Biotechnology's Potential Contribution to Global Wood Supply and Forest Conservation

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Abstract

Over the past 30 years, industrial plantation forests have become a major supplier of industrial wood. There are several reasons for this, including the improved economics of planted forests due to biotechnological innovations, the increases in natural forest wood costs due to increasing inaccessibility, and rising wood costs from natural forests due to new environmental restrictions related to logging.

Forestry today is on the threshold of the widespread introduction of biotechnology into its operational practices. In many cases, the biotechnology likely to be introduced is simply an extension of that being utilized in agriculture, such as herbicide-tolerant genes. However, biotechnology in forestry also is developing applications unique to forestry, including genes for fiber modification, lignin reduction and extraction, and for the promotion of straight stems and reduced branching.

Key Words: Biotechnology, breeding, forestry, tree plantations, timber, fiber, genes, GMOs, industrial wood, economics, benefits, costs

JEL Classification Numbers: Q21, Q23, Q16, O32, L73

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Biotechnology's Potential Contribution to Global Wood Supply and Forest Conservation

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During the past 30 years, industrial plantation forests have become a major supplier of industrial wood, gradually displacing wood from natural forests. The reasons for this change include the improved economics of planted forests through technological innovations, relative increases in costs of wood from natural forests due to rising extraction costs, and increased logging costs associated with stricter forest practices regulations.

Forestry is currently undergoing an important transition from a wild resource that typically had been foraged to a planted agricultural crop that is harvested periodically, as are other agricultural commodities (although the time scale for forestry is longer). The transition of forestry from foraging to an agricultural cropping mode has been underway on a significant scale only within the past half century (Sedjo 1999).

As with other agriculture, economic incentives for investments in plant domestication, breeding, and plant improvement activities will occur when the investor can capture the benefits of the improvements and innovations. In recent decades, traditional breeding techniques have been practiced in forestry as they have been in other agriculture. As in other types of agriculture, early plant improvements involved identification of trees with desired traits and attempts to capture offspring that had the desired traits through the identification of superior trees. In the 1990s, however, modern biotechnology, including tissue culture, was applied in earnest in forestry. Additionally, a relatively large number (124) of introduced traits of transgenic (genetically engineered) trees have been introduced into the regulatory process for commercial approval in the United States, but only one transgenic tree species (papaya) has been authorized for release (McLean and Charest 2000).

The benefits from the introduction of biotechnology to forestry are potentially large. The economic benefits will be found in the form of lower costs and increased availability to

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consumers of wood and wood products. Environmental benefits can be found in the rehabilitation through biotechnology of habitats under pressure either from an exotic disease, as with the American chestnut tree (*Castenea dentate*) in the United States (Bailey 1997), or from invasive exotics. Additionally, an implication of the increased productivity of planted forests due to biotechnology may be that large areas of natural forest might be free from pressures to produce industrial wood, perhaps thereby being better able to provide a more biodiverse habitat. Also, through biotechnological improvements, trees can be modified to grow in previously unsuited areas such as arid lands, saline areas, and so forth, thereby providing missing environmental functions, such as watershed protection. Such uses could not only increase wood outputs, but might be appropriate for promoting increased carbon sequestration in forest sinks, thereby contributing to the mitigation of the global warming problem, (IPCC 2001).

The ownership issues and environmental dimensions of biotechnology in forestry differ in some ways from those of agriculture and so raise somewhat different questions. Ownership and property rights issues related to biotechnological innovations appear to be more manageable in part due to the longer harvest rotation of forestry than in typical seasonal agriculture. This is because it usually takes several years for a tree to flower and the seed to be available; by that time, the seed technology in the tree may have become obsolete, being replaced by new technology. On the environmental side, unlike most agriculture products, there are few major concerns for direct health or safety from the consumption of genetically modified wood products, although cellulose is sometimes used as filler in food products. There are, however, concerns related to genetic transfers that might occur between transgenic and wild trees, and the potential implications for the natural environment.

I. Overview

Modern civilization would be impossible without the domestication of a small number of plants, particularly wheat, rice, and maize. Common features associated with plant domestication include high yields, large seeds, soft seed coats, non-shattering seed heads that prevent seed dispersal and thus facilitate harvesting, and a flowering time that is determined by planting date rather than by natural day length (Bradshaw 1999).

