provide the operator with information on how to obtain the highest grade after edging. Similar systems for hardwood trimming should be available in the future. These systems will be designed to increase grade output.

Improvements will continue to be made in hardwood lumber drying. They will improve grade recovery by reducing drying degrade. Most of the improvements will be a result of more control over the initial drying phase with the use of predriers and by better kiln drying with use of computer controls that allow smooth or continuous curve drying.

A system under development which will incorporate many of the above technologies and more is the Automated Lumber Processing System (ALPS). ALPS will include new techniques for log processing, board defect detection and optimum board cutting in order to maximize the yield of clear wood parts for furniture production. In an ALPS sawmill, logs are scanned internally to locate the position of internal defects, Computers use defect position information to determine and control log breakdown that maximizes grade or value yield of boards. After drying and superficial surfacing, video image analysis locates and classifies defects on each board. Computers use board defect information to determine and control board cutting to yield the maximum number of clear parts for a given cutting bill. Cutting is carried out by computer controlled conventional cutting or high-powered laser cutting. ALPS will increase the recovery of high grade material (McMillin et al. 1984).

Projected Lumber Recovery

The overall impact of changes in technology and other factors will be to improve both grade recovery and overall recovery. The modest assumption of 1% per decade increase in LRF for hardwood lumber processing seems reasonable. Table 136 shows average recovery of hardwood lumber by grade from various size trees for the late 1970s. Larger trees yield a higher proportion of higher grade lumber .[50] For the projections of hardwood lumber consumption in Chapter 7, it was assumed that overall hardwood lumber recovery increased 1% per decade in each tree size category. It was also assumed that the relative proportion of various lumber grades produced from a given size of tree remain constant. This assumption is conservative because improved technology is likely to improve the proportion of higher grade lumber obtained. Other factors that will tend to improve overall recovery and grade recovery are a moderate shift to use of a wider range of hardwood species and increased availability of slightly larger logs, on average, in the future. Slightly larger logs will be the result of increased inventory of hardwoods.

[50]Yield from trees includes all losses from parts of the tree stem initially considered usable to make lumber plus losses in the sawmill. These overall losses are estimated to be greater for trees of smaller diameter.

Softwood Plywood Processing

Plywood is a glued wood panel made up of thin layers of wood with the grain of adjacent layers at an angle, usually 90 degrees. Each layer consists of a single thin sheet, called a ply, or two or more plies laminated together with grain direction parallel. The usual constructions have an odd number of layers. The outside plies are called faces or face and back plies, the inner plies are called cores or centers. As compared to solidwood, the chief advantages of plywood are its nearly equal strength properties along its length and width, its greater resistance to splitting, and its size, which permits coverage of greater surfaces.

Two types of structural plywood are produced: sheathing and sanded. The chief distinguishing characteristic between the two is the quality of the face veneer(s). Sanded products require relatively clear veneer whereas sheathing grades tolerate knots and knotholes. Most structural plywood is sheathing grade and this is where oriented strand board and waferboard are competing.

Technology Developments

To improve profitability, softwood plywood mills have to increase wood use efficiency and reduce nonwood costs in several ways. Since sheathing can be made with lower quality veneer, sheathing mills can utilize smaller diameter, less expensive logs. The extent to which smaller diameter logs can be used, however, depends on the ability of the technology to deal with physical differences in logs as size declines. These include (1) a higher proportion of wet sapwood which decreases dryer capacity; (2) an increase in the proportion of the tapered part of the log relative to the cylindrical part, which decreases clipper capacity; (3) the rise in the fraction of the wood contained in the core, which decreases veneer recovery; and (4) the increased wood loss caused by a given error in centering the bolt in the lathe, which decreases overall veneer and full sheet veneer recovery.

Several technological changes have emerged over the last decade that address small log processing problems

Table 136.—Hardwood lumber recovery by size of tree harvested, late 1970s.

	Lumber grade			
Tree diameter	Higher grades	No. 1 Common	Lower grades	Total
inches	*Board feet lumber tally per board foot input*[1]			
11-15	.02	.07	.42	.52
15-19	.10	.25	.42	.76
19+	.20	.31	.37	.88

[1]Input is standing tree volume harvested as measured by the international quarter-inch log rule. The recovery ratios include loss of volume due to tree defects, hauling, storage and processing prior to entering the sawmill plus losses during sawmilling.

Source: Recovery data used in the Hardwood Assessment Market Model (HAMM). HAMM recovery figures are based on lumber recovery data by log grade in Hanks et al. (1980) and calculations of logs contained in various size trees, see Binkley and Cardellichio 1985.

(see table 137). In the past, plywood glues were unable to tolerate veneer moisture much above 4%. With modified High Moisture Veneer (HMV) glues now available, that limit has been increased to 12% and higher. Consequently, the wet sapwood of small logs can be accommodated in existing dryers by running the dryers faster. Added benefits are less veneer shrinkage, less breakage from too brittle veneer, and higher moisture in finished panels reducing warpage (Wellons 1988).

Clippers have traditionally been of the guillotine type with maximum running speeds of about 350 ft/min and much slower speeds for roundup (less than full width veneer from the tapered part of the bolt). A new clipper with a rotary cutting motion in place of the up-and-down motion of traditional clippers has become available and has been widely adopted. Clipper speed in excess of 500 ft/min during full sheet clipping can be achieved (Maxey 1977).

To maintain veneer recovery from smaller blocks, the core size and spinout rate have been reduced. This has been accomplished by supplying additional rotational power at the bolt periphery by powered rolls. Core sizes as small as 2 inches are being achieved (Knokey 1986).

In the area of charging, laser scanning is achieving more accurate bolt placement in lathes at speeds rapid enough to maintain throughput with small logs. Charging times approach 2 seconds. Microprocessor-controlled arms place the log into the lathe to achieve the largest possible cylinder, given bolt shape and other characteristics (Moen 1985).

To reduce the traditional labor intensive nature of plywood manufacturing, mills have automated several important facets of the process including green and dry veneer stacking, layup, and press loading. Hours of labor required to produce a thousand square feet of product can be reduced to about 2 from about 3-1/2 through this process of automation.

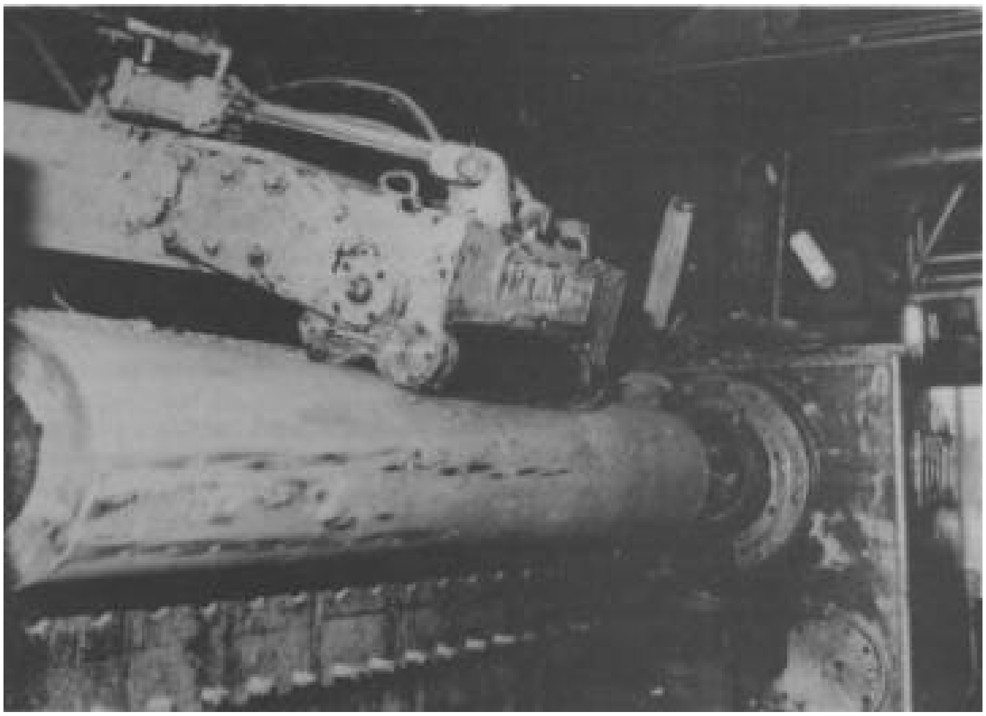
Projected Characteristics of Present and Future Panel Processing Systems

To quantify the effects of these and other technological changes, three mill designs were prepared to represent the level of technologies roughly equivalent to those available in the mid 1970s, the mid 1980s, and the late 1980s (see table 138).

Chief features of the mid-1970s design were (1) dropout cores of 5.25 inches, (2) spinout rate of 8% with average spinout core size of 9.5 inches, (3) charging time

Table 137.—Technological developments in structural panel processing.

Product type and development	Description	Impact
Softwood plywood		
Computerized lathe charging systems	Laser beams reflected off the bolt are analyzed by a computer to determine bolt shape from which the bolt's geometric center is determined	More accurate measurements of bolt's shape and easier maintenance increase veneer recovery
Hydraulic carriage drives	The rate of knife advance is controlled using a hydraulic drive in place of mechanical linkages	Reduced thick-and-thin veneer and increased on-target cutting
Powered nosebars and back-up rolls	Supplementary power to turn bolts provided by powered back-up roll and nosebar	Reduced incidence and size of bolt spinouts, fewer sliver plug ups
High-moisture content gluing	Glue formulations with increased tolerance of moisture in veneer	Increased drier output
Radio-frequency redrying of veneer	RF redrying uses microwaves to redistribute moisture inside a stack of veneer eliminating wet spots	Reduced broken veneer and increased capacity of primary driers
Press pressure controls	High initial press pressures are reduced in increments during the press cycle	Permanent compression in panels is reduced allowing thinner target veneer thickness
Nonveneered structural panels		
Isocyanate binders	Isocyanate binders are used to replace phenolic resins to glue panels	Reduced energy requirements, shorter press times increase output on thicker panels
Long log flaker	Flaker produces flakes from random length logs	Reduced generation of fines and saw kerf
Continuous presses	Uninterrupted mat flow through the press	Reduced trim loss



The powered backup roll helps prevent veneer log spin-out by providing torque to the surface of logs. More veneer may be obtained by peeling logs to smaller cores. (Credit: Boise Cascade

of 3 seconds per bolt, (4) average veneer thickness variation of 6%, (5) maximum clipper speed of 375 feet per minute, (6) conventional moisture target of 4% for veneer, and (7) no automation in veneer stacking, drying, layup, and pressing.

The mid-1980s design featured (1) dropout core size of 3.25 inches, (2) spinout rate of 3% with average spinout core size of 6.8 inches, (3) charging time of 2 seconds per bolt, (4) average veneer thickness variation of 3%, (5) maximum clipper speed of 500 feet per minute, (6) high moisture veneer target of 9%, and (7) automated green and dry veneer stacking, panel layup, and press loading. The late-1980s mill design differed from the mid-1980s mill design with respect to core size, which was 2 inches, and spinout rate, which was set at zero.

The average cost and recovery and optimum bolt diameter range were determined for each design using a mill simulation program. [51] Real energy and wage costs were assumed fixed at 1986 levels. Thus, projected changes in processing costs are due solely to changes in technology.

[51] *The Plywood Mill Analysis Program (PLYMAP) is an economic/engineering model of the plywood manufacturing process. PLYMAP calculates material flows and economic costs based on parameters describing machine capabilities and capacity at each discrete stage of plywood processing. It identifies potential bottlenecks, indicates areas of slack, and calculates overall revenues and costs for a given set of economic and process assumptions. The modal has been documented by Spelter (in press). PLYMAP was used to compute recovery factors and processing costs of 3 mill types representing technology levels for the mid 1970s, the mid 1980s, and the late 1980s using parameters shown in table 138 and discussed in the text. A more detailed discussion of technologies in plywood mills is given by Spelter and Sleet (1989).*

Projected Mix of Panel Processing Systems

Average veneer recovery factors and costs were computed for three regions representing almost all softwood plywood manufactured in the United States: Pacific Northwest-West, Pacific Northwest-interior, and South. For each year in the forecast, a capacity mix of old, modern, and advanced technologies was projected in each region (table 139). Each technology type was assumed to process a distribution of log sizes determined by the simulation program to be optimal for that particular set of technologies and consistent with the overall reduction in average log diameter (table 140).

Rapid adoption of new technology is projected in all three regions. By the year 2010, old or mid-1970s equipment was projected to be completely phased out in the South and almost replaced in the West. Because of the higher proportion of old-growth timber in the West, the displacement of older technologies in mills specializing in sanded items was assumed to proceed more slowly.

Projected Recovery and Costs

Softwood plywood product recovery factors have tended to increase with increasing production of commodity sheathing which generates less residue and can use lower grade veneer. Increased use of smaller but less defective second-growth timber has also helped boost recovery. Veneer recovery in plywood mills is estimated to average about 50%. of the cubic volume of wood processed. Higher recovery is projected with the mix of capacities shifting to modern and advanced equipment.

Table 138.—Current and projected designs of softwood plywood systems.

Process parameters	Technology type: Mid-1970s	Mid-1980s	Late-1980s
Percent of bolts which spinout	8	3	0
Spinout core size (inches)	9.5	6.8	N/A
Target core size (inches)	5.0	3.3	2.0
Ratio of actual-to-nominal veneer thickness	1.024	1.000	1.008
Ratio of thickness variability to actual veneer thickness	.055	.032	.040
Clipper speed (fpm)	375	500	500
Target veneer moisture (percent dry basis)	4.5	9.0	9.0

Table 139.—Proportion of various softwood plywood systems by region in 1985, with projections to 2040.

