# CHAPTER 9
# Properties and utilization of poplar wood

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## Introduction

To satisfy the increasing demand for forest products, fast-growing trees such as poplar grown on managed plantations are being seriously considered for future supply needs. This chapter discusses the properties of poplar that make it appealing for a number of different utilization options and the characteristics that cause it to have some unique drawbacks. Utilization options for hybrid poplar will also be evaluated.

The genus *Populus* includes trees that are commonly called “poplar.” The genus has a very wide distribution in North America, with various species inhabiting a triangular region stretching from Louisiana to Newfoundland to Alaska. *Populus* includes the species trembling aspen *(P. tremuloides),* bigtooth aspen *(P. grandidentata),* balsam poplar *(P. balsamifera),* eastern cottonwood *(P. deltoides),* and black cottonwood *(P. trichocarpa).* All of these species can be characterized as fast-growing, moisture-loving, and shade-intolerant medium to large trees with a short life span. The most frequently used and widely distributed commercial species are trembling aspen, bigtooth aspen, and the hybrid poplars.

In the past, poplar trees were regarded as weed trees that needed to be removed from timber stands. Most harvested aspen was used for pulp, lumber, hardboard, and insulation board. With the introduction of waferboard and oriented strandboard (OSB), aspen utilization exploded, increasing threefold from 1975 to 1989 (Fig. 1, Youngquist and Spelter 1990), with a utilization level today almost four times greater than in 1975. The utilization level has increased so much that there is a concern that the aspen cut will exceed growth and the aspen supply will not be adequate to support the growing solid wood, composite, and paper industries

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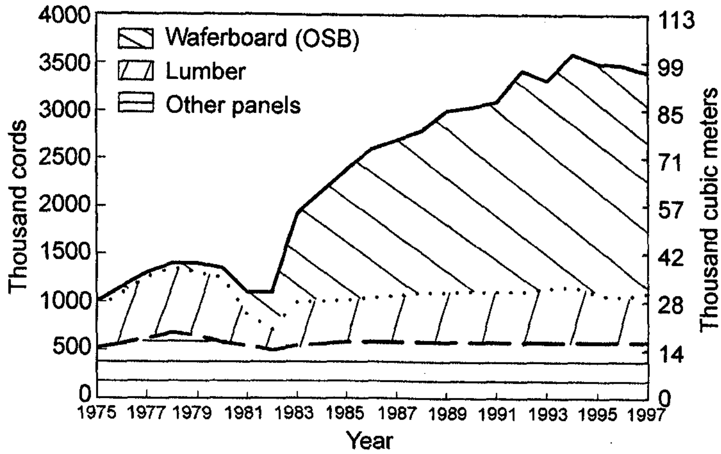
**Fig. 1.** Utilization of aspen solid wood products (converted to cords) from 1975 to 1997.




in the Lake States region (Youngquist and Spelter 1990). Poplar trees are no longer regarded as a weed species.

Hybrid poplars offer a possible solution to the potential shortage of native poplars. By hybridizing poplars, the positive characteristics of two fast-growing species can be combined to make an even more hardy and faster growing variety. Poplars are one of the more easily cloned woody species, which allows for greater availability of promising crosses.

Hybrid poplar plantations in Europe have for centuries been based on crosses of European black poplar *(P. nigra)* and the North American species eastern cottonwood *(P. deltoides).* It was not until the 1930's that North Americans began discussing the potential of hybrid poplar plantations.

During the past 30 years, much work has focused on genetics of *Populus* species (Riemenschneider et al. 1996*a, b)* to develop improved hybrids. Numerous experimental studies have been planted across the Lake States, the Pacific Northwest, and Canada to investigate improved *Populus* clones. In most improvement programs, the focus has been on growth rate, form, adaptability, and disease resistance. Chemical properties have also been investigated (Dickson et al. 1974). They found large clonal differences among hybrid poplar clones in wood chemical composition. Additional emphasis has recently been placed on improving utilization properties of the material.

Wood from hybrids that have superior growth, improved form, greater adaptability, and improved fiber characteristics for paper may be less suited to solid wood processing than wood from either parent tree. The mechanical properties of particular hybrid poplar clones for structural lumber have been investigated (Holt and Murphey 1978; Bendtsen et al. 1981; Hall et al. 1982; Brashaw 1995; Kretschmann et al. 1999). This research has shown that the mechanical properties of these trees are comparable with similar native poplar species. Fast-growing clones, however, reach harvestable size more rapidly and therefore contain greater proportions of juvenile wood (juvenile wood is the first few years growth near the pith) compared with current aspen harvests. There is still a need for a better means of predicting the final mechanical properties of a hybrid based on its parent types.