Recent decades have seen continuing increases in biological productivity, especially in agriculture. These increases have been driven largely by technological innovations that have generated continuous improvements in the genetics of primarily domesticated plants and animals. Many of these changes have been the result of plant improvements that have been accomplished through traditional breeding techniques that incorporate desired characteristics of plants and animals, such as growth rates or disease resistance, into the cultivated varieties of the species in question.

Changes driven by technology, however, are not new. Hayami and Ruttan (1985) have pointed out that, in the United States, most of the increased agricultural production that occurred during the two centuries before 1930 was the result of increases in the amount of land devoted to agriculture, as most of the increased production reflected increased inputs in the form of labor-saving technology—either animal or mechanical. In Japan, however, where land was limited, substantial improvements in rice productivity were made by careful selection of superior, yield-increasing seed. U.S. grain production showed little increase until the 1930s, as most of the gains in production were due to innovations that allowed more land to come into production through, for example, new equipment and mechanization. However, after the 1930s, when most of the highly productive agricultural land was in use, the focus of innovation was redirected to plant improvement, which increased land productivity through higher yields. Until fairly recently, these improvements were achieved through the use of traditional plant breeding techniques, which gradually increased agricultural yields.

Plantation Forestry

The planting of timber forests began in earnest in the 19th century in Europe and about the middle of the 20th century in North America. During the past 30 years, industrial plantation forests have become a major supplier of industrial wood. The reasons for this are several and include the improved economics of planted forests, which are due in large part to technological innovations that increased planted forest productivity. Also responsible are the relative increases in natural forest wood costs, which are due to rising extraction costs and pressures by environmental activists to provide more stringent harvesting standards, thereby reducing harvesting in old-growth forests.

Early tree planting activities typically were intended to promote regeneration after a timber harvest. Factors important in the decision to replant included property rights that insured those who incurred the planting costs would be able to capture the benefits of a future harvest, and protection capacity that would make the premature destruction of the tree crop by pest or fire unlikely. It is not a coincidence that widespread tree planting occurred only after forest control had substantially reduced the incidence of forest wild fire (Sedjo 1991). Much of the early planting in the United States took place on lands that once had been naturally forested, but in more recent decades on land that had been used for agriculture. In the South, for example, these lands had often been used for cotton or tobacco. A similar phenomenon was seen in newly established planted forests overseas. In New Zealand, forests were planted on sheep pasture, in Chile, on marginal grain lands, in Argentina and Brazil, forests were often established on grasslands.

Importantly, it was soon recognized that if the costs of planting were to be undertaken, production would be enhanced to the extent that improved seed or tree seedlings could be used. Thus, the decision to plant also provided incentive for tree improvement. Initially, tree improvement was accomplished through traditional breeding techniques.

In recent decades, traditional breeding techniques have been practiced in forestry as they were in other agricultural pursuits. Early improvements in trees involved identification of “superior” trees with desired traits and attempts to capture offspring having the desired traits. The planting of genetically improved stock began in, approximately, 1970. In the 1990s, modern biotechnology, including tissue culture and genetic modification, was applied to forestry in earnest. As more of the world’s industrial wood is being produced in planted forests, the potential to introduce genetic alterations into the germ plasma utilized in planting is obvious. Commercial forestry today is on the threshold of the widespread introduction of biotechnology in the forms of sophisticated tissue cultures for cloning seedlings and genetically modified organisms.