Section and region	1985	Projections: 2000	2010	2020	2030	2040
South						
Mid-1970s	40	5	0	0	0	0
Mid-1980s	60	70	65	63	62	60
Late-1980s	0	25	35	37	38	40
Pacific Coast						
Pacific Northwest						
Pacific Northwest-West						
Mid-1970s	70	30	20	17	16	15
Mid-1980s	30	55	52	51	50	50
Late-1980s	0	15	28	32	34	35
Pacific Northwest-East						
Mid-1970s	40	20	15	12	10	10
Mid-1980s	60	66	65	60	55	55
Late-1980s	0	12	20	28	35	35

Table 140.—Trend in diameter of softwood veneer logs processed by plywood mills, by plywood mill system and region in 1985, with projections to 2040.

Section and region	1985	Projections: 2000	2010	2020	2030	2040
			Inches			
South						
Mid-1970s	12.0	12.5	12.7	12.6	12.5	12.4
Mid-1980s	11.0	11.0	11.0	11.0	11.0	11.0
Late-1980s	9.0	9.0	9.0	9.0	9.0	9.0
Pacific Coast						
Pacific Northwest						
Pacific Northwest-West						
Mid-1970s	15.5	14.8	14.5	14.3	14.1	14.0
Mid-1980s	14.5	13.0	12.5	12.1	11.7	11.5
Late-1980s	12.0	11,8	11.5	11.0	10.6	10.2
Pacific Northwest-East						
Mid-1970s	15.5	14.5	14.0	13.5	13.2	13.0
Mid-1980s	14.0	12.5	12.0	11.7	11.6	11.5
Late-1980s	10.0	10.0	10.0	10.0	10.0	10.0

This occurs despite the drop in average bolt diameters that would tend to depress recovery. Overall recovery is expected to increase by 6% in the Pacific Northwest-West and 20% in the South between 1985 and 2040 (table 89); average U.S. recovery would rise by 15% to 58% by 2040.

Processing costs are also projected to decline by about 5-7% in real terms between 1985 and 2040 (table 83). This development continues historical trends (interrupted briefly by rising energy costs in the 1970s) toward lower real manufacturing costs in plywood and is a direct outgrowth of labor and material saving technologies installed in modernized facilities.

The Impact of Technology Change on Plywood Manufacturing Costs

Plywood manufacturing costs include costs for stumpage, harvesting and hauling, and processing. The technology changes discussed previously hold down the cost of making plywood by decreasing the delivered cost of logs per unit of plywood output and by holding down plywood mill processing costs.

Projected improvements in plywood recovery will hold down the cost of logs as a component of plywood costs. Even though delivered log costs for the Pacific Northwest-West and South are projected to increase by 10.2% and 13.0% per decade through 2040 respectively, the cost per unit of plywood output increases only 9.8% and 10.5% per decade, respectively (fig. 80). Technological change is projected to be more effective in holding down log costs as a component of plywood costs in the South due to smaller projected declines in log diameters.

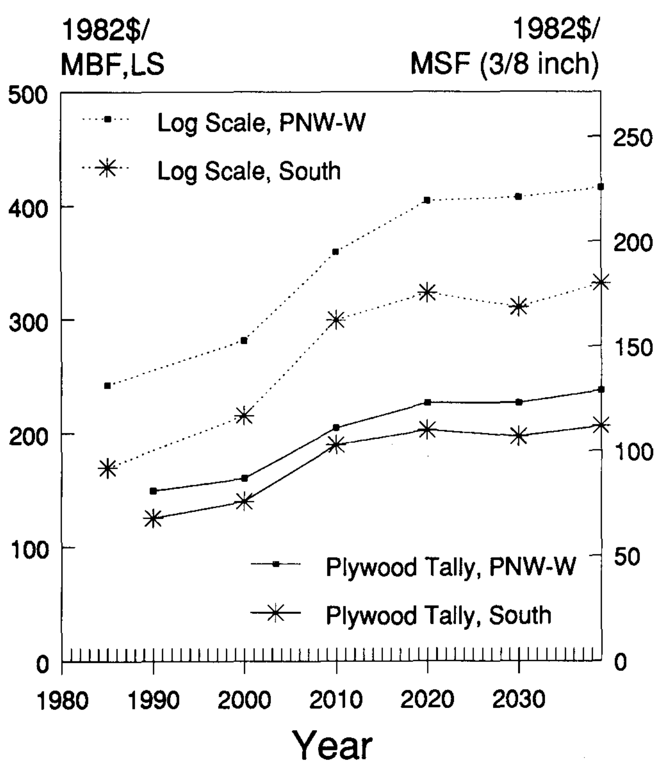


Figure 80.—Delivered log cost for softwood plywood, PNW-West and South.

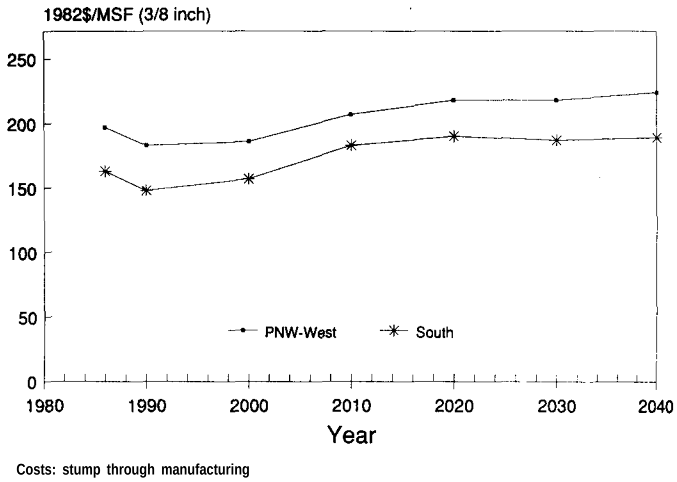


Figure 81 .—Total softwood plywood-making costs, PNW-West and South.

Projected improvements in plywood processing costs will further shield the cost of making plywood from projected increases in log costs. Even though delivered log costs for the Pacific Northwest-West and South increase by 10.2% and 13.0% per decade through 2040, total manufacturing costs increase only 2.4% and 2.7% per decade on average (fig. 81). Most of the projected increase occurs by 2010 to 2020, Technological change in both regions is projected to maintain a nearly constant level of comparative advantage for the South in plywood manufacturing costs relative to the Pacific Northwest-West over the projection period (fig. 81).

Nonveneered Structural Panel Processing

Nonveneered panels consist of wood wafers or strands smaller than veneer sheets but larger than wood fiber, Unlike conventional particleboard, the raw material for structural products normally comes direct from roundwood sources rather than mill byproducts; adhesives used are exterior rather than interior type; particles are usually aligned in several discrete layers rather than laid down at random.

Technology Developments

Technology developments in processing oriented strand board and waferboard are likely to focus on two areas: increasing their range of applications and decreasing wood loss during the flaking, forming, and trimming processes.

Oriented strand board and waferboard have been used as sheathing in walls and roofs, and for floor underlayment, and technology has more recently been developed for applications such as concrete forms and siding. Suitable performance is being achieved by using phenolic paper overlays to stabilize the surface and provide a

Examples of structural composite products, from top left: wood joist with laminated veneer lumber (LVL) flange and plywood web, wood joist with LVL flange and wood particle web, waferboard and subfloor/underlayment, Parallam (reg. trademark of McMillan Bodel Inc.), conventional plywood, COM-PLY (reg. trademark of the American Plywood Association), LVL, and Waveboard (reg. trademark of the Alberta Research Council). (Credit: Forest Products Research Society)

suitable basis for paint or concrete forming. To improve panel stability, the trend has been to displace phenolic adhesives, either totally or in part, with isocyantate adhesives. While more costly than phenolics on a pound for pound basis, isocyanate adhesives are more profitable for a given level of panel stability than phenolic adhesives because they allow shorter press times and more moisture in the furnish.

Better flaker designs are likely to be adopted in the future to reduce the generation of fines (pieces of wood too small to be used) and improve forming techniques to increase wood utilization. Disc flakers are normally used in mills today. These machines normally require logs to be reduced to 4-foot bolts for processing. The flakers generate from 8-10% small particles (fines) that are unsuitable for use in panels along with about 4% kerf losses caused by the primary and secondary slasher saws. To reduce these losses, whole log flaking utilizing ring and disk waferizers, with losses due to fines also in the 8-10% range but lower slasher kerf losses of about 2%, seems likely to be adopted (Pallmann GMBH 1987).

In current practice, fines are burned for fuel, but with improved mat formers, some of the fines could be used in the core layer of panels without reducing panel strength. This can be accomplished by electrostatically orienting particles. Panel strength increases as uniformity of particle alignment improves (Fyie et al. 1980). Electrostatic orienters achieve higher orientation ratios than mechanical orienters, thus achieving panel strength with smaller particles that are as good as mechanically oriented panels with standard size furnish. The effectiveness of electrostatic orientation, however, decreases with large particle sizes, thus electrostatic orientation will likely complement mechanical formers rather than displace them (Buecking et al. 1980).

Another means to reduce wood losses is to employ continuous presses now gaining acceptance in particleboard and medium density fiberboard facilities. Continuous mats would eliminate end trimming resulting in wood savings of 1-2%. But the larger size and rougher surface of oriented strand board and waferboard furnishes wear out the steel bands used in these presses and for that reason their adoption by industry appears unlikely (Soine 1988).

Projected Recovery and Costs

Nonveneered structural panel wood recoveries are estimated to average between 55% and 60% (based on losses of 4% for trimming log ends and log rejects, 8-12% for fines, 35-38% for panel densification, and 3% for panel trim). This rate of recovery is projected to increase about 2% between 1986 and 2040 due to improvements in bolt preparation and flaking and more complete utilization of fines (table 90).

Oriented strand board and waferboard manufacturing costs have decreased during the past 5 years because of savings made possible by improved glue blenders. Resin dosages of liquid phenolic resins have declined from over 5% to less than 4%. Powdered resin dosages have also been reduced from 3% to 2%. Further potential for savings in this area is limited, so the projections of processing costs for waferboard show more modest declines than those for plywood. The adoption of modern technology by remaining mills is expected to account for the bulk of the projected 4% reduction in

An experimental spinning disk separator takes a stream of recycled paper slurry and spins sticky contaminate to an outer ring while dropping useable pulp fiber to an inner ring. (Credit: USDA Forest Products Laboratory)

Pulp, Paper, Paperboard and Related Products

Paper and board products are made primarily from new or recycled wood fiber. New wood fiber is in the form of woodpulp which is made from pulpwood. Recycled wood fiber is derived from wastepaper which consists of old newspapers, old corrugated containers, mixed grades, pulp substitutes, and high grade deinking, Different paper and board products use different mixes of woodpulps, wastepaper, and other fiber, This mix, or fiber furnish, reflects the requirements for a particular product grade, the level of technology, and the availability of fibers.

Paper and board products are classified into paper grades and paperboard grades. The major paper grades include tissue (sanitary products, napkins, toweling), printing and writing (bond paper, computer paper, copying paper, and paper for books and magazines), packaging and industrial (wrapping papers, bags, and sacks), and newsprint. The major paperboard grades include unbleached kraft (linerboard for corrugated boxes), semichemical (corrugating medium for boxes), solid bleached (folding boxes and food containers), and recycled paperboard (a variety of products including gypsum wallboard facing).

Although specific manufacturing processes and fiber requirements differ among the product grades, paper and board processing generally involves wood handling (debarking, chipping, and chip screening), pulping and bleaching (conversion of chips into pulp using chemical or mechanical processes, bleaching when needed), stock preparation (repulping, deinking, and removal of other contaminants from wastepaper furnish, fiber refining, mixing pulp with additives and recycled fiber), and conversion to paper and board (sheet formations, pressing, drying).

Technological Developments

Technological developments in the U.S. paper and board industry focus on the ability to improve production efficiency and product quality while mitigating or eliminating negative impacts on the environment. Some of the technical challenges facing the industry include the need to reduce energy costs, reduce capital equipment costs, improve strength and quality of recycled fiber, increase fiber recovery, develop processes that can use more hardwood fiber, develop processes that are more environmentally benign, and provide better quality paper products for present and future uses.

Many current and likely future technological developments address the above challenges. Table 141 provides a list of such developments in paper and board processing, describing the likely impact of each development on wood requirements. These developments are viewed as very likely to take effect over the next 50 years, They were incorporated into the projections of paper and board, woodpulp, and pulpwood production shown in Chapter 7 (Ince et al., in prep.).

Table 142 lists those technological developments that were considered, but not included in the projections, They were not included because they were viewed by industry, university, and government researchers as less likely to be commercially significant during the next 50 years.

Paper and Board Manufacturing Processes

As mentioned above, each paper and board product grade uses specific production processes. These processes can be defined in terms of the percentages of fiber used, the nonfiber manufacturing costs, and the date of commercial availability. Technological developments result in new, more cost-effective processes which use increasing amounts of wastepaper and mechanical pulps and have lower nonfiber manufacturing costs.

Table 141.—Technological developments in pulp and paper processing included in the projections.