## Properties

The wood of all poplar species has relatively low density and diffuse porous structure. The average relative density (that is, specific gravity) of species grown in natural forests in North America is in the range of 0.30–0.39. The strength properties of poplars are relatively low. However, in bending strength and stiffness they compare favorably with common construction species such as spruce, pine, and fir (Table 1). Thus, poplar-based wood products (such as lumber, composite panels, and structural composite lumber products) can compete successfully with softwood-based products in the huge construction markets of North America. This is especially true for OSB, laminated veneer lumber (LVL), and structural composite lumber (such as parallel strand lumber (PSL), and laminated strand lumber (LSL)). These products are discussed in greater detail later in this chapter.

Standing poplar trees have high moisture content, typically about 100%, with only minor differences between sapwood and heartwood. Seasonal fluctuations exist, with summer values being somewhat lower than winter values. These high moisture levels make the wood suitable for cutting strands or wafers without

**Table 1.** Specific gravity and flexural properties of indigenous North American poplar species and a few selected softwoods.[a]

| Species | | Specific gravity | Modulus of rupture (MPa) | Modulus of elasticity (GPa) |
|---|---|---|---|---|
| Aspen | Trembling | 0.35 | 35.0 | 5.9 |
| | Bigtooth | 0.36 | 37.0 | 7.7 |
| Cottonwood | Eastern | 0.37 | 37.0 | 7.0 |
| | Black | 0.31 | 34.0 | 7.0 |
| Balsam poplar | | 0.31 | 27.0 | 5.2 |
| Black spruce | | 0.38 | 42.0 | 9.5 |
| Jack pine | | 0.40 | 41.0 | 7.4 |
| Balsam fir | | 0.33 | 38.0 | 8.6 |

[a] The properties are for green wood. Source: Forest Products Laboratory (1999).

steaming. Considering their low density, poplar species have high volumetric shrinkage (11-12%). Poplars also have a high ratio of tangential to radial shrinkage, which is the main cause of form defects during drying (such as cupping and diamonding).

The volumetric composition of poplar wood is dominated by the relatively high proportion of fibers (53–60%), followed by vessel elements (28–34%), ray cells (11-14%), and a negligible proportion of axial parenchyma (0.1–0.3%) (Panshin and de Zeeuw 1980). The relative density of wood is most strongly influenced by the vessel-to-fiber ratio, as well as the diameter and wall thickness of fibers and vessel elements. Notably, the aspens (such as trembling and largetooth aspen), which have higher relative density than the cottonwoods (such as eastern and black cottonwood), are characterized by vessels with smaller diameters and fibers with slightly thicker walls.

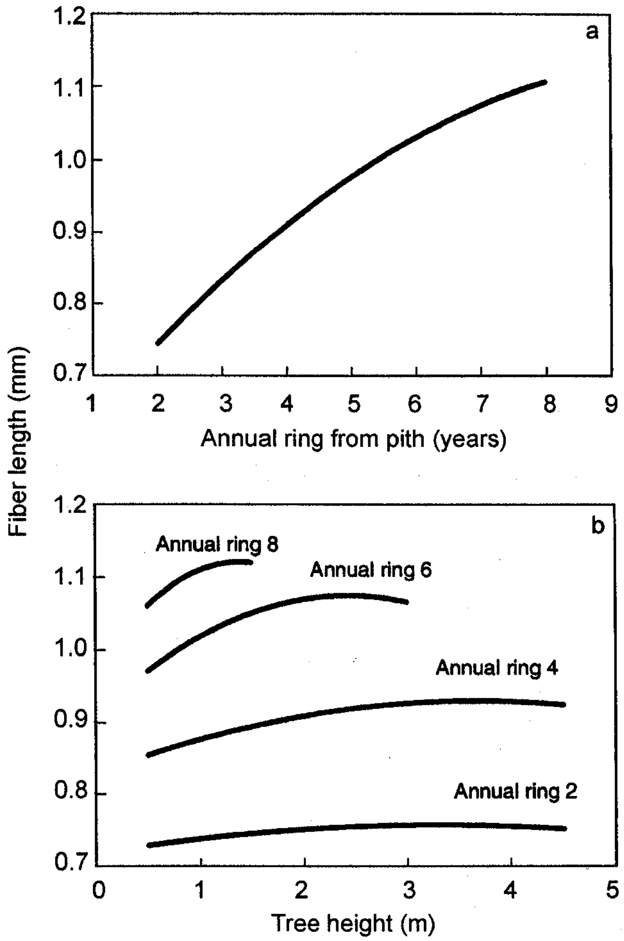
Key characteristics of the cellular structure of poplars include short fibers with small cells compared with many other hardwoods. Poplars also have considerable shrinkage (Koubaa et al. 1998a, b). The fiber length, important for papermaking, can vary considerably by clone type and height in the tree (Fig. 2, Koubaa et al. 1998b).