The Effects of Plantation Forests

Figure 1: Industrial Wood

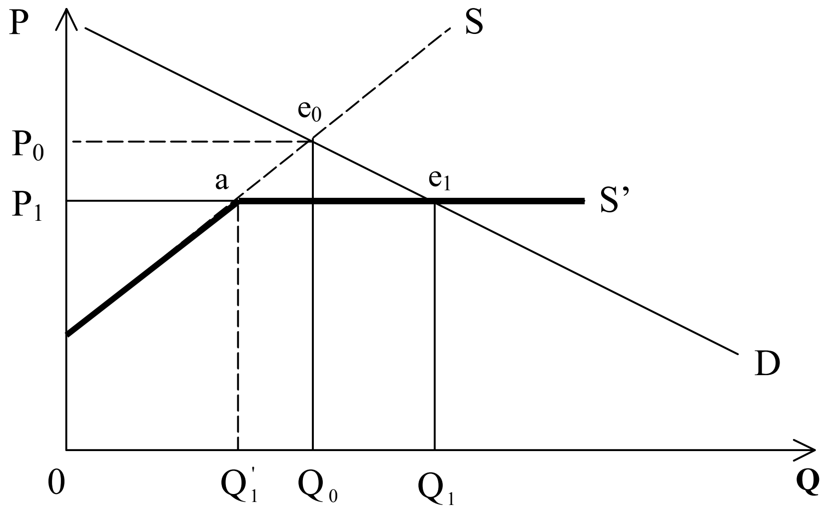

Figure 1 provides a simple schematic that illustrates the effects associated with the lowering of costs provided by planted forests. In the absence of forest plantations, the volume of industrial wood harvested in a period is determined by the intersection of supply, S., and demand, D, at e_0. In this situation, price is P_0 and the quantity harvested is Q_0. The introduction of relatively low cost plantation forestry is represented by the line segment aS'. At price P_1, plantations provide cheaper sources of industrial wood than do natural forests. This new source of timber results in a new equilibrium, e1, with a lower price, P1 and a higher harvest volume, Q_1. Notice, however, that the volume harvested from natural forests in reduced from Q_0 to $Q_{1'}$. This reflects the fact that the low-cost plantation wood is displacing wood from natural forests. The effects of biotechnology are to reduce future costs of production, thereby shifting down even further the aS' portion of the supply curve (not shown in figure 1).

Impacts of Biotechnologically Induced Changes in Forestry

Currently, most of the world's industrial wood is drawn from natural forests in what is, essentially, a foraging operation. In the past, harvests were collected from forests created by nature, as humans simply collected the bounty of nature. Figure 2 indicates how this process has changed over time as humans gradually developed silvicultural technology.

As table 1 indicates, even today, a large portion of the world's industrial wood supply originates in natural, unmanaged forests. In recent decades, however, the widespread introduction of tree planting worldwide for industrial wood production has resulted in most of the increases in global harvests being drawn from planted forests.

The potential of the widespread introduction of genetically improved trees can have important environmental and economic effects. With increasing yields and shortened rotations, planted forests become increasingly attractive as a wood-producing substitute for the natural forest. The plantation manager can control some of the important variables, such as choosing a location for the planted forest and the species. Former agricultural sites often are desirable locations for planted forests, usually being accessible and reasonably flat, thereby lending themselves to both planting and harvesting. Often, acceptable access exists via the former agricultural transport infrastructure. The planted forest also can be located in proximity to important markets. Within limits, the manager can chose a species appropriate to the site, which also may have good market access and a reasonably short harvest rotation.

The economic advantages of planted forests have led to their widespread adoption in a number of regions throughout the globe; they are having an important influence on global timber supply. Over time, a greater share of the world's industrial wood supply has been and will be coming from planted forests. Planted forests today account for most of the increased global output and their production is replacing the timber formerly provided by native and old-growth forests, which are no longer available for harvest due to political changes, such as those in Russia, or policy changes, as with the U.S. National Forest System.

Figure 2. Transitions In Forest Management and Harvests

Type	Period
Wild forests	10,000 BC - present
Managed forests	100 BC - present
Planted forests	1800 - present
Planted, intensively managed	1960 - present
Planted, superior trees, traditional breeding techniques	1970 - present
Planted, superior trees, genetic modification	2000 - future

Table 1. Global Harvests by Forest Management Condition Circa 1995

Forest Situation	Percent of Global Industrial Wood Harvest
Old-growth	22
Second-growth, minimal management	14
Indigenous second-growth, managed	30
Industrial plantations, indigenous	24
Industrial plantations, exotic	10

Source: Sedjo 1999.

Notes: Old-growth includes: Canada, Russia, Indonesia/Malaysia

Second-growth, minimal management: parts of the U.S. and Canada, Russia

Indigenous second growth, managed: residual

Industrial plantations, indigenous: Nordic, most of Europe, a large but minor portion of U.S., Japan, and some from China and India.

Industrial exotic plantations: South America, Oceania, Southeast Asia

Second-growth, minimal management: the residual

This estimate recognizes the huge decline of Russia havests since the demise of the Soviet Union.

II. Traditional Breeding

Selection

Tree improvement most often relies on traditional breeding techniques that selected superior trees with increased growth rates and other desired traits, such as stem straightness. These trees are then introduced into breeding orchards through grafting and other techniques, which are used to produce seed for seedlings. When breeding orchards begin to flower, pollination of selections is artificially controlled, seeds are collected, progeny tests are established, and the best offspring are chosen for the next cycle of breeding. By identifying desired traits, breeding can select for a set of traits that can improve wood and fiber characteristics, improve the form of the tree, provide other desired characteristics, and improve growth. These traits are introduced into the genetic base that is used for a planted forest. This contributes to the more efficient production of industrial wood and to an improved quality of the wood output of the forest. In the past, operational quantities of seed from production seed orchards were derived from open pollination. Today, however, more sophisticated large-scale controlled pollination techniques are in place that offer the potential of further improvement of the offspring of two superior parents.