Type of development	Description	Impact
Meeting needs for improved stacking strength in corrugated boxes	Edgewise compressive strength eventually becomes the principal performance criterion	Compressive strength is improved with higher density linerboard, increased use of higher-yield pulps and more hardwood; improved quality control in kraft linerboard
Meeting increasing demands for quality and uniformity in printing and writing papers with improved papermaking technology	Increased use of higher quality fillers, drainage and retention additives, coating pigments, and hardwood fiber; more machine finishing and alkaline papermaking	Less total wood fiber use per ton of product; lower basis weight with more uniform quality; more hardwood
Meeting demand for printability and quality in linerboard with improved forming and finishing technology	Development of multi-ply forming; improved stock preparation systems; use of hardwood fiber for printability on the surface, or sandwiching hardwood or recycled fiber in the core for economy	Higher proportions of hardwood fiber and recycled fiber in unbleached kraft paperboard; separate pulping and refining for hardwoods and softwoods
Gradual replacement of traditional groundwood pulp by modern mechanical pulps in newsprint and other groundwood papers	Thermomechanical (TMP), Chemi-thermomechanical (CTMP), and pressurized groundwood (PGW) replace some older groundwood and refiner processes, with improvement in pulp quality	Wider market potential for higher yield mechanical pulp; greater ability to substitute for lower yield chemical pulp
Improvement in pulp bleaching systems to reduce capital costs and operating costs, and to meet environmental objectives	Adoption of short-sequence bleaching systems, chlorine dioxide in bleaching, and lower yield in bleached kraft pulping; development of peroxide and other bleaching technologies for TMP and CTMP; use of higher yield bleached mechanical pulps	Greater use of bleached mechanical pulps will reduce wood input requirements, although lower yield kraft pulping will increase wood requirements
Modernization of equipment and processes in older mills to improve efficiency and reduce costs	More tree-length wood handling and chip thickness screening; improvements in stock preparation, paper machine systems, and kraft chemical recovery; energy savings through use of variable-speed drives, high-efficiency motors and upgraded turbine generators; use of more wood or bark for fuel	Lower wood requirements due to gains in wood utilization efficiency, especially in older bleached kraft and sulfite mills; offset somewhat by more use of wood for fuel
Better recycled fiber recovery, improved contaminant removal technology for wastepaper furnish, and increased use of recycled fiber; technological responses to increased supply of recyclable paper	Improved centrifugal cleaners, slotted screens, deinking systems, and high-consistency refining; technology for removal of contaminants such as "stickies"; chemical treatment to restore some bonding strength to recycled fibers	Modest growth in recycled paperboard production, but substantial growth in use of recycled fiber in traditionally virgin fiber grades, such as kraft linerboard, semichemical corrugating medium, newsprint, and tissue
Displacement of chemical pulp fractions by modern high-yield mechanical pulp, in newsprint and tissue, and to some extent in printing and writing paper, reducing capital requirements and wood costs	TMP and CTMP with higher percentages of hardwood fiber will replace some chemical pulp fractions in newsprint and tissue, providing better opacity and bulk; substitution in printing and writing limited by color reversion and brightness	Higher yield and cost savings; increased use of hardwoods with CTMP
Continued adoption of improved pressing technology in papermaking, reducing sheet drying costs, increasing throughput, and improving product quality	Wide-nip and high-impulse press sections will continue to be installed in linerboard mills, and will be installed in mills producing other grades	Increased ability to use hardwood and recycled fiber in kraft linerboard; higher production rates; energy and capital cost savings
Commercial adoption of impulse drying, press drying, or related improvements in pressing and drying technology	Interfiber bonding and substantial strength improvements with higher yield pulps, especially with hardwoods, result from drying under pressure or simultaneous pressing and drying	Substantial savings in capital, energy, and wood requirements; increased use of higher yield pulp and more hardwood in grades like kraft linerboard
Further development of nonwoven products and improvements in sanitary products based on fluff pulp	Innovation in sanitary products and new durable nonwoven products; use of new specialty market pulps; some displacement of woodpulp by "superabsorbent" additives	More efficient use of wood fiber per unit in sanitary and nonwoven products; more use of bleached CTMP
Development of laminated paper and packaging products	Development of laminated or coextruded packaging structures based on paper or paperboard with plastic or metal foil surfaces	Expanded product market potential, but lower wood use for current paper and board packaging
Continued displacement of some fiber products by plastics and other substitutes	Continued innovation and substitution of plastics in packaging, especially food packaging, bag and grocery sacks, and shipping containers; use of synthetic polymers to reinforce paper and paperboard	Decline in the long-term rate of growth in demand for packaging grades relative to GNP and population growth

Table 141.—Continued.

Type of development	Description	Impact
Substitution of paper by electronic means of communication and information storage	Gradual long-term displacement of print media and written communication by electronic and computer technology; short-term complementary effects on demand for printing and writing paper	Decline in the long-term rate of growth in demand for newsprint and printing and writing grades relative to GNP and population growth
Regulation related to recycling	Decreasing availability of sanitary landfill capacity and escalating waste disposal costs are prompting legislative initiatives on recycling	Increased supply of recycled fiber from wastepaper
Increased demands for product uniformity and quality control; better control of inventory in packaging and shipping	Improvements in instrumentation and on-line testing for product quality control, mill test labs, and computer controls in production;	With the assurance of better quality control and uniformity, lower basis weights will be acceptable in some markets; more consumer demand will be satisfied per ton of product output

Table 142.—Potential technological developments in pulp and paper processing not included in the projections.

Type of development	Description	Impact
Expanded use of new chemical treatments to improve properties of paperboard products	Chemical impregnation to increase strength and moisture resistance; chemical saturation for flame resistance	Improved product performance can be achieved for specialty applications
Expanded use of anthraquinone (AQ) in kraft, sulfite, and soda pulping	AQ additives provide marginal enhancement of chemical pulping processes; neutral sulfite AQ process is an alternative to bleached kraft for high tensile strength products	Marginally higher pulp yield is achieved, but concept is limited by cost of AQ chemical, plus differences in capital and energy inputs
Biological fiber treatment, and "biopulping"	Pretreatment with biological lignases or fungi prior to mechanical pulping; treatments could include biobleaching	Improved efficiency in mechanical pulping processes with application of biotechnology, but development is in early stages
Advances in biological effluent treatment systems	Use of microbial agents for decolonization, removal of waste, and improvement in effluent treatment systems	Improved efficiency in effluent control and waste treatment; potential impact on optimal pulp yield or pulping process
Commercial development of nonsulfur chemimechanical pulping process (NSCMP)	Potential application in corrugating medium and linerboard mills; a relatively high yield process suitable for small or medium size mills using hardwoods or mixed species	Elimination of inorganic sulfur emissions; less wood input with higher pulp yield
Organisolv pulping	Development of pulping processes based on organic solvents instead of water; includes alcohol pulping as a substitute for kraft, and ester mechanical pulping with chemical recovery	Economic advantages derive from higher yield and lower capital costs; likely to require additional development
Fiber-based structural products	Development of molded fiber structural components and products; includes potential products reinforced with high-strength polymers or carbon fibers;	New product market potential for use of wood fiber in high performance products, but mass-commodity markets likely to be met by lower cost solid-wood products
Production of new food substances for animals or humans using wood or pulpmill by-products	Traditional examples include vanillin, torula yeast, animal feed molasses, shiitake mushrooms, wood chip animal fodder and ruminant feed	Product development likely to be limited except in a national emergency
New chemicals from wood	Various chemical feedstocks can be produced from wood, in addition to the conventional silvichemicals, naval stores, lignosulfonates, and other pulp mill by-products; direct acid hydrolysis, "wood-to-oil" processes, and fermentation offer alternatives	Technologies will remain available, but will not likely be developed so long as adequate supplies of petroleum, coal, and other resources are available at low cost
Substitution of wood fiber by kenaf or other natural fibers	Kenaf, bagasse, straw, cotton, and other natural fibers are used for specialty products, or in regions of the world with scarce wood resources	Limited development potential in the United States because of abundant wood resources

Table 143 describes the processes used to make selected paper and board grades. The table describes those processes which are currently available as well as those future processes that are expected to become available in the next 50 years. For example, in making newsprint, there are four processes which are currently used. Newsprint processes one and two use mostly mechanical pulp with smaller fractions of chemical pulps. Newsprint process three uses only wastepaper, and has a lower nonfiber manufacturing cost than processes one and two. Newsprint process four uses equal amounts of mechanical pulp and wastepaper. Another example is unbleached kraft, for which two current processes and two future processes are identified. Unbleached kraft processes one and two use principally chemical pulp with only a small portion of wastepaper. Unbleached kraft process three, a future process, uses higher yield kraft pulp and more hardwood. Another future process, unbleached kraft process four, shifts a substantial portion of the furnish to high yield mechanical pulps, while further increasing the amount of wastepaper used. Nonfiber manufacturing costs are the highest for process one and the lowest for process four.

The projections of paper and board, woodpulp, and pulpwood in Chapter 7 are based, in part, on projections by product grade and process. Figures 82 and 83 show

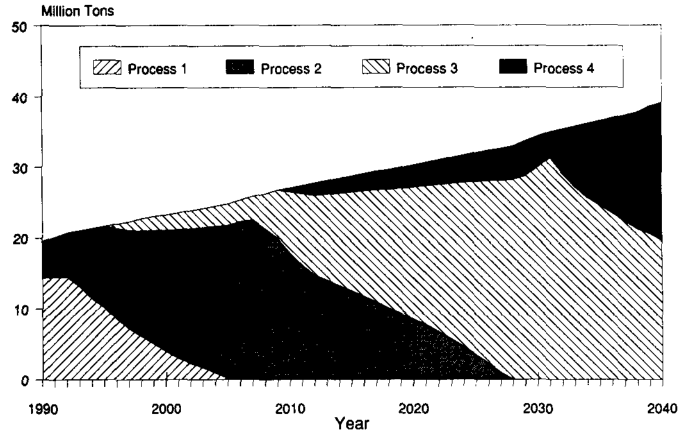


Figure 82.—Unbleached kraft production in the United States by process.

the production of unbleached kraft and newsprint by process. For unbleached kraft, the projections show a shift from processes one and two to processes three and four, Newsprint process three, which uses only wastepaper, is projected to become the dominant process for manufacturing newsprint in the United States, although the Canadians are expected to continue to make newsprint largely from raw wood fiber.

Table 143.—Fiber consumption and date of availability of paper and board manufacturing processes, by product grade.

Product grade	Chemical pulp	Mechanical pulp	Wastepaper	Nonfiber costs per ton of product	Date available[1]
	Fiber consumption				
	Percent			*1986 dollars*	*Year*
Newsprint					
Process One	25	75		360[2]	—
Process Two	9	91		386[3]	—
Process Three			100	351[2]	—
Process Four		50	50	399[4]	—
Unbleached Kraft					
Process One	93		7	177[3]	—
Process Two	85		15	156[3]	—
Process Three	85	15		140[3]	1,995
Process Four	50	30	20	133[3]	2,010
Semichemical					
Process One	60		40	201	—
Process Two	90		10	214	—
Process Three		100		215	2,000
Solid Bleached					
Process One	100			460	—
Process Two	37	63		370	1,995
Recycled					
Process One			100	230[3]	—

[1] *No year is specified for processes that are currently available*

[2] *North and South.*

[3] *South.*

[4] *Rocky Mountains and Pacific Coast.*

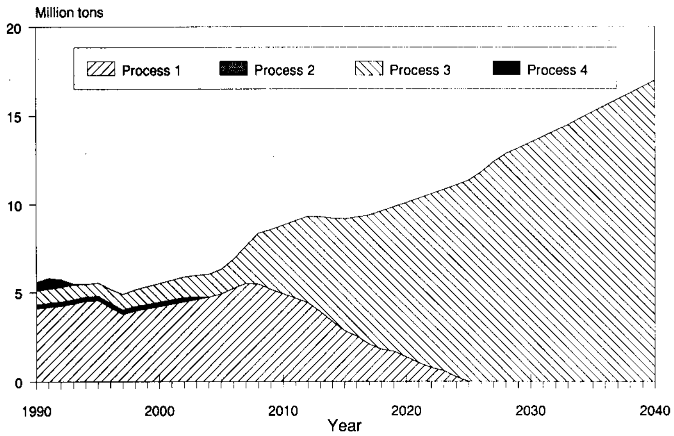


Figure 83.—Newsprint production in the United States by process.

Wood Product Use in Construction

Construction, and repair and alteration of houses, apartments and nonresidential structures use most of the structural lumber and structural panels that are produced (tables 95 and 98). There are many opportunities to improve construction practices to reduce the volume of wood used while maintaining the quantity and quality of construction (Row and Hagenstein 1988). There are also opportunities to expand wood use, such as use of wood in place of concrete in making residential housing foundations.

Possible Changes in Technology

There are many ways to save wood in construction because most wood structures are built stronger than needed (NAHB Res. Foundation 1971). Although this has long been recognized, builders continue to rely on conservative practices that waste material. For example, 90% of exterior wall framing is spaced at 16-inch intervals (McKeever 1988) even though 24-inch spacing gives adequate strength for one-story homes and the top floor walls of multistory structures. Similarly, 91% of interior walls space framing at 16-inch intervals. Even in roofs, where structurally efficient wood trusses are widely used, 28% of roof framing is placed at 16-inch intervals.

Overdesign is partly a holdover of practices imposed by older technologies. Sixteen inch spacing probably stems from the time when walls were plastered over wooden lath. Tradesmen found it difficult to plaster on lath when studs were spaced more than 16 inches apart. In modern times, most walls are finished with plasterboard that easily spans 24 inches. Approximately 400 board feet of lumber could be saved in walls and partitions of a typical single-family home by converting to 24-inch spacing.

Where walls intersect to form corners, it is necessary to provide supports for finish wall sheeting. This has traditionally been done by using an additional stud at intersections. Three-stud corners could be replaced by metal brackets that are available to support wallboard. In a typical home, the elimination of 3-stud corners could save about 100 board feet.