The average length of vessel elements in mature poplar wood is in the range of 0.58–0.67mm, whereas average fiber length ranges from 1.32 to 1.38 mm (Panshin and de Zeeuw 1980). The “paper-making fibers” (that is, tracheids) of softwoods are considerably longer (3–4mm long). These fundamental differences in fiber length explain why softwood pulps have better properties, especially in tear, burst, and breaking length. On the other hand, the vessel elements of poplar significantly enhance the smoothness and opacity of sheets, making poplars well suited for printing papers.

The chemical composition of poplar wood is characterized by high polysaccharide content (approximately 80% holocellulose, made up of 50% cellulose and 30% hemicelluloses) and low lignin content (about 20% or less). Consequently, sulfate pulp yields are in the range of 52–56%, which is considerably higher than the 44–46% yields achieved for most softwoods. The extractives content of poplar toxic to fungi is low, which makes the wood susceptible to decay.

A number of factors make poplar appealing for growing as a forest crop. Poplar is a fast-growing, moisture-loving, full-sun-loving, large tree with a short life span. In addition, poplars can be cloned, so heritable traits can be improved more rapidly than in trees species that cannot be cloned. Hybrid poplars are specifically bred to improve disease resistance and improve the volume production and length of wood fibers for a particular site condition. Once established, poplars do not require replanting because they will reestablish themselves by their coppicing root system. After trees are harvested, the new crop emerges from suckers originating from roots or stumps. An increase in woody biomass produced after coppicing has also been reported (Phelps et al. 1987). Many plantations, however, will

**Fig. 2.** *(a)* Average trend line for fiber length as a function of annual ring breast height; *(b)* trend line for fiber length as a function of stem height for various annual rings (plots created from data of Koubaa et al. 19986).




likely be replanted in spite of coppicing potential in order to capitalize on the availability of new and better clones.

Poplars also possess a number of characteristics that present challenges to utilization. Poplars in general are known to have stems with wet wood pockets, which makes uniform drying difficult. Poplar stems are susceptible to discoloration and decay. Discolored and decayed wood can be a major defect that limits the value of wood for certain finished solid-wood products such as cabinetry or moldings. Results suggest that the compartmentalizing capacity (the ability of a stem to restrict spread of discoloration or decay) of hybrid poplar trees is under genetic control (Eckstein et al. 1979). Eckstein and others found that the major difference between a strong compartmentalizing capacity, type A, and a weak compartmentalizing capacity, type C, was the vessel system (Fig. 3). Their results show that anatomical differences of the xylem existed between groups of several hybrid poplar clones. They further suggested that selecting clones based on conducting tissue may be an effective strategy for breeding trees for use in secondary lumber manufacture (molding and millwork, cabinetry).

Poplars also tend to be prone to considerable warping when dried. Special drying methods like “Saw-Dry-Rip” significantly decrease stability problems in final lumber products (Kretschmann et al. 1999).