The results of traditional breeding approaches to improve tree yields are instructive to illustrate the possibilities of traditional breeding (Table 2). For most tree species the typical approach involves the selection of superior trees for establishment in seed orchards. Experience has shown that an orchard mix of first-generation, open-pollinated seed can be expected to generate an 8% per generation improvement in the desired characteristic—for example, yield. More sophisticated seed collection and deployment techniques, such as collecting seed from the best mothers (Family Block), can result in an 11% increase in yield, while mass-controlled pollination techniques, which control for both male and female genes (full sibling), have increased yield by as much as to 21%.

Table 2: Gains from Various Traditional Breeding Approaches: Loblolly Pine

Technique	Effect (increase in yields)
Orchard Mix, open pollination, first generation	8 %
Family Block, best mothers	11 %
Mass Pollination (control for both male and female)	21 %

Source: Westvaco Corporation.[1]

Hybridization

A variant of the traditional breeding techniques is hybridization. As in agricultural products, tree hybrids are often a means to improve growth and other desired characteristics. Hybridization crosses trees that are unlikely to breed in nature, often where parents do not occur together in sympatric populations. These crosses often exhibit growth and other characteristics that neither of the parent species alone can match. In the United States, for example, several hybrid poplars have shown remarkable growth rates exceeding that found in parent populations.[2] The same is true for the *Eucalyptus grandis* and *urophylla* hybrid in many parts of the tropics and subtropics. This approach is widely used in forestry.

III. Biotechnology

Biotechnologies used in forestry fall into three main areas: the use of vegetative reproduction methods, the use of genetic markers, and the production of genetically modified organisms (GMOs) or transgenic trees. Most of the biotechnologies used in forestry today are in the category of tissue culture and molecular marker applications (Yanchuk 2001).

Cloning and Vegetative Reproduction

Vegetative reproduction comprises a broad range of techniques involving the manipulation of plant tissue that ultimately allows for vegetative reproduction, that is,

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[1] Source: Conversation with Westvaco researchers, Summerville, SC

[2] Growth in hybrid poplar stands is 5-10 times the rate experienced in native forest growth rates (Toby Bradshaw, University of Washington, personal communication).

reproduction by planting cuttings from a live plant, which are planted and in turn produce anew plant. Tissue culture broadly refers to clonal techniques of growing plant tissue or parts in a nutrient medium containing minerals, sugars, vitamins, and plant hormones under sterile conditions. However, for some tree species, cloning approaches have been limited (Pullman et al. 1998). In general, thus far there has been greater success cloning hardwoods, such as poplar and some species of eucalyptus, than conifers.

The development of cloning techniques in forestry is important for a number of reasons. First, if superior trees are available, an approach must be developed to allow for the propagation of large numbers of seedlings with the desired characteristics if these traits are to be transferred into a planted forest. With tree planting often involving more than 500 seedlings per acre,[3] large-scale planting of improved stock requires some method of generating literally millions of seedlings, at a relatively low cost, which embody the genetic upgrading. The costs of the improved seedlings are important in a financial sense, since the benefits of improved genetics are delayed until the harvest. With harvests often being 20 years or more after planting, large costs for improved seed may seem difficult to justify financially. However, if the costs of plantings are going to be incurred, the incremental costs associated with planting improved genetic stock are likely to be quite modest and therefore may be financially justified. Additionally, the clone provides the vehicle through which desired foreign or artificial genes are transferred. Thus, for genetic engineering in forestry to be viable, cloning techniques must be developed.

The ability to use inexpensive cloning techniques varies with species and genus. For some species, typically hardwood species, cloning can be as simple as using the vegetative propagation properties inherent in the species to accomplish the genetic replication. This might involve taking a portion of a small branch from a desired superior tree and putting it into the ground, where it will quickly take root (rooted cuttings). Where vegetative propagation is part of the natural process, large amounts of “clonal” material can be propagated via rooted cuttings, the cuttings of which come from “hedge beds, that provide bulk genetic material from which commercial seedlings can be generated. Here the process continues until sufficient volumes of vegetative materials with the desired genes are available to meet the planting requirements.