Overdesign extends to floors where bridging between joists and overlapping of joists on the center girder are common. But bridging adds nothing to the strength of a floor, and joints that are butted on the center girder instead of overlapped can be adequately held together by metal plates and plywood subflooring. Additional material could be saved by using l-inch boards for header joists (at the end of the floor joists) instead of 2-inch stock. Shorter joists may be used with an “in-line” joist system where one joist is cantilevered (extended) over the center girder and held to a second shorter “in-line” joist by a structural splice. Stress is reduced in the overhanging (extended) joist. Structurally sound floors have also been built using only l-inch wide stock, but this reduces the nailing surface (Hanke 1986). A more practical approach is to continue to use 2-inch stock, but with narrower dimensions such as 2x8s instead of 2x10s. The amount of lumber saved by using smaller joists, thinner headers, and butted joints is about 700 board feet in an average size home; but the nationwide impact of such a change would be about half that savings per home since about half of new homes are built on a concrete slab and use no lumber for flooring.

Adoption of "optimum value engineering” practices such as those listed above could save 10-15% of the dimension lumber required in a conventional house. Another way to economize on wood use in a building is to develop more efficient building materials. The metal plated wood roof truss is one example. Roof trusses transfer loads to exterior load bearing walls, eliminating outward thrust and the need for interior load bearing walls. Wood roof trusses are widely used in all construction sectors in increasingly diverse shapes and configurations. A high percentage of residential structures already use trusses; thus, increased savings due to expanded use in housing is limited.

A more recent wood saving product is the prefabricated wood I-joist. I-joist design recognizes that the most critical parts of a member are its top and bottom edges, Accordingly, most of the material is contained in the two flanges (the edges). The flanges are connected by a web of plywood or structural flake board. I-joists are usually used in floors where they replace traditional 2x10 and 2x12 joists, but they can be used for longer spans up to 40 feet. Because they are a fabricated product, they can be made in continuous lengths. They are also less likely to shrink and swell over time and thereby reduce the likelihood of squeaky floors. They are lighter and stronger than lumber, and precut holes in the web easily accommodate piping and duct work. Web stiffeners are required at points where they support load bearing walls and lateral support is critical in many applications.

Another engineered product that saves wood is laminated veneer lumber (LVL). LVL is a solid structural product made from 1/10 or 1/8-inch thick veneers, laid together in parallel grain pattern, coated with waterproof adhesives which are cured by heat and pressure, with lengths ranging up to 80 feet. It is somewhat stronger

Engineered wood structural members are used frequently in nonresidential structures. (Credit: USDA Forest Products Laboratory)

and stiffer than lumber. LVL has been used for flanges of I-joists, headers and beams, concrete forms, scaffold planks and partition framework. It has found uses in prefabricated housing where its higher strength is better able to resist forces while house sections are moved.

Structural members are also being made from reconstituted strands of wood. A product is being made by laminating long strands of wood with exterior adhesives and heat pressing into shapes similar to dimension lumber. Its properties and uses are similar to those for LVL.

Stressed skin panels, consisting typically of two outer layers of plywood or oriented strand board with foam insulation in the core, can reduce wood use in timber frame residential construction and construction of industrial and commercial buildings. In timber frame construction and many industrial/commercial buildings, the loads are carried by a few key members. The intervening bays require only a nonload bearing wall. This means that the structural requirements on the wall are less than for walls in light frame construction. A conventional built-up system using 2X4S and foam sheathing results in overdesigned wall sections and inferior insulation. In contrast, stressed skin panels require less lumber and provide superior insulation performance. These panels may be used in roofs as well as walls in industrial/commercial buildings.

Decay of wood in structures due to moisture is a serious problem and an increasing concern since insulation in walls has increased which may lead to greater condensation. Correcting this problem will hold down need for wood use in repair. Under winter conditions, humidity from the building enters into the framing cavities and condenses. This reduces the R value of the insulation, and promotes fungus growth, which leads to decay. Proper installation of polyethylene vapor retarders avoids the problem, but proper installation is difficult in practice because of the many breaks in the sheet to accommodate electrical outlets and the like. An alternative system, called the Airtight Drywall Approach (ADA), uses gaskets between the framing and the interior drywall only (Lstiburek 1985). The vapor retarder is the painted drywall. The system is based on the idea that infiltration through gaps in the barrier, rather than the permeability of the barrier, is the chief cause of excessive vapor transmission. By closing off infiltration routes with gaskets, infiltration is decreased, and drywall is less likely to be inadvertently punctured during construction than a plastic barrier. Studies have shown that if air vapor movement from the inside of the structure is controlled, moisture build-up in insulated walls is not severe enough to cause structural decay.

The rate of adoption of the wood saving techniques mentioned above will depend in part on the in-place costs of wood products and the resultant pressure to reduce wood cost and wood use.

Substitution Between Wood and onwood Materials

Wood use may decrease or increase in certain types of construction as its competitive position changes with respect to steel and concrete. In evaluating suitability for various types of construction, wood products are compared to steel and concrete in structural capability, fire resistance (in large structures), insulation, and cost.

The main structural property of concrete is its compressive strength. In addition, reinforced concrete possesses good tensile strength. But these favorable properties are in excess of what is typically required in residential and smaller commercial structures. At over $100/cubic yard, this material is expensive for the required performance levels in such structures. Moreover, other positive features of concrete, such as its fire insulating capabilities and low sound transmission, become crucial factors only in large structures. The superior strength of concrete becomes economic only when it is fully utilized, e.g., in larger structures. Thus, no major displacement of wood by concrete is expected in most construction markets.

One area where concrete is used in light frame construction is for basement walls and footings because it is impervious to decay by soil organisms. Improper curing, however, may lead to basement walls that leak and opportunities to use treated wood products for foundations. A chemically treated but otherwise conventional stud and plywood wall may be placed over a coarse gravel footing. The key element is a drainage path through the gravel to a gravel bed under the floor where the water collects and is removed by a sump pump or is diverted by pipe to daylight. By not allowing moisture pressure to build up, leakage is eliminated, and the chemical treatment makes the structure durable and lasting. Preserved wood foundations generally cost less than poured concrete and are slightly more economic than concrete block due to speed of installation (Spelter 1985a). But quality control requirements (use of galvanized steel nails, proper chemical treatment, proper installation technique, etc.) are strict and the system has not been as widely adopted as initially thought, although many homes in colder climates have been built with chemically treated wood foundations.

Like concrete, steel has superior strength properties compared to wood, and can cost less than wood in some cases. But the rate that heat is conducted through a 2x4 steel stud is about two and a half times that conducted through a wooden stud. Sound transmission through steel is also greater. These drawbacks cannot be overcome without incurring expenses that negate what initial economic advantage may exist, Nevertheless, steel construction is more likely than concrete to displace wood, particularly in larger residential and mid-sized commercial structures. The degree of displacement will depend on relative changes in in-place wood and steel costs .

Projected Wood End-Use Rates in Construction

Projected wood use rates in this analysis take into account the potential effects of technology developments mentioned above and the expected changing competitive position of wood materials compared to steel and concrete. The rate of change in use rates is driven by the economic pressure of changing in-place wood prices and changing in-place prices for steel and concrete. Higher prices for wood will increase adoption of wood saving practices and decrease the competitiveness of wood versus steel and concrete in selected applications, Under the economic scenario portrayed in the base projections in Chapter 7, use of softwood lumber per square foot of floor area in residential construction declines by 24% between 1986 and 2040 (table 144). Total structural panel usage is more stable, however, because one consequence of more efficient lumber use is a need for thicker structural panels in walls, roofs and floors.

Wood needed per household for repair and alteration is projected to remain relatively constant for softwood lumber and plywood, but is expected to increase for oriented strand board and waferboard. Wood use per dollar of nonresidential construction is projected to remain stable for softwood lumber, and rises slowly for structural panels as declines in use of softwood plywood are offset by increases for oriented strand board and waferboard (table 145).

Table 144.—Single-family and multifamily average floor area and wood product use per square foot of floor, 1986, with projections to 2040.

Year	Average floor area	Softwood lumber	Structural[1] panels
	Square feet	*Bd. ft./ sq. ft.*	*Sq. ft. 3/8-inch basis per sq. ft.*
		Single-family housing	
1986	1825	6.3	3.4
2000	1950	5.9	3.2
2010	1975	5.5	3.3
2020	1990	5.2	3.3
2030	2000	5.0	3.2
2040	2010	4.8	3.2
		Multifamily housing	
1986	956	4.2	2.6
2000	1065	4.0	2.5
2010	1080	3.9	2.5
2020	1090	3.7	2.5
2030	1100	3.6	2.5
2040	1100	3.6	2.5

[1]*Softwood plywood and oriented strand board/waferboard.*

Table 145.—Wood product use factor indexes for housing alteration and repair, nonresidential construction, manufacturing and shipping, 1986, with projections to 2040.

Year	Softwood lumber	Hardwood lumber	Structural panels
		(1986 = 100)	
		Housing alteration and repair[1]	
1986	100	—	100
2000	100	—	111
2010	105	—	113
2020	105	—	117
2030	105	—	120
2040	100	—	124
		Nonresidential construction[2]	
1986	100	—	100
2000	100	—	127
2010	100	—	103
2020	100	—	108
2030	100	—	112
2040	100	—	115
		Manufacturing[3]	
1986	100	100[4]	100
2000	80	74	95
2010	74	57	89
2020	69	42	85
2030	67	39	80
2040	65	18	76
		Shipping[3]	
1986	100	100	100
2000	61	83	82
2010	45	79	66
2020	35	68	62
2030	27	57	63
2040	24	46	66

[1]*An index of board feet (or square feet) per household per year.*
[2]*An index of board feet (or square feet) per constant dollar of construction.*
[3]*An index of board feet (or square feet) per unit of the Federal Reserve Board index of manufacturing output.*
[4]*An index of board feet per unit of furniture production.*

Wood Product Use in Manufacturing and Shipping

Manufacturing and shipping consume more lumber and panel products than for any use except new residential construction. Manufacturing, as defined here, includes production of furniture, other wood products made for sale,[52] and wood products used in various production processes. Shipping includes pallets and skids, wooden containers, and dunnage, blocking, and bracing. In 1986, an estimated 72% of all hardwood lumber consumed was for manufacturing and shipping (7.3 billion board feet). Lesser volumes of softwood lumber (4.3 billion board feet), and structural panels (1.6 billion square feet, 3/8-inch basis) were also consumed. Nonstructural panel consumption for manufacturing and shipping was 44% of total consumption in 1986 (8.0 billion square feet 3/8-inch basis) (table 21). Nonstructural panels include hardwood plywood, hardboard, insulating board, particleboard, and medium density fiberboard.

[52]*Includes sporting goods, musical instruments, boat-building and repair, toys and games, luggage and trunks, handles, wood pencils, mortician's goods, shoe and boot findings, wooden matches, commercial refrigeration, signs and displays, patterns and jigs, truck bodies and trailers, general machinery, agricultural implements, electrical equipment, and textile machinery supplies.*

Improvements in manufacturing and shipping technologies have the potential to decrease or increase wood consumption. Technology changes may decrease wood use by enabling producers to use less wood in manufacturing process, in finished products, and in packaging and shipping of the finished products. Other technology changes may increase wood use by permitting substitution of wood parts for nonwood parts, by requiring more wood per unit output, or by opening new markets for wood products. Technology changes may also extend timber supply by allowing products to be made from trees, logs and lumber of previously unused species, sizes or grades.

Furniture and pallets are the largest users of wood in manufacturing and shipping. In 1986 furniture production used 43% of the lumber used in manufacturing, and pallets used 93% of the lumber used in shipping (tables 11 and 12). These products have traditionally been large users of hardwood lumber. Half of all lumber used in furniture, and more than three-fourths of all lumber used for pallets is hardwood (McKeever and Martens 1983, McKeever et al. 1986, McCurdy et al. 1988).

The production of furniture, and, to an increasing extent, the production of pallets, tends to be highly mechanized. Adoption of new technologies by furniture and pallet manufacturers can hold down timber demand by reducing the amount of wood used per unit of output. Selected technologies likely to affect furniture and pallet production are discussed below.

Possible Changes in Furniture Production

There are several technology developments which may reduce the wood needed to make a given furniture part, or reduce the proportion of high grade lumber needed to make a given set of parts. Technologies being developed could increase the efficiency of the breakdown of hardwood lumber and, to a lesser extent softwood lumber, to make furniture parts. These technologies are the Automated Lumber Processing System (ALPS) (McMillin et al. 1984), and YIELD-O-MATIC. ALPS and YIELD-O-MATIC are in the basic development stage, and are not expected to be commercially available for more than 10 years. Both systems will increase both lumber recovery value and volume. Growth and improvements in existing technologies such as edge, end and finger jointing; computer assisted cross and rip sawing; and better finishing of less desirable species are now increasing both lumber recovery value and volume. Other technologies such as computer numerical control of woodworking operations in furniture plants will lower costs by speeding production, improving accuracy, and using labor more efficiently.

Technology improvements in structural and nonstructural panel processing will increase the substitution of panels for lumber, and the substitution of nonstructural panels for structural panels. As a result, demand will increase for hardwood veneer and panels using paper overlays. These two types of substitution will reduce the demand for medium-to-high grade hardwood lumber, and will hold down timber demand generally as a greater proportion of product volume uses more efficient panel making techniques to convert logs to products.

Other factors affecting the use of lumber and wood products for furniture include changing consumer preferences for wood versus nonwood furniture, particularly for higher value furniture, the relative cost of producing furniture from wood verses other materials such as steel, and the competition from foreign producers. We expect increased use of nonwood materials in low-to-middle quality furniture, and relatively constant use of wood in high value furniture. Foreign trade in unassembled wood furniture and parts is expected to increase.