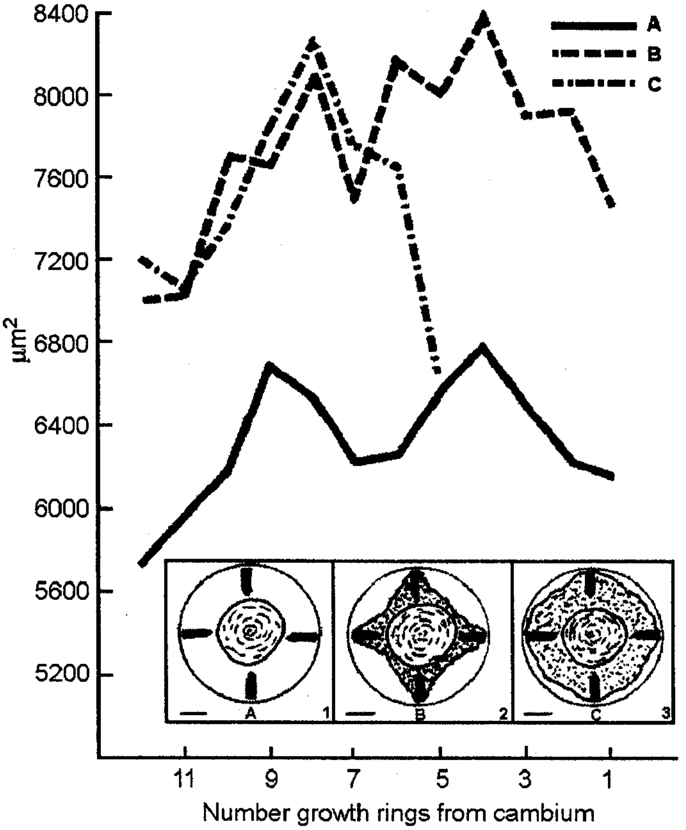
Finally, poplars develop tension wood quite readily (Isebrands and Parham 1974; Parham et al. 1977; Holt and Murphey 1978). Tension wood is reaction wood that is formed on the upper sides of branches and the upper, usually concave, side of leaning or crooked stems. It is characterized anatomically by the lack of cell wall lignification and often by the presence of a gelatinous layer in the fibers. Holt and Murphey’s work also showed that planting hybrid poplar trees at different spacings does not affect the physical, chemical, or anatomical properties of one hybrid poplar clone. Tension wood is also higher than normal in cellulose and ash content but lower in lignin and hemicellulose.

The machining, bonding, and finishing properties of poplars are quite good, making the wood well suited for a variety of conversion technologies, from sawing to veneer peeling and flaking. The relative density of a wood species determines the ideal peeling and flaking temperatures. For poplars, because of their low density, the projected “ideal” peeling and flaking temperature is in the range of 16–20°C, but acceptable results can be achieved between 7 and 30°C. Consequently, poplar requires little or no preconditioning because of both low density and high green moisture content. The low wood density is also an advantage in bonding of flakes and particles during the manufacture of composite panels because moderate pressure will bring the individual flakes and particles into intimate contact, thus ensuring a medium-density board with good strength. The pores in poplar wood are generally small enough to allow surface finishing without filler treatment.

## Utilization options

Poplar wood is used for the manufacture of a large number and variety of primary and secondary forest products in North America. These products include pulp and paper, lumber, veneer and plywood, composite panels, structural composite lumber, pallets, furniture components, fruit baskets, containers, and chopsticks. The wood-using industries have turned more to indigenous poplar resources, both in the United States and Canada, during the past 30 years because of the rapidly escalating costs of softwood fiber and the broad availability of poplars at a much lower cost. The same utilization possibilities exist for hybrid poplars. Hybrid poplars will have the added advantage that they can be produced closer to markets and user industries and perhaps be genetically engineered with quality traits for

**Fig. 3.** Apparent relationship of the compartmentalization of discolored wood cambium (A, strong; B, weak; C, very weak) to mean vessel size for the number of growth rings (from Eckstein et al. 1979).




specific products. Hybrid poplars have the potential to be a major source of wood fiber in the next century.

## Pulp and paper

One of the major uses of the indigenous poplar resource is for pulp and paper products. Poplar wood can be pulped by all commercial pulping methods. Mechanical, semi-chemical, kraft (or sulfate), and sulfite processes are now being used. Pulp mills designed for hardwood pulping can use up to 100% poplar.

The major uses of poplar pulp fall into three categories:

*(a)* Specialty paper products, such as napkins, tissues, towels, fine paper, paper board for packaging, and roofing felt;

*(b)* Building boards, such as insulation board, ceiling tiles, and hardboard;

*(c)* General purpose pulp, including groundwood, kraft, semi-chemical, and bleached sulfite.

Poplar kraft pulps are particularly well suited to fine paper manufacture because of inherently desirable properties such as excellent sheet formation, high opacity, good bulk, and good printability. Poplar kraft pulps can, however, have large amounts of fines and debris. Hybrid poplars have been shown to have properties similar to those of native poplar (Zarges and Neuman 1980).