Eucalyptus, poplar, and acacia also tend to be effective propagators. Other genera propagate less readily. Many species in the pine family, such as loblolly and, to a lesser extent

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[3] It is estimated that four to five million trees are planted in the United States every day.

slash pine, are difficult propagators. Radiata pine, common in plantations in New Zealand and Chile, appears to have the best record on this account. Propagation improves when certain procedures are undertaken. For example, using the shoots emerging from newly trimmed clonal hedges increases the probability of successful regeneration. For many species, however, the process is more difficult, as simple vegetative propagation does not normally occur or occurs only infrequently. Here, "tissue culture" techniques provide the tools to quickly produce genetically engineered plants and clones to regenerate trees with desired traits (Westvaco 1996, 8-9).

Genetic Markers

Genetic markers are used to try to find a relationship between the markers and certain characteristics of the tree. A common approach to genetic manipulation of trees utilizes molecular biology. Molecular biology has two facets. The first facet is that which may aid the efficiency of traditional breeding programs. One problem with traditional approaches in tree breeding is the long growth cycles generally required by trees, which make this process very time consuming. Techniques—such as molecular biology and molecular markers—that identify areas on the chromosome where genes that control desired traits occur, can accelerate the process and enhance the productivity of the traditional approach. The second facet is where specific genes are identified and modified to affect biochemical pathways and the resulting phenotypes. For example, lignin genes can alter the amount, type, and form of lignin that is produced.

In recent years, molecular approaches to tree selection and breeding have shown significant promise. The molecular approach, although limited in application by its expense, involves genetic material being identified, collected, bred, and tested at a wide range of sites. Rather than simply choosing specific tree phenotypes on the basis of their outward appearance, the molecular approach identifies the areas of the chromosomes that are associated with the desired traits. "Markers" are used to identify the relative position of genes on the chromosome that control the expression of a trait. This approach exploits the genetic variation, which is often abundant, found in natural populations. Molecular markers and screening techniques can be used to examine the DNA of thousands of individual trees to identify the few, perhaps less than a dozen, with the optimal mix of genes for the desired outputs. These techniques are currently being applied to the development of improved poplar in the United States and eucalyptus in Brazil.[4]

Recent work on hybrid poplar in the Pacific Northwest has shown a 20% increase in yields in plantations and an additional 20% on dry sites, where irrigation can be applied (east of the Cascade Mountains).[5] Growth rates with these plantations are impressive. Annual yields are about 7 tons per acre, or about 50 cubic meters per hectar (ha) and improvements in the yield continue.[6] These growth rates are approximately three times the growth rates of typical pine plantations in the South. Elsewhere in the world—for example, Aracruz in Brazil—yields of hybrid eucalyptus are reported to have more than doubled those of earlier plantings.

GMOs

The term biotechnology is often associated with generically modified organisms (GMQs) or transformations that involves the introduction of selected foreign genes into the plant genome. In this approach specific genes are identified and modified to affect biochemical pathways and the resulting phenotypes. Thus far, transgenic trees have not been used commercially for wood production (McLean and Charest 2000). However, the promise is substantial, as has been demonstrated in agriculture. Potential applications include herbicide resistant genes, pest resistant (Bt) genes, and genetic alteration that would provide certain desired wood characteristics; for example, the promise of controlling the lignin in trees is dependent on the ability to identify and modify lignin genes, thereby altering the amount, type, and form of lignin that is produced in the tree (Hu et al. 1999). As noted, the ease of gene introduction (transformation) varies with different tree species and genus, generally being more difficult in conifers than hardwoods.

IV. Future Biotechnological Innovations in Forestry

Gene alteration can result in unique gene combinations unachievable by traditional tree breeding. This allows species to have attributes that would not be possible through natural

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[4] Personal conversation with Toby Bradshaw, director of the Poplar Molecular Genetic Cooperative at the University of Washington, Seattle. Also see Westvaco, 1997.

[5] Personal communication: Toby Bradshaw.

[6] Withrow-Robinson et al., 1995, 13.

processes. Thus, for example, in concept, frost-resistant genes could be transferred from plants or other organisms found in cold northerly regions to tropical plants, thereby increasing their ability to survive in cooler climates.

These attributes or traits can be characterized as silvicultural, adaptability, and wood quality (table 3). Silivicultural traits would include growth rate, nutrient uptake, crown and stem form, plant reproduction (flowering), and herbicide tolerance.