Projected Wood Use Rates in Furniture Manufacturing

The overall impact of technology changes and other factors on wood use in furniture manufacturing are summarized in table 145. Overall, hardwood lumber use per unit of furniture production is expected to fall over the next 50 years even though use may increase for high value furniture. The decline will be caused by several factors, including technology changes that increase the efficiency of lumber conversion to furniture parts, substitution of panels for lumber, substitution of nonwood materials for wood in low-to-middle quality furniture, and increasing imports of unassembled wood furniture. Softwood lumber and structural panel use are also expected to decline, but not as much as hardwood lumber. This is because the relative lower cost of these products makes substitution of other nonwood products less profitable. Nonstructural panel use is expected to increase.

Possible Changes in Pallet Production and Use

The pallet industry is the single largest consumer of lower grade hardwood lumber. One-third to one-half of all hardwood lumber is used for pallets. Pallets have traditionally been a means for sawmills to use the lower grade lumber they produce. They produce one or two types of pallets using little or no automated equipment. Today up to half of all pallets are produced using nailing machines and a limited number of producers have large, modern facilities with automated sawing, lay-up, and nailing, and a large product line. There is great potential for raw material savings through increased use of these new sawing and pallet construction techniques.

The greatest potential for saving wood in pallets is from increased use of new computerized pallet design systems. Pallets have traditionally been designed to support the heaviest possible load. This results in excessive lumber use. Computerized pallet design systems permit producers to quickly change pallet design based on the type of load. More efficient lumber use will result as the pallets are better matched to their loads.

Wood use in pallets may also be affected by a shift from reusable to expendable pallets. Expendable pallets will use less wood per pallet, but due to a shorter life, more will be produced. Reusable pallets require more wood but last longer, especially with repairs. Another shift that could save large amounts of wood would be the salvage and repair of reusable pallets. Salvage and repair is expected to increase with increasing costs of pallet production and disposal of damaged pallets. Mechanical pallet dismantles will make pallet repair operations more profitable.

Lumber consumption in pallets may also decrease as more composite materials are used in pallets. Pallet decks made from structural panels provide a flatter, more uniform surface than lumber decks. Pallets made from molded particleboard can be custom made to meet the specific transportation needs of products.

Growth in pallet production is also expected to be held down with increasing competition from substitute materials-handling products, such as plastic slip sheets, and from increasing saturation of industries that can use palletized shipping.

Projected Wood Use Rates for Shipping

The overall impact of technology change and other factors on wood use for shipping are shown in table 145. Hardwood lumber use in shipping per unit of manufacturing output is expected to decrease over the next 50 years. The decrease will be caused by several factors, including technology changes that increase the efficiency of lumber use in pallets, substitution of panels for lumber, a trend towards greater re-use of damaged pallets, and increased use of pallets made from nonwood materials. Use of oriented strand board and waferboard in shipping per unit of manufacturing output is expected to increase as it becomes an acceptable substitute for lumber decking. Softwood lumber and plywood use are also expected to decline with the rapidly declining use of wooden containers in favor of paper and plastic, and the virtual elimination of wood use for dunnage, blocking, and bracing during transportation. A small increase is expected in the use of nonstructural panels.

Wood Use for Energy

Wood, together with bark, is most widely converted into energy by direct combustion in many types of burners. Black liquor, a woodpulp byproduct, is also used to produce energy at pulp plants. Some wood or black liquor is used to produce electricity in cogeneration plants. Technology is also available, although not always economical, to (1) convert wood to gas by thermochemical gasification and burn it in boilers, driers, and kilns or internal combustion engines; (2) convert wood to synthesis gas for manufacture of liquid fuels such as methanol, or chemical feedstocks; (3) convert wood to gas, liquids and solids (such as charcoal) by pyrolysis; and (4) convert wood to other liquid fuels such as ethanol by hydrolysis and fermentation.

Recent and future technology improvements in converting wood to energy will improve wood energy's competitive position relative to alternate fuels and increase wood energy use. Technology improvements will also improve the efficiency of wood conversion to energy and tend to hold down wood demand for energy.

With decreasing fossil fuel supplies and environmental and economic problems in the use of other alternatives such as nuclear energy, there is an overall tendency for increased use of wood for energy. Wood use for energy has both environmental benefits and costs. Unlike much coal and some petroleum, wood has little or no sulfur and appears less likely to produce oxides of nitrogen during combustion. Therefore wood burning emissions are less likely to contribute to the production of acid rain. This is in contrast to fossil fuels which increase atmospheric carbon dioxide content and may cause damage because of the greenhouse effect (Zerbe and Skog 1988). However, caution must be used to prevent excessive removal of biomass in forest harvests to avoid nutrient depletion or increased potential for soil erosion. Wood burning may have other environmental costs. Combustion of wood in inefficient combustors without proper controls adds smoke and particulate emission to the air. This problem has resulted in development of residential wood stove performance regulations by the U.S. Environmental Protection Agency which limit particulate emissions. There has also been concern about proper combustion of wood contaminated with other materials such as paint, adhesives, and/or preservatives.

Improved wood conversion technology may make wood for energy more competitive, even with oil prices increasing more slowly than anticipated. But, a major factor in using more wood for energy is high cost of forest harvesting. It is prudent to use wood for energy that is less valuable and less suited for use in other consumer products. However, the lower value wood is often from smaller trees that are more expensive to harvest. Harvesting is also more expensive for lower density stands and stands that have a higher proportion of hardwoods rather than softwoods.

While harvesting of small trees for fuel maybe expensive, increased use of logging residue may be an inexpensive way to aid in forest management. In public and private forests under management for timber production and other purposes, there are significant management costs from cleanup after logging operations. Often brush from logging operations is broadcast-burned to prepare land for new tree growth. This is costly and subjects the atmosphere to more particulate loading. On some national forests in California, broadcast burning is avoided through cleanup credits for harvesting excess wood for energy. In some areas of California, dense brush in forests at urban-forest interface areas is being successfully harvested for energy, thereby significantly decreasing the fire hazard to houses at the forest perimeter.

Possible Changes in Technology

Use of wood for energy may be divided into three roughly equal categories of consumption. These are residential wood burning, black liquor burning, and industrial wood waste/roundwood burning. Lesser, but growing, amounts of wood are consumed in power generation and commercial and institutional applications.

For residential use of wood for energy the traditional approach has been roundwood consumption in fireplaces or simple stoves. Fireplaces are inherently inefficient and are more esthetic than utilitarian. However fireplaces are being used more efficiently with newer technology developments in the control of makeup air and hot air distribution, and in the use of better designed insert units (stoves) for fireplace spaces. Stoves are also being designed to use roundwood more efficiently with better control of air for combustion.

A newer development in residential wood burning is the combining of improved fuels with improved combustion units to attain more efficient and more automatic operation. Fuels may be made more efficient, cleaner burning, and easier to handle by control of size and moisture content. Examples are dried chips and pellets. A new product is chunkwood which comes in larger size particles, and may be more efficient to produce, handle, and store. More sophisticated stoves and furnaces have been designed to take advantage of improved fuels such as pellets.

In industrial applications, older boiler technologies such as the Dutch oven and traveling grate are still operating satisfactorily, but new technologies including the fluidized bed and gasification are providing advantages in combustion and emission control, Promising developments for industry in the future are a gravel bed combustor; new technology for gas, liquid, and char fuels; and burning wood in combination with coal.

Development of a pressurized gravel bed combustor may allow wood to be used to power gas turbine engines, primarily for generation of electricity. Advanced industrial and utility power systems often use gas or liquid-fueled gas turbine engines. They burn fuels directly in a turbine, without going through an intermediate heat exchanger to heat air for use in the turbine. This is an efficient means of generating electricity. Using coal or wood combustion gases to directly power a gas turbine has yet to be accomplished commercially, primarily because the ash can cause erosion, deposition, and corrosion of the turbine blades. The size, distribution, concentration, and composition of the ash, as well as the turbine design, determine the lifetime of the turbine blades. New direct combustion turbines using pressurized gravel bed combustors to alleviate these problems are under development (Ragland and Baker 1987). Successful completion of this work could make wood power generation in the range from 10 MW to 50 MW more competitive.

Improvements in converting wood to gas, liquid and char fuels are possible. If wood is to become a viable, more general replacement for oil as oil becomes more expensive, wood needs to be used in ways other than as a boiler fuel and residential space heating fuel. Wood may be converted to liquid and gaseous fuels and to improved forms of solid fuel such as charcoal. Technology is available to make ethanol from wood at a cost comparable to making ethanol from corn, but this technology is only economical with a large subsidy in today's market. The current large federal subsidy which sets the pattern for state subsidies is scheduled for elimination by the end of 1992, and a more competitive liquid fuel is needed to compete in later years. Provision of gaseous fuel from wood can be achieved with known technology, but the cost of gas derived from wood is much higher than the cost of natural gas (Zerbe 1988).

Gasification and pyrolysis research may lead to more economical liquid fuels from wood such as methanol, pyrolysis oils, or conventional gasoline. For the near term, development of a viable methanol from wood process is realistic to expect. Other potential products are gas for operation of internal combustion engines, turbines, and lime kilns, and pyrolysis oils for diesel fuel.

Wood may be increasingly burned along with coal in industrial boilers. Federal regulations stipulate that for coal boilers with capacities of 100 million Btu/hr or more, the particulate emission limit is 0.05 lb/million Btu heat input if coal is burned alone; but if coal is cofired with wood, the limit is raised to 0.1 lb/million Btu heat. Emission limits for sulfur dioxide and oxides of nitrogen from combustion of coal and wood are based on total heat input, no matter what the fraction of wood used. These regulations provide an incentive to burn wood in combination with coal in large boilers, particularly in the case of high sulfur coals (Dykes 1988).

Projected Efficiency in Conversion of Wood to Energy

The preceding discussion suggests many ways that the demand for and efficiency of residential and industrial wood burning may change. The projections of wood energy use given in table 107 resulted in part from the influence of the changes discussed here. The projections in Chapter 7 assumed that the efficiency of industrial/commercial wood burning will increase at the same rate as for fossil fuels between 1985 and 2040. For residential wood burning between 1985 and 2000, the efficiency of wood and fossil fuel burning was assumed to increase, but the increase in fuel oil efficiency will be somewhat faster than for wood or natural gas. After 2000, all fuels were assumed to increase in efficiency at the same rate (tables 93 and 94).

RESEARCH AND CHANGES IN WOOD UTILIZATION TECHNOLOGY

The first two sections of this chapter discussed historic trends and prospective future trends in wood utilization technology. This section discusses the linkage between research, technological change in industry, and various economic benefits, especially changes in timber consumption and prices. The questions we address are: (1) What are the key influences on research, development and adoption of new technologies and resulting technology change? (2) How effective has past wood utilization research and resulting technology change been in creating various benefits? and (3) How effective might selected current areas of Forest Service research be in changing technology and altering timber consumption and prices?

Key Influences on Research, Development, and Adoption of New Technology

Several influences are particularly important for the forest products industry in determining the course of research and development, and the pace of adoption of new technology. These include (1) innovations imported from other industries, (2) the effect of raw material shortages, (3) the effect of economic performance of innovations, (4) problems in developing and using innovations for a heterogeneous raw material, and (5) problems in developing and using innovations for heterogeneous final products.[53]

Innovations Imported from Other Industries

Prospects for technological change in forest products are heavily influenced not only by commitment of resources to research and development within public and private institutions focused on the industry but also by developments that are remote from forest products. A study for 1974 found that lumber and wood products firms were the expected main user of $67 million (1974 dollars) of R&D performed in other industries and $64 million of R&D performed inside the industry (Scherer 1982).[54] The highest dollar value of other industry research used was in industries making machinery, motor vehicles and equipment, paints and other chemical products, and fabricated metal products (75% of $64 million). For the pulp and paper sector, the figures were $120 million and $86 million, respectively. The dollar value of other industry research used most heavily was in industries making machinery, paints and other chemical products, synthetics/resins/fibers/rubber, and computer and office equipment (55% of 120 million).

One example of use of outside technology in forest products industries has been the considerable use of sophisticated electronic components, including computers and lasers, for quality control of processing and products. The extent to which new outside technologies will be applied to forest products will depend upon the

[53] *Matarial for this section is selected from a study report by Nathan Rosenberg (1988) for the USDA Forest Service, Forest Products Laboratory.*

[54] *Excludes innovations developed by government and university laboratories.*

rate at which those technologies experience reductions in their own costs of production as well as improvements in their performance and versatility. In this respect, the future of the forest products industry is influenced by forces largely beyond its own control. Improved monitoring and evaluation of developments in other domestic industries and foreign industries could speed development and transfer of technology to U.S. forest products industries.

The Effect of Raw Material Shortages

Technology change in forest products industries although influenced by outside technology developments is also strongly influenced by the structure of raw material costs within the industry, and more broadly by the structure of costs for all manufacturing inputs and the prices of products competing with forest industry products. Here, because of our interest in timber resources, we focus on the response to raw material scarcity. The industry has an advantage in being able to predict with some confidence the trend in availability of logs of various sizes in a region 20 years ahead. But forecasting a response, including a technology response, to a particular timber trend may be difficult.

Public and private research are responsive to expectations concerning future availability of various types of timber and will develop research programs to counter the scarcity. Increasing scarcity of an input, and the associated rise in its price, calls into play a wide range of more immediate economic and social adjustments—simple conservation measures, changes in design of products, and substitution of products using more abundant materials. Technology response may include technological changes that reduce costs by reducing labor and capital requirements, or substitute more abundant for scarcer inputs (e.g., capital for material), or reduce the quantity or quality of wood input per unit of output. For example, increasing scarcity of saw logs in recent decades has encouraged use of a technology that uses smaller logs and lower quality timber in general. Also, the sharp increase in veneer log prices in the early 1970s undoubtedly spurred the expansion of waferboard/oriented strand board production which uses lower cost wood input. Expected long range and short range trends in raw material scarcity and associated trends in labor and capital scarcity, while being key influences on technology change, induce a wide range of adjustments which require a detailed analysis to sort out.