Poplar kraft pulps are not made directly into paper; rather they are first blended with long-fibered softwood pulp to facilitate the development of wet web strength on fast-running paper machines. Poplar sulfite pulps (mainly from aspen) have been produced in North America for nearly 40 years. These pulps are used mainly in admixtures with bleached softwood kraft for the manufacture of high-quality printing and writing papers. Relatively recent technical advances in anthraquinone-catalyzed sulfite pulping are helping to increase pulp yield and strength properties of paper (Wong 1987).

The suitability of different poplar clones for paper making has been investigated by Labosky et al. (1983) and Law and Rioux (1997). Their work suggests that in general, hybrid poplars have a high proportion of very short cells (<0.2 mm) and high lignin content compared with trembling aspen. The chemithermomechanical pulps that were produced from this material were of acceptable quality but may require more energy for refining than aspen. Other research has shown that selection of a faster growing hybrid does not affect the fiber length (DeBell et al. 1998). Growth rate of short-rotation poplar can be increased without concern that fiber length may be negatively affected, which has led to investigation of the quality of a second rotation crop. No significant differences in total kraft pulp yields were found between first and second rotations (Labosky et al. 1983). Hybrid poplars, however, are not immune to the difficulties caused by the large amounts of fines and debris found in *Populus* tree pulps.

## Lumber

Sawmills in the aspen belt of Canada and the United States have been manufacturing poplar lumber for the past several decades. Production volumes, however, remained quite low mainly because of economic factors. Due to small log diameters and the high incidence of decay, the average cost of sawing aspen is generally higher than for other hardwoods and is much higher than for softwoods. Markets for poplar lumber, while diverse, are also limited by strength properties and grade. The huge residential construction market in North America has always been dominated by softwood.

Stress-graded poplar dimension lumber (including native aspens, cottonwoods, and balsam poplar) is acceptable for framing applications. It is classified under the Northern Species group in Canada and as cottonwood or aspen in the United States and has lower allowable design stresses than the predominant S-P-F (Spruce–Pine–Fir) species group, thus putting poplar at a disadvantage. Non-stress-graded poplar lumber is used in a broad range of applications and products (pallets, crates, boxes, furniture components, lumber-core panels, and interior trim).

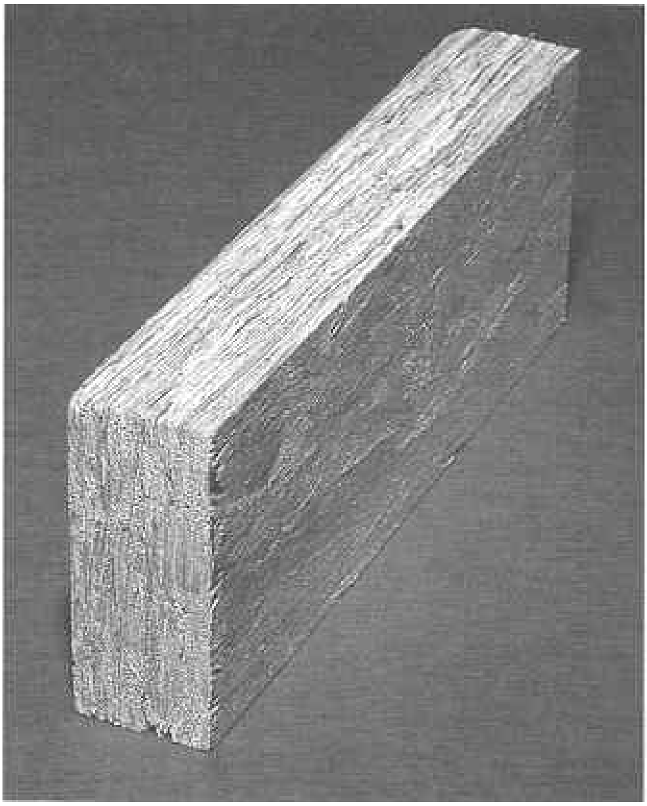
Davidson (1979), Hall et al. (1982), Hernandez et al. (1998), and Kretschmann et al. (1999) investigated the use of hybrid poplar for lumber. Hybrid poplar clones have mechanical properties similar to native cottonwood but slightly lower than those of aspen. Poplar clones have been shown to have a distinctive juvenile wood period. Strength-related properties increase with distance from the core. Therefore, the longer a poplar stand is allowed to mature, the more high-strength material will be available. Bendtsen et al. (198 1) indicated that if hybrid poplar were harvested within the first few years after planting, it would have lower properties than cottonwood because of the high juvenile wood content. There is a weak but significant correlation between growth rate, density, and mechanical properties at breast height. Significant differences in mechanical properties have been found between various clones. This finding suggests the potential for genetically selecting higher strength clones specifically for structural lumber use.