The Effect of Economic Performance of Innovations

Decisions to develop and to adopt new technologies are ultimately based upon economic performance and not purely technological considerations. Seemingly superior technologies may be adopted slowly because, when all costs are taken into account, they are not decisively cost-reducing in their impact. Most distinctly new technologies do not constitute just a slight modification in a single dimension of an existing technology. Rather, they represent clusters of new characteristics, some of which are positive and some of which are negative. Development and commercialization involves a sorting out process, in which negative features are reduced while positive ones are enhanced. One example is promising new mechanical pulping technologies, which hold out the prospect of higher yield, but are burdened with the requirement of higher energy costs (Ince 1987). The speed of adoption of innovations will turn heavily upon the nature of the positive and negative features and their relative ease of malleability. In many cases this situation gives rise to a long and costly period of development activity. When commercial introduction of an innovation is contemplated, costly new equipment is often required. Therefore, the introduction is likely to be associated with replacement of depreciated equipment or establishment of new mills. In either case, required special market conditions for inputs, or access to favorable financing may long delay introduction.

In the forest products industry there is a particular institutional feature that may significantly influence the timing of the adoption decision. Substantial research is currently done in the public sector, by the USDA Forest Products Laboratory, regional Forest Service research stations, and state universities. But commercial success usually requires more research, development, and demonstration than can be attained by a public agency. That is, fine tuning product design and characteristics to user needs, as well as further process and machinery improvements may be needed. Therefore, the final push in making improvements and adoption has to come from the private sector and must await the stimuli of changing prices or costs that ordinarily influence private firm decisions. These stimuli may be particularly important to large corporations that may be more resistant to change (Blair 1972).

After initial commercial adoption, a technology's technical and cost performance continues to change. The first application of a new technology is typically crude in comparison to characteristics eventually attained. Although this feature is shared with other industries, it may assume greater importance in forest products where improvement from one generation to the next may be slower because of difficulties in acquiring information about harvesting, processing, and using wood of widely varying properties.

Problems in Using Innovations for a Heterogeneous Raw Material

The forest products industry, if not unique, is at least at the extreme end of a spectrum of possibilities with respect to the variety of inputs that it employs in its different productive processes. Wood is an organic material with a remarkable degree of natural diversity and versatility which reflects a range of conditions: species of tree, age, location, growing space, climate, moisture, position in the tree, etc. Such heterogeneity complicates the process by which useful knowledge is accumulated and diffused within the industry. Research findings in aluminum, iron and steel, pharmaceuticals, or electronics have the potential for some immediate wider degree of generality, but the situation is very different for forest products. The behavior of wood is highly variable not only from one species to another, but even from one location in a log to another. Many of the difficulties of the industry in developing and applying innovations result from the fact that technological problems are often too subtle and too multivariate for scientific methodology to offer general guidance. It is not that the necessary information cannot be obtained, but that each relatively small "bit" of information typically has to be acquired at a slow pace and at a high cost. Furthermore, scientific information, once obtained, cannot be readily used in other contexts involving other species, subspecies, or locations. It is this inherent difficulty in the information acquisition process, and not the mature stage of the industry, that accounts for the difficulties in bringing scientific methodologies more effectively to bear upon the industry's technical problems. A major thrust of research and technological change in the industry has been to overcome these effects of input heterogeneity.

Problems in Using Innovations for Heterogeneous Products and Product Use Conditions

The heterogeneity of wood input leads directly to heterogeneity in characteristics of wood products. In addition, when placed in use, wood products face a wide range of demanding use conditions. In wood-based construction, for example, every final product, even after grading, is to some degree unique, and its required performance is unique because of the specific environment where it is used. A consequence of having heterogeneous outputs, plus long life of products in construction, is that it takes an unusually long time to sort out the contributions of separate variables on product performance. One major thrust of research and technological change in the industry is to make products of relatively uniform performance characteristics from heterogeneous inputs. Many innovations have involved taking a diversity of low quality timber and converting it into more reliably performing products with lumber-type, or plywood-type characteristics. Examples are laminated veneer lumber, parallel strand lumber, waferboard and oriented strand board. Problems of acquiring information about performance is similar for the pulp and paper sector. It may take years to clarify something as elementary as the energy requirements associated with a new pulping technology, partly because of heterogeneity among wood inputs and partly because of the varied performance requirements of the pulp.

The Impact of Past Research

Having discussed several important influences on the course of research, and development and adoption of innovations, we turn to more specific discussion of the actual effectiveness of research, development, and technology transfer efforts. In general, successful research and technology transfer efforts lead to technology change that has been shown to be a major component of economic growth and development. New technologies can create new industries, replace old products with new ones, and, in many ways, improve processes which provide goods and services. The role of public and private research in generating technical change has been examined extensively during the past several decades, and the link between investment in research and productivity growth has been repeatedly demonstrated in empirical studies (Mansfield 1972, Evenson et al. 1979, Griliches 1987).

Similarly, forest products research and resulting technology change have been major forces influencing timber resource utilization. Changes in species availability and growing stock have been accommodated by changes in forest products technology, thus averting severe dislocations and scarcity. "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" (U.S. Congress OTA 1983, p. 130).

The sweeping changes in wood utilization technology in recent decades suggest that the economic impacts of forest products research have been substantial. Until recently, however, there has been no empirical evidence to support this notion. Table 146 summarizes the results of recent economic evaluations of wood utilization research, categorized as either aggregate or case study evaluations. Aggregate studies examine the relationship between investment in research and productivity growth in an entire industry or sector of the economy. Innovation case studies focus on the impacts of specific new technologies produced by a research effort.

Aggregate Evaluations

Haygreen et al. (1986) evaluated the impacts of seven major timber utilization technologies. They compared actual research expenditures to projected benefits (net savings of timber value) due to technology adoption. Even with a very conservative assessment of benefits and liberal estimate of costs, the calculated rate of a return on the investment in forest products research is 14-36%.

Seldon (1987) used an econometric modeling approach to estimate returns[55] of research conducted to produce softwood plywood in the South. He explained the high internal rates of return—in excess of 300%—mainly by the fact that public softwood research was applied research that was quickly adopted by softwood plywood producers.

Seldon and Hyde (1989) applied Seldon's (1987) econometric modeling approach to the U.S. softwood

[55] *Returns included estimated savings to consumers in the form of lower product prices and savings to producers in the form of lower production costs.*

Table 146.—Economic evaluations of wood utilization research.

Study	Research evaluated	Time period	Measures of economic impact Marg. IRR(%)[1]	Avg. IRR(%)	B/C Ratio
Aggregate evaluations					
Haygreen et al. (1986)	Timber Utilization	1972-2000		14-36	
Seldon (1987)	Softwood plywood	1950-80	+ 300		
Seldon & Hyde (1989)	Softwood lumber	1950-80	5-30	13-47	
Brunner & Strauss (1987)	Wood preserving	1950-80			15/1 -66/1
Bengston (1985)	Lumber & wood products	1942-73		34-40	
Innovation case studies					
Bengston (1984)	Structural particleboard	1950-2000	27-35	19-22	
Mansfield et al. (1977)	Paper innovation	1960-73		82	

[1]IRR = internal rate of return.

lumber industry for the period 1958-80. Average internal rates of return of public research in this area ranged from 13% to 47% over this period, depending on several assumptions. Marginal IRR ranged from 50% to 30%.

Brunner and Strauss (1987) evaluated the economic benefits of public research and development in the U.S. wood preserving industry. Technical change in this industry involved innovations in chemical preservatives, new treatment methods, and new methods for conditioning wood prior to treatment. Using the evaluation method developed by Seldon (1987), Brunner and Strauss found significant social benefits[56] stemming from this public research. Over the period 1950 to 1980, the net present value of research benefits amounted to between $7.5 and $17.7 billion (1982 dollars) depending on several assumptions, and benefit-cost ratios ranged from 15 to 66.

Bengston (1985) estimated the rate of return to investments in U.S. lumber and wood products research from 1942 to 1973 to be 40%.[57] Recognizing that technical change in the lumber and wood products industry depends in part on innovations developed in other industries, the costs of interindustry technology flows were included in the analysis. After adjusting for the flow of technology changes from other industries, the rate of return was calculated at 34%.

Innovation Case Studies

Bengston (1984) estimated the return[58] on investment in public and private research which led to the manufacture of oriented strand board / waferboard. Oriented strand board / waferboard is a reconstituted wood panel with properties suitable for structural and exterior applications. This major innovation has a significant impact on timber utilization in North America because it uses relatively abundant soft or low density hardwoods rather than scarce softwood species. Using an economic surplus model, estimated rates of return from investment in oriented strand board / waferboard research range from 19% to 22%. Estimated marginal rates of return ranged from 27% to 35%, suggesting that even higher investments in this type of research would have produced even more attractive returns.

Mansfield and others (1977) evaluated an innovation in paper manufacture—a new paper product that cut costs for users—in an evaluation of 17 industrial innovations. They estimated the social and private returns[59] from research and development that generated these innovations. The social rate of return to research leading to the paper innovation was estimated to be 82%. The private rate of return was found to be 42%, indicating that the benefits from this innovation were shared between consumers and the innovating firm.

Conclusions

These studies confirm that many types of utilization research have significant economic returns, Some studies suggest the returns are higher than for other public forestry investments such as public nonindustrial private forest incentives or public forest timber management investments (Boyd and Hyde 1989). Utilization research has been a highly attractive investment compared to public investments generally—the social rate of return to utilization research is substantially above the return obtainable from most other public investments, which typically range from 5% to 15%. This is some evidence of an underinvestment in utilization research. An optimal level of investment is one where the returns to all investments are equal at the margin, i.e., the returns to added research investments are equal to returns on other investments (given equal levels of risk). Higher levels of investment in utilization research would be justified if, after adjusting for different risk, return on additional investment is above the average return for other public investments.

[56]See note 55.

[57]Returns included estimated savings to producers in the form of lower production costs.

[58]Returns included estimated savings to consumers in the form of lower product prices.

[59]Returns included estimated savings to consumers in the form of lower product prices and selected returns to inventors.

The Impact of Selected Areas of Current Forest Service Research

The previous section indicates how past utilization research leads to benefits in the form of lower costs to consumers for products, and/or lower production costs for producers. In this section, to more closely evaluate the potential effect of research on the adequacy of future timber supplies, we evaluate how selected current U. S. Forest Service research may, in association with other research, development, and technology transfer efforts, change future timber consumption and prices. Because of our focus on the timber market consequences of research we do not evaluate many other important potential benefits of utilization research, such as improved worker or consumer safety, or environmental protection.

To conduct this evaluation, seven areas of Forest Service research were identified which, if successful, would influence prices and consumption in timber markets. These areas ranged from basic research on certain pulping processes, to applied research on timber harvesting, to technology transfer efforts to improve lumber and plywood/veneer production. The research areas are as follows:

1. Harvesting,
2. Lumber and plywood/veneer processing,
3. Design and performance of wood structures,
4. Development of improved adhesives from renewable resources,
5. Expanded use of timber bridges,
6. Development of new or improved composite products using wood, and
7. Pulp, paper, and paperboard processing.

Scientists at the USDA Forest Service, Forest Products Laboratory (FPL) and other regional forest research stations identified how successful completion of research-development-adoption efforts would alter timber processing or demand for timber products. For many research areas, we assumed complementary research and development would be done by universities and/or industry. For each research area (other than pulp, paper, and paperboard) scientists described how research would alter such technical factors as product recovery factors, processing costs, or rate of wood use in various end-products, as well as the timing of such changes. These expected technology changes were translated into sets of changes (one set for each research area) to the base case assumptions used to make timber market projections to 2040 with the Timber Assessment Market Model (TAMM) and the Hardwood Assessment Market Model (see Chapter 7). We use 'TAMM' to refer to both models. The sets of changes were used to make separate simulation runs to project timber market conditions that reflect successful completion of each research area. Finally, we compared TAMM projections of timber and wood product consumption and prices between the base case and the altered cases. For research area 7—pulp, paper and paperboard—we used the FPL Pulpwood Model. Scientists estimated technical characteristics (pulp yield and cost) of new ways to make various grades of paper, and the timing of their commercial introduction. These new processes were inserted in the FPL Pulpwood Model to alter projections of pulpwood and paper/paperboard production and prices (Howard et al. 1988). Altered projections of pulpwood and selected paper/paperboard price and production were compared to the base case. Altered projections of pulpwood consumption were then inserted in the TAMM model and the resultant saw timber and solid product projections were compared to the TAMM base case.

The first section below explains the research being conducted in each area and the resultant anticipated technology changes as implemented in TAMM or the FPL Pulpwood Model. The section on findings explains the potential impact of the research areas in terms of differences in timber and wood products prices, differences in harvest/consumption levels, and differences in total annual product value (price times volume) between the base case and altered projections.

Harvesting

We evaluated two kinds of Forest Service harvesting research in terms of their potential impact on softwood saw timber/veneer log harvesting: (1) research to transfer analyses and ideas about which types of existing equipment are best to use in various situations, and (2) research to improve equipment and systems efficiency with new types of hardware or new designs. To implement the effect of the first research activity, we increased the pace of change in the mix of harvesting systems used (see harvesting section above and Bradley 1989). We assumed the base case system mix for the year 2001 would be achieved by 2000. To implement the effect of the second research activity, Forest Service harvesting researchers estimated how cost efficiency could be improved in various equipment systems by 2040 with continued research by the Forest Service, universities, and industry. We assumed the Forest Service would produce about one-third of the efficiency gains (in rough proportion to research expenditures). The combined effect of the two research activities, after accounting for projected changes in stand density and stem diameter, is estimated to reduce harvesting cost 5-7% by 2040 in various U.S. regions.