The most significant drawback to the use of hybrid poplar for lumber is its tendency to warp. Special drying is required to improve the yield of material cut. Also, the relatively low mechanical properties of poplar species in general indicate that it is unlikely that poplars could ever compete with higher value commercial species like Douglas-fir and the Southern pine.

## Composite products

A composite is any combination of two or more materials in any form and for any use. Composites take advantage of the beneficial characteristics of each component material and often have more useful properties than any of the constituents on their own. This broad definition includes a wide range of wood products, from composite panels (particleboard, fiberboard, waferboard, OSB, and even plywood) to composite lumber (LVL, PSL, LSL (Fig. 4), and composite wood I beams). Depending on the type of adhesive system used in the manufacture of these products, they may be destined for “interior” (generally decorative) or “exterior” (generally structural) applications. One of the many advantages of composites is that they use wood fiber more efficiently than sawn lumber. Typical conversion efficiencies are in the range of 52% for LVL, 64% for PSL, 76% for LSL (Nelson 1997), 80–90% for OSB, and 85–95% for particleboard and fiberboard, whereas that of sawn lumber is around 40%.

**Fig. 4.** Example of laminated strand lumber, TimberStrand ® (Trus Joist, a Weyerhaeuser Business, Boise, ID), made from aspen.



Because OSB and other structural composites will probably play a dominant role in the future production and utilization of hybrid poplars, following is a brief of these products and their process technologies. The intent is to provide poplar breeders and growers with some relevant information about wood property and wood quality traits that will be desirable for composites.

The manufacture of all wood-based composite products requires the initial conversion of logs into smaller elements (veneers, wafers, strands, flakes, particles, and fibers) that are subsequently reassembled and bonded into efficient structural shapes and sizes (panels and lumber-like profiles) with appropriate adhesive systems. The end result is increased product yield, improved product uniformity, and enhanced fiber value.

Composites are more flexible and tolerant of wood property variation than sawn lumber, but their manufacture and properties are nevertheless influenced by wood quality. For example, the high incidence of tension wood has a negative impact on all wood machining operations involved in the manufacture of composites (veneer peeling, flaking, stranding, and sanding). Similarly, if the proportion of weak juvenile wood in the log furnish is high, the mechanical properties of the end product will be reduced. Thus, good communication between breeders, growers, and users of poplar wood will continue to be important.

The historical development of waferboard and OSB and their manufacturing processes was reviewed recently by Lowood (1997). The first OSB plant was built in Edson, Alberta, in 1982, and since then it has become a global industry. OSB is made from long, narrow strands (flakes) of wood. It is made of several layers of these strands, with the strands in each layer aligned parallel to one another. Adjacent layers of strands are perpendicular to one another, like the cross-laminated veneers of plywood. This unique mat construction gives OSB strength and stiffness properties equivalent to plywood.

The manufacture of OSB includes the following main process steps: debarking of logs, cutting and drying of strands, blending of strands with synthetic resin and wax, mat forming, hot pressing, and finishing. Markets and applications of OSB are broad and diverse. The product can be used in virtually any structural or nonstructural application where a large, thin, uniform, and dimensionally stable panel is needed. While its principal markets are in residential construction (floor, roof, and wall sheathing, siding), OSB is used in many other industries for numerous applications (including concrete forms, packaging and crating, chair seats and backs, hardwood floor core, stress skin panels, structural insulated panels, I-joist webs, pallets, shelving and display racks, and furniture frames). The continuing growth of the OSB industry will provide a major market opportunity for hybrid poplar wood from actively managed plantations.

From the family of structural composite lumber products, LVL and LSL deserve special mention because of the suitability of poplar wood for the manufacture of these products. Nelson (1997) provided an excellent overview of the manufacturing processes for LVL and LSL.