Lumber and Plywood/Veneer

We evaluated three Forest Service activities that will improve lumber and plywood/veneer processing: the IMPROVE program, research to use Best-Opening-Face (BOF) concepts for hardwood lumber production, and research to develop the Automated Lumber Processing System (ALPS) for hardwood lumber. IMPROVE is a technology transfer program to develop and distribute a series of personal computer programs for sawmill, veneer, and plywood industries for improving product output and profitability from existing operations. Applying BOF concepts to hardwood lumber will increase overall lumber recovery and grade recovery from hardwood logs. Research on ALPS is intended to: (1) develop tomography and computer software for internal defect detection and breakdown of logs, (2) develop computer vision and computer control for cutting lumber into furniture parts, and (3) develop lasers to cut lumber into furniture parts.

We estimate the IMPROVE program would speed up improvement in softwood lumber and plywood recovery, and reductions in processing costs. The program would also help increase hardwood lumber recovery, as described later in this report. As a result of such acceleration, we assume improvements formerly estimated to occur by 2001 would occur by 2000. By 2000, softwood lumber and plywood recoveries would improve an extra 0.3% and 0.5%, respectively, and processing costs would decrease an extra 0.5% and 0.1%, respectively.

With successful completion and adoption of BOF research to make hardwood lumber, as well as efforts in the IMPROVE program, we estimate that overall hardwood lumber recovery would increase at a rate of 1.6% per decade between 1985 and 2000, and 1.5% per decade between 2000 and 2040. In the base case, hardwood lumber recovery would increase 1% per decade.

ALPS would increase recovery of higher hardwood lumber grades by using tomography to scan for internal defects and computers to aide in breakdown. With use of this technology, we estimate 10% of the lumber formerly graded as less-than-l-common would move to l-common, and 10% of the lumber formerly graded as l-common would move to higher grades. We assume this technology would be used for 25% of lumber production by 2040. ALPS would also decrease the amount of lumber needed to produce a given quantity of furniture parts by using computer vision and computer controlled conventional or laser cutting. We assume computer vision would initially reduce lumber use per unit of furniture parts by 10% in 1995, expanding to 15% by 2040. By 2040, we assume 50% of furniture parts production would use the technology.

Design and Performance of Wood Structures

The Forest Service is engaged in 10 research activities that will improve the design and performance of wood structures. These include:

1. Development of more reliable engineered wood structural components such as wooden I-beams,
2. Improved design criteria for efficient and reliable structural connectors,
3. Accurate determination of effects of use conditions on structural components,
4. Improved resistance of wood products and assemblies to fire,
5. Improved techniques for rehabilitating wood structures,
6. Development of advanced design procedures to improve competitiveness of designs using wood relative to designs that use steel or concrete,
7. Improved adhesive-connected structural components,
8. Accurate assessment of structural lumber properties (aids in using advanced design concepts),
9. Flexible and precise nondestructive evaluation techniques to-aid grading of lumber, and
10. Development of stress class/species independent grading to enhance use of diverse species.

We judged that success in these research activities would increase lumber and panel use for nonresidential structures, and decrease lumber use and increase panel use per square foot of residential construction. For nonresidential structures, we assume that by 2010 and thereafter the research will increase lumber, plywood, and oriented strand board / waferboard use by 15% over levels in the base case by increasing the number of buildings where wood is used. This increase accounts for the fact that advanced design procedures will reduce the wood used per square foot of floor area. For single- and multifamily homes, we assume this research will accelerate technology changes projected to occur at a slower pace in the base case. For single-family homes, lumber use will decrease 15% because of more efficient design (by 2010 rather than 2040), and structural panel thickness will increase (to provide needed strength with wider stud spacing) in floors, wall sheathing and siding by an average of 7.5% to 12% by 2010. For multifamily homes, lumber use in floors will decrease slightly and average floor panel thickness will increase. Lumber use in roofs and walls is already quite efficient. The aggregate effect of research on design and performance of wood structures will be to increase both lumber and structural panel consumption above levels in the base case projections.

Adhesives From Renewable Resources

Adhesives developed from renewable resources, particularly tree components, may be important because they may be cheaper than petroleum-based phenolics if oil prices increase substantially. The availability of adhesives from renewable resources may hold down the cost of structural panels, especially oriented strand board. If adhesives from renewable resources are not available, and if oil prices roughly double to $50 per barrel (1982 dollars) by 2020, we estimate increases in phenolic adhesive prices would increase plywood prices by 5–160/. and oriented strand board prices by 46% by 2020. Availability of economical adhesives from renewable resources would hold down such panel price increases.

Expanded Use of Timber Bridges

The Forest Service has undertaken a program to promote use of timber to replace thousands of smaller bridges in the United States each year. Roughly one-quarter million bridges are in need of eventual repair or replacement. Currently, less than 1,000 timber bridges are built each year. With improved economical designs, we estimate that the annual construction of timber bridges could be increased to 7,500 bridges by 1995 and continue at that level through 2040. An average bridge would use 1,300 cubic feet of wood, for a total of 9.75 million cubic feet per year. We estimate that between 1995 and 2040, the West would produce an extra 60 million board feet per year of softwood lumber/timber for bridges, and the East produce an extra 30 million board feet of both hardwood and softwood lumber/timber. This extra production would be 0.19% and 0.33% of 1986 softwood and hardwood lumber production, respectively.

New or Improved Composite Products

Forest Service research on composite wood products includes development of steam injection pressing to form panels, chemical treatments to improve dimensional stability and water resistance of composite panels, and composites of wood and nonwood materials (e. g., plastics) for many applications.

We assume that chemicals will be injected by steam injection pressing in oriented strand board-type products to make them dimensionally stable and suitable for exterior use in construction. Specifically, treated oriented strand board will be used more widely for concrete forms in construction and for wood foundations, siding, and exterior millwork for single-family housing. We assume that by 2040 (1) treated oriented strand board will largely substitute for plywood in foundations and concrete forms, (2) treated oriented strand board will substitute for some plywood in single-family housing and will slightly expand the market, and (3) treated oriented strand board will substitute for about half the lumber millwork in exterior applications. These changes amount to a relatively small shift from plywood and lumber to oriented strand board-type products compared to the base case.

Research on composites of wood and nonwood materials could yield products that pair wood with nonwood biomass, metal, plastics, glass, or synthetic fibers. Much current research is devoted to wood-plastic composites. These composites could substitute for existing wood products such as packaging (containers, cartons, pallets) and decrease wood use, or they could substitute for nonwood products such as auto and truck components and increase wood use, We assume wood-plastic composites will have the widest use, and will, overall, tend to increase wood use. We use wood-plastic composites in auto or truck components as a proxy to indicate the overall net increase in wood use. Wood use in such composites would be 3.6 million cubic feet by 2040, assuming 15% wood use in 30% of such auto or truck components. This increased consumption is small compared to 1987 wood consumption of 18.7 billion cubic feet.

Pulp, Paper and Paperboard

We evaluated five areas of Forest Service pulp, paper, and paperboard research: improved mechanical pulping of hardwoods to make linerboard, and printing and writing paper; peroxymonosulfate pulping for cheaper, less polluting pulping of hardwoods; techniques to increase or improve wastepaper recycling; production of newsprint from 100% hardwoods; and development of Spaceboard I (a replacement for corrugated boxboard). Anticipated developments in these areas were used to make 18 changes in the way 8 grades of paper and paperboard are made in the FPL Pulpwood Model (Howard et al. 1988).

Research on mechanical pulping for hardwoods in linerboard could lead to use of pulp with yields of 85% to 95% compared to levels of 50% to 55% for conventional unbleached kraft pulp. The research may provide a means to make linerboard from 100% hardwoods with 80% yield by the year 2015—specifically, chemithermomechanical pulping (CTMP) with press drying to form paperboard. Mechanical pulping could also increase the use of hardwoods in making printing and writing papers. Research on mechanical pulping is oriented toward reducing energy consumption, increasing paper strength, and, for printing and writing grades, maintaining optical properties as needed, reducing color reversion, and achieving high brightness.

By 2010, research on peroxymonosulfate pulping may facilitate the increased use of hardwood in newsprint, unbleached kraft paperboard, solid bleached paperboard, printing and writing papers, packaging and industrial papers, and tissue. Peroxymonosulfate pulping may be able to produce a relatively high-yield pulp from 100% hardwoods that has improved bonding strength and higher brightness relative to other hardwood pulps. Peroxymonosulfate pulp could be used in combination with other pulps to make many grades of paper.

By 2010 to 2015 research on wastepaper recycling may facilitate additional increases in “use, or altered use, of recycled paper for newsprint, unbleached kraft paperboard, solid bleached paperboard, recycled paperboard, printing and writing paper, packaging and industrial paper, and tissue. To increase recycling, research is being done in the following areas: development of a disk separation process to separate contaminants from recycled fiber, improvement of means to remove contact and noncontact ink from printing and writing papers, and development of chemical and biological treatments to restore bonding strength to recycled paper fibers.

Research on CTMP and biomechanical pulping (BMP) with press drying may be successfully combined to make newsprint from 100% hardwoods. Mills using CTMP/press drying, or BMP/press drying may be possible beginning in 2015 and 2025, respectively. Combining CTMP with press drying may achieve higher sheet strength previously attainable only with softwoods. Bleaching may be needed when using certain hardwood species. Combining BMP with press drying has the possibility of increasing strength and also retaining optical properties for more hardwood species (low and medium density species).

Research may provide a new product, FPL Spaceboard I, that would replace some corrugated fiberboard to make boxes (Setterholm 1985), Spaceboard is a sandwich of two or more pulp-molded structures. The structures have a flat surface on one side and a structural waffle-like rib pattern on the other. The structures are glued together, rib to rib, to form a structural board. Spaceboard could be made with several kinds of fiber. We assume that manufacturing plants for Spaceboard I, located near large cities, will be built by 2000 and will use 100% recycled corrugated containers as raw material. We estimate Spaceboard I may replace 25%. of corrugated container board by 2040.

General Findings

As we have described, the objectives of wood utilization research are diverse. They serve a wide variety of interest groups, including forest landowners, loggers, product producers, and consumers. To conduct a welfare analysis that would identify a complete range of welfare gains and losses for all forest sector interests is beyond the scope of this study. (For an example of such an analysis see Adams et al. 1977.) Nevertheless, the limited set of measures used in our study clearly show that the interest groups who gain and lose vary from one research area to another. The approach used here is similar to one used by Skog and Haynes (1987) to evaluate past wood utilization research.

To measure market impact, we used the change in timber and wood product prices, harvest / consumption volume, and harvest / consumption deflated dollar value (1982 dollars). These measures clearly indicate gains or losses for some groups. For example, stumpage price increases or harvest volume increases that lead to increased value of harvest are a gain to landowners, whereas price increases for final products are a loss for consumers. But these measures do not clearly indicate gains or losses for producers. For example, a decrease in lumber price caused by reduced cost of timber may lead to a profit gain for producers, but a decrease in lumber price caused by reduced demand for lumber may lead to a profit loss.

For all research areas, change in price, harvest / consumption, and value were estimated for softwood and hardwood saw timber, softwood and hardwood lumber, softwood plywood, and oriented strand board / waferboard. These estimates were produced using TAMM model projections .[60] For pulp, paper, and paperboard research, change in price of softwood pulpwood, and change in production of softwood and hardwood pulpwood and selected grades of paper and paperboard were estimated. These estimates were made using the FPL Pulpwood model.

In terms of the magnitude of impact, the research areas fall into three groups. Research on harvesting, lumber and plywood / veneer, timber bridges, and composite products cause less than 5% change in price, harvest / consumption, and value through 2040. Research on design and performance of wood structures and development of adhesives from renewable resources may change the price or consumption of some products bv 5-20% by 2040. Research on pulp, paper, and paperboard may decrease softwood pulpwood consumption by 36% by 2040. A key difference between the first two categories and pulp and paper research is that the full effect of research in the first two categories is expected well before 2010, whereas the effect of pulp and paper research will not begin until 2010-2020. The six research areas (except for pulp, paper, and paperboard) are expected in the long run to lead to higher softwood saw timber prices; and with the exception of adhesives and pulp, paper, and paperboard research, to higher softwood saw timber harvest.

The percentage of change in softwood saw timber prices caused by the alternate research areas is generally greater than the change in harvest volume. This is because stumpage supply is not very responsive to price changes and solid-wood product demand is not very responsive to product price changes. As a result, the increase in softwood saw timber value caused by research in categories 1 and 2 is caused primarily by increases in stumpage price and not increases in harvest volume.

The potential decreases in pulpwood harvest volume resulting from pulp, paper, and paperboard research are much larger than any potential increase in saw timber harvest resulting from any of the research areas. The potential 36% decrease in pulpwood harvest by 2040 is equal in volume to 30% of the projected softwood saw timber harvest in 2040.

The potential decreases in harvest value—both for pulpwood and saw timber—resulting from pulp, paper, and paperboard research are much greater than any potential increase in saw timber harvest value caused by other research areas. The potential annual value decrease in pulpwood alone would exceed $1.4 billion by 2020, and $3 billion by 2040. The associated annual value decrease for softwood saw timber could be $0.2 billion by 2020, and $3.2 billion by 2040.