In a typical LVL process, rotary-peeled dried veneers coated with a waterproof structural adhesive are laid up into a thick sandwich with parallel grain orientation between all layers of veneer. The veneer sandwich is consolidated into a solid billet under heat and pressure. LVL is manufactured to either a fixed length using a stationary or staging press or to an indefinite length in a continuous press. The solid billets exiting the press are cut into desired cross sections and lengths. The process facilitates the placing of lower-grade veneers into the core and higher-grade veneers on the faces. Trials and tests undertaken in Canada have shown that LVL made from industrial-grade poplar veneer was nearly as strong and stiff as LVL made from Douglas-fir veneer. Veneer from poplar has shallower lathe checks than those that occur when dense softwoods are peeled. This reduces adhesive penetration and produces a more uniform bond. The advantages of LVL over sawn lumber include greater product uniformity, predictability of performance, broader range of available sizes, dimensional stability, and treatability.

In the manufacture of LSL, long and slender dry strands (more than 300 mm long) of wood are coated with waterproof adhesive and formed into a thick mat with parallel grain orientation between strands. The mat is consolidated into a thick (up to 140 mm thick), wide (2.4 m), and long (up to 15 m) billet, which is subsequently sawn into desired structural sizes. The principal advantage of LSL is the ability to convert small-diameter (even crooked) logs. Other advantages are similar to those of LVL.

Hybrid poplar has been successfully used as a substitute for aspen in a number of structural panel products in the United States and Canada (Geimer and Crist 1980; Zhou 1990; Roos and Brashaw 1993). Poplar clones have been shown to have similar properties to products made completely of aspen. However, a noticeable difference between specific gravities of aspen and hybrid poplar may require adjustments during processing. Spacing and rotation age can also have a significant impact on the quality of the resulting structural panel product.

## Biomass for energy

During the energy crisis of the 1970's, hybrid poplar was seen as a savior for power companies. During this time, a shortage of petroleum and increased petroleum prices were responsible for a significant move towards establishing intensively cultivated and managed short-term rotation plantations of hybrid poplars. These were to be used as short-rotation crops that would feed co-generation power plants (Hansen et al. 1983). "Poplar farming" became a common term meant to describe plantations that would be harvested within 2–5 years.

The amount of energy that can be produced from short-rotation intensively cultured poplar trees is substantial. Caloric values for poplar biomass components have been reported to be between 4.3 and 4.8 kcal/g, which is equivalent to approximately 27 barrels of oil per hectare per year (Isebrands et al. 1979). The interest in biomass has been greatly reduced as energy costs have declined during the 1990's. However, recent volatility in energy prices has reinvigorated the discussion of poplars as an energy source. Poplars also offer a supplemental source of fuel that can be mixed with coal to reduce unwanted power plant emissions.

## Other uses

Other utilization options have been investigated for hybrid poplars. For example, phytoremediation is an emerging use of poplars (see Chap. 6). Also, the protein-rich foliage of the poplar trees has been considered as a source of forage (Nelson et al. 1984; Morley and Balatinecz 1993). In addition, hybrid poplars have been used in secondary manufactured products like pallets, boxes, millwork, and hockey sticks.

## Summary

Hybrid poplars are fast-growing, moisture-loving, full-sun-loving large trees that can be a rapid source of wood fiber. With the introduction of waferboard, oriented strandboard (OSB), and laminated strand lumber (LSL), aspen utilization has dramatically increased. Indigenous and hybrid poplars, however, present their own challenges, such as high discoloration potential, difficulty in drying, and high tension wood content. Further research is needed for improved selection of clones to ensure that desirable physical and mechanical qualities of poplar wood are produced for the anticipated site location and final utilization,

To date, the most promising utilization possibilities for hybrid poplar appear to be in the pulp and paper, laminated strand lumber, and structural panel industries. The mechanical properties of structural lumber cut from hybrid poplar will only compete in the stud market. Structural composites such as OSB and LSL made from indigenous and hybrid poplars can, however, be used effectively in other engineered structural applications (Fig. 5). Secondary manufacturing of clear wood

**Fig. 5.** Hybrid poplar demonstration center, Broadacres Nursery, Hubbard, OR. Ninety-eight percent of the materials in the center are from hybrid poplar.

cuttings of hybrid poplar may also offer possible uses of this material. A more idealistic goal for poplars is to make use of the rapid growth and deep root structure of these poplar clones for phytoremediation efforts to clean up contaminated sites.

In the past, poplar trees had been regarded as weed trees that needed to be removed from a stand. Changes in resource availability, advances in technology, and imagination have proven that there are many uses for indigenous and hybrid poplar clones that take advantage of their special properties.

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