Findings for Specific Research Areas

Harvesting research, by holding down softwood saw timber harvesting costs, would increase lumber consumption and softwood saw timber production by a few tenths of a percent over the projection period, and increase softwood saw timber price by up to 4.2%. The annual value of softwood saw timber harvest increases by up to 4.6% ($413 million in 2030). Lower harvest cost reduces lumber prices and overall value for softwood lumber consumption by up to 0.9% by 2040. The price and consumption of plywood and oriented strand board / waferboard vary above and below the base case as variation in relative prices causes substitution between panels and lumber.

Lumber and plywood / veneer research and technology transfer raise softwood lumber and plywood conversion efficiency and lower manufacturing costs through the year 2000. Efficiency improvements result in a near-term

[60] *To try to avoid observing the effects of technology differences on short-term business cycles generated in TAMM, we compared average price and consumption levels between the base case and altered cases. Averages were taken for 9-year periods around 2000, 2010, 2020, and 2030.*

reduction in softwood saw timber price and harvest, and a slight increase in lumber production. In the long run, lower manufacturing costs increase saw timber harvest, price, and value. The annual value of saw timber harvest increases by up to 2.3% (in 2030). Higher timber costs lead to higher lumber prices, lower production levels, and lower lumber value (by 0.4% in 2040), a counterintuitive result. Research on hardwood lumber leads to higher hardwood lumber conversion efficiency and less lumber use per unit of furniture production. This results in lower hardwood saw timber and lumber consumption, prices, and value. The value of hardwood saw timber and lumber decrease by 2.0% and 2.7%, respectively, by 2040. The price, consumption, and value of plywood and oriented strand board / waferboard vary above and below the base case as variation in relative prices causes substitution between panels and lumber.

Research on design and performance of wood structures increases consumption, prices, and value for softwood saw timber, lumber, and plywood, as would be expected. The value of softwood saw timber, lumber, plywood, and oriented strand board increases by 7.0%, 3.1%, 6.2% and 5.0%, respectively, relative to base case projections by 2040. Hardwood saw timber and lumber prices remain relatively unchanged because hardwood lumber demand is not altered (table 147).

Research to produce adhesives from renewable resources would keep down the price of adhesives as petroleum-based products increase in price, This would keep oriented strand board / waferboard prices as much as 20% lower, and plywood prices as much as 3.9% lower, These estimated price effects are greater than could actually be achieved because we assumed in our analysis that the new adhesives could keep glue prices constant at current levels. Because of the price inelasticity of demand for panels, a much lower oriented strand board / waferboard price (held down by cheaper glues) would result in only 2% higher production. Plywood production with cheaper adhesives will be lower than in the base case. This is because oriented strand board / waferboard will be in a relatively stronger competitive position with cheaper glue than in the base case. With lower glue costs, the annual value of panels consumption is $831 million less by 2040. Much of this will be saving of glue costs. The combined annual value of softwood plywood and oriented strand board is lower by 4.6% and 22.8%, respectively, by 2040. With lower glue costs there is higher timber demand for panels, saw timber and lumber prices are higher, their harvest / consumption is lower, and their change in value is mixed over time (table 147).

The expanded use of timber bridges increases saw timber harvest by roughly 0.2% and 2 .5% for softwoods and

Table 147.—Potential impact of research on engineered structures and adhesives, on price, production level, and value of various types of timber and wood products in the future.

Market characteristic and product	Design and performance of structures					Adhesives from renewable resources				
	2000	2010	2020	2030	2040	2000	2010	2020	2030	2040
	Percent difference from base case projection[1]									
Price[2]										
SW sawtimber	3.1	5.6	6.0	7.4	6.8	0.2	0.9	*	1.5	1.2
HW sawtimber	*	–0.1	*	0.1	0.1	*	0.1	0.2	0.4	0.6
SW lumber	0.9	1.1	1.3	1.9	1.4	0.2	0.5	–0.2	–0.3	0.1
HW lumber	*	*	*	0.1	0.1	*	0.1	0.2	0.3	0.4
SW plywood	1.0	2.1	3.5	0.9	6.0	–1.8	–3.4	–3.5	–3.8	–3.9
OSB/waferboard	0.2	–0.8	0.5	–0.2	–0.1	–10.0	–15.0	–20.0	–19.0	–19.0
Harvest/consumption[3]										
SW sawtimber	0.3	0.5	0.1	0.3	0.1	*	–0.1	–0.2	–0.4	–0.6
HW sawtimber	*	*	*	–0.1	*	*	*	–0.1	–0.1	–0.2
SW lumber	0.7	1.4	1.5	1.6	1.7	–0.1	–0.2	–0.1	*	0.1
HW lumber	*	*	*	*	*	*	–0.1	–0.1	–0.1	–0.2
SW plywood	0.7	1.0	0.9	1.0	0.2	–0.6	–1.2	–1.4	–0.9	–0.5
OSB/waferboard	2.3	4.5	4.7	4.8	5.0	1.3	2.0	1.6	1.1	0.8
	Value difference in millions of 1982 dollars[1]									
Value										
SW sawtimber	183	461	539	701	664	–13	–54	13	–100	–59
HW sawtimber	–1	–6	0	0	6	0	–3	–8	–18	–29
SW lumber	278	520	654	817	740	–27	–68	64	73	–32
HW lumber	0	3	2	4	3	0	0	7	13	21
SW plywood	67	137	204	93	331	–94	–211	–238	–249	–246
OSB/waferboard	37	71	110	104	127	–134	–304	–473	–513	–585

**Value is between -0.05 and 0.05.*
[1]A positive value indicates the altered case is greater than the base case.
[2]Sawtimber prices are for stumpage. Other prices are for delivered products.
[3]Sawtimber volume is for U.S. harvest. Other volumes are for amounts consumed in the United States. Net imports from Canada may change and are included.

hardwoods, respectively. Softwood and hardwood saw timber prices will increase by 1-2%. This will lead to an annual saw timber value increase of about $300 million in 2040. The value of softwood and hardwood saw timber harvest will increase by 0.9% and 2.7%, respectively, by 2040. The increased demand for hardwood lumber for bridges in the East will lead to higher consumption and prices. However, the increased demand for softwood lumber in the West and East, while leading to greater consumption, will unexpectedly lead to a mix of increases and decreases in softwood lumber price over time. The greater demand for softwood lumber will create a greater demand for softwood plywood as a substitute and result in higher plywood prices and annual plywood consumption value.

Research on composite products could lead to a decrease in softwood plywood use (1.6% by 2040), and an increase in oriented strand board / waferboard use (2.4% by 2040) and softwood lumber use. These shifts result in an increase in softwood saw timber price and harvest of slightly less than 1% by 2040. They also result in varying changes in softwood plywood and oriented strand board / waferboard price above and below base projections. As a result of the consumption and price trends altered by research, annual saw timber value is generally higher, up to $80 million higher in 2030; softwood lumber value is generally lower, up to $126 million lower in 2030; oriented strand board / waferboard value is generally higher, up to $64 million higher in 2030; and softwood plywood value varies above and below base case value projections.

Table 148.—Potential impact of selected pulp, paper and paperboard research on price, production level, and value of softwood pulpwood, hardwood pulpwood, and selected grades of paper and paperboard in the future.

Market characteristic and product	Pulp, paper, and paperboard				
	2000	2010	2020	2030	2040
	Percent difference from base case projection[1]				
Price[2]					
SW pulpwood	1.3	-0.6	-13.1	-7.2	-8.7
Harvest/production					
SW pulpwood	-0.3	-1.0	-13.7	-20.1	-32.7
HW pulpwood	-0.5	0.4	-0.8	-1.9	-0.8
	Value difference in millions of 1982 dollars[1]				
Value[3]					
SW pulpwood	39	-74	-1,304	-1,530	-2,459
HW pulpwood	-11	14	-30	-74	-353

[1]A positive value indicates the altered case is greater than the base case.
[2]Price change is from the price-endogenous portion of the FPL Pulpwood Model, which takes into account technology changes only in making semichemical paperboard, solid bleached paperboard, and recycled paperboard. Harvest change is from combined estimates from the price-endogenous and exogenous portions of the FPL Pulpwood Model and takes into account technology changes in all eight paper and paperboard grades.
[3]Softwood (SW) pulpwood value change includes price change noted in table. Hardwood value change assumes no change in hardwood prices between the base case and altered case.

Table 149.—Potential impact of research on pulp, paper and paperboard on price, production level, and value of various types of timber and wood products in the future.

Market characteristic and product	Pulp, paper, and paperboard				
	2000	2010	2020	2030	2040
	Percent difference from base case projection[1]				
Price[2]					
SW sawtimber	–6.1	2.5	–5.6	–29.0	–43.0
HW sawtimber	(4)	–.1	–.1	–.2	–2.0
SW lumber	–1.2	(4)	–4.1	–14.1	–37.9
HW lumber	(4)	–.1	(4)	–.1	–.3
SW plywood	–2.3	.8	–.1	–10.7	–10.4
OSB/waferboard	.3	(4)	.4	–2.0	–5.2
Harvest/consumption[3]					
SW sawtimber	.5	.7	3.0	11.7	16.8
HW sawtimber	(4)	(4)	(4)	(4)	–.1
SW lumber	.5	.5	1.0	3.0	4.7
HW lumber	(4)	.1	(4)	.1	.1
SW Plywood	.7	.2	.2	1.7	1.8
OSB/Waferboard	–.4	–.2	(4)	–.1	–.1
	Value difference in millions of 1982 dollars[1]				
Value					
SW sawtimber	–307	240	–241	–1873	–3189
HW sawtimber	2	–3	–2	–8	–170
SW lumber	–133	108	–729	–2690	–8243
HW lumber	1	–1	–2	–5	–18
SW plywood	–62	44	4	–460	–474
OSB/waferboard	–1	–5	–10	–47	–135

[1]A positive value indicates the altered case is greater than the base case.
[2]Sawtimber prices are for stumpage. Other prices are for delivered products.
[3]Sawtimber volume is for U.S. harvest. Other volumes are for amounts consumed in the United States. Net imports from Canada may change and are included.
[4]Value is between -0.05 and 0.05.
Sources: Forest Service harvesting research projects and scientists—Northern flat terrain: Michael Thompson, NCFES, Houghton, Michigan; Southern flat terrain: Donald Sirois and Bryce Stokes, SFES, Auburn, Alabama; Eastern mountainous terrain: Penn Peters, NEFES, Morgantown, West Virginia; Rocky Mountain: Michael Gonsior, IFRES, Bozeman, Montana; and Pacific Coast: Charles Mann and Robert McGaughey, PN WFRES, Seattle, Washington.

Pulp, paper, and paperboard research leads to substantially different effects than the other categories of research. First, the effects are expected much further in the future (after 2010); second, both pulpwood and sawtimber harvest and prices will be substantially affected; and third, the potential changes in price, harvest / consumption, and value will be much greater. Projections of pulpwood consumption using the FPL Pulpwood Model indicate that greater efficiency in pulpwood use; a continuing shift from softwoods to hardwoods; and greater recycling will lead to a 14% reduction in softwood pulpwood use and a 1% reduction in hardwood pulpwood use by 2020 (table 148), These reductions would reach 33% and 8%, respectively, by 2040. The hardwood reductions are smaller because of a shift to greater relative use of hardwoods, The 33% reduction in softwood pulpwood use is equal in volume to 27% of the projected base case softwood sawtimber harvest in 2040. The softwood pulpwood price would decrease roughly 9% by 2040. Hardwood pulpwood price would also decline given the decrease in harvest, but a specific estimate is not possible with the current structure of the FPL Pulpwood Model. If we assume no change in hardwood prices from the base case, the combined decline in annual pulpwood harvest value would be $1.2 and $2.8 billion in 2020 and 2040, respectively. For 2040, this value decrease is 39% and 8% for softwood and hardwood pulpwood, respectively.

Declines in pulpwood harvest would increase the supply of sawtimber, and lead to increased solid-wood product consumption (table 149). The largest change is for sawtimber stumpage; price decreases 5.6% and 43.0% by 2020 and 2040, respectively; and harvest increases by 3.0% and 16.8%, respectively, by 2020 and 2040. The annual value of softwood sawtimber harvest would decline $.2 and $3.2 billion by 2020 and 2040, respectively.

The FPL Pulpwood Model estimates that the price and consumption of the five grades of paper in the endogenous portion of the model would change less than 0.05% relative to the base case. This lack of change, despite substantial pulpwood cost savings, is due to the relatively small cost contribution of pulpwood to overall paper/paperboard costs, and the fact that demand for paper and paperboard is relatively unresponsive to changes in price. Annual consumption value changes are less than 0.0570. In dollar terms, the total annual value decrease for the five grades of paper and board would be $868 million in 2020 and $112 million in 2040.

Conclusions

Research on pulp, paper, and paperboard processing has by far the greatest long-term potential for altering timber and wood product prices, harvest/consumption, and value; although the research-induced changes would not occur until after 2010. Softwood pulpwood consumption may decrease by one-third, and softwood sawtimber consumption may increase by one-sixth by 2040 relative to the base case if research is successful. The value of pulpwood harvest may decrease by $1.4 and $3.0 billion by 2020 and 2040, respectively. In addition, the value of softwood sawtimber harvest may decrease by $0.2 and $3.2 billion by 2020 and 2040, respectively, because of declines in stumpage prices.

The full effects of solid-wood products research would occur well before 2010. The solid-wood product research areas evaluated would, in the long run, all increase softwood sawtimber price. Their effect on product prices and on harvest/consumption levels would vary. Research on design and performance of wood structures has the potential for increasing sawtimber and wood product value the most—by $0.6 billion in 2000 and 1.9 billion in 2040 relative to the base case.