Growth potential, for example, has a substantial genetic component with rates differing by 50% between families or different clonal lines. Traditional breeding approaches are steadily improving the yield potentials of elite lines (professionally improved lines).

A subset of these traits is found in table 4. These traits include those that are most likely to use biotechnology for further commercial development.

Table 3. Forest Traits That Can Be Improved through Biotechnology

Silviculture	**Adaptability**	**Wood Quality Traits**
Growth rate	Drought tolerance	Wood density
Nutrient uptake	Cold tolerance	Lignin reduction
Crown/stem	Fungal resistance	Lignin extraction
Flowering control	Insect resistance	Juvenile fiber
Herbicide		Branching

Source: Context Consulting[7]

Table 4. Traits of Interest in Forestry

Herbicide tolerance
Flowering control
Fiber/Lignin modification
Insect tolerance
Disease tolerance
Wood density
Growth
Stem straightness
Nutrient uptake
Cold, wet, drought tolerance

*Note:*The first three traits of the list in table 4 are traits that, in the judgment of many experts, could be featured prominently in biotechnological innovations in forestry during the next decade.

Planted trees typically require herbicide and, in some cases, pesticide applications for one or two years after planting. The introduction of a herbicide resistant gene can reduce the costs of herbicide applications by allowing fewer but more effective applications without concern of damage to the seedlings. The use of a pest resistant gene can eliminate the requirement to apply the pesticide altogether. Flowering control allows a delay of several years in flower initiation, nonflowering habit, or sterility. This control may be useful in preventing certain transgenic plants from transmitting genetically modified matter to other plants and/or from migrating into the wild.

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[7] Context Consulting provided information on potential innovations and their likely cost implication based on the best judgment of a panel of experts.

As with pest resistance, disease resistance is important and the technology for genetic modification for disease resistance is fairly well developed. In New Zealand, for example, the first applications of genetically modified pine (*pinus radiata*) are likely to involve "stacking"—that is, combining several genetically modified genes, perhaps including those of pest and disease resistance— and flowering control, in the seedling.

Lignin control is viewed by the industry as an important priority. Trials with low lignin trees have already been undertaken in Aracruz Cellulose in Brazil (Hall 2000).

V. Benefits of Biotechnology

Benefits come in different forms. The economic benefits can be realized in the form of lower market costs for production. This typically converts to lower prices for consumers. Some of these cost reductions are examined in detail later in this paper. Additionally, benefits can be realized through the development of increased quality and/or new products. These benefits are typically recognized within the market and are reflected by cost or price changes.

Benefits, however, also can be realized outside the market. In agriculture, for example, benefits can accrue due to increased protein content in genetically modified rice. One important set of nonmarket benefits in forestry has been the substitution of plantation-grown wood for the wood of primary forests. This has reduced the commercial logging pressure on natural forests, thereby reducing pressures on certain biodiversity and habitat (Sedjo and Botkin 1997). Modified tree species also give promise of being useful for providing environmental services in areas where trees now have difficulty surviving. For example, in arid or drought-prone areas, areas with saline conditions or frost zones, and for certain species that might provide other, useful services. Also, given little emphasis is being placed on biological sinks as a tool to mitigate the build-up of greenhouse gases associated with global warming, the ability to establish carbon sequestering plantations in regions not currently forested could become a very important tool in mitigating climate change (IPCC 2001).

Productivity

A distinguishing feature of the introduction of technology is increased productivity, such as in output per unit input. Alternatively stated, technology can be viewed as either cost reducing or yield (output) enhancing. From a societal point of view, this implies that society gets more output for its expenditure of inputs—for example, a societal increase in efficiency. For the consumer, the implication typically is that relative prices of the desired good fall compared to what they would have been in the absence of the innovation. Plantation forestry has enjoyed success in recent decades in part because it has experienced cost-reducing technology, thereby giving planted forests a competitive advantage over natural old-growth forests (Sedjo 1999). Furthermore, the opportunities to be derived from the application of biotechnology to forestry appear substantial.

Tree Improvements

With the planting of trees for industrial wood production there is an inherent incentive to improve the quality of the germ plasma so as to generate tree improvements that can be captured at harvest. Tree improvements can take many forms (figure 3). Thus far, the most common emphasis of tree improvement programs is increased growth rates, stem form, and disease resistance. Growth typically refers to wood volume growth or yields. Disease and pest resistance traits also are desired to promote or insure the growth of the tree. Resistance traits may be oriented to specific problems common in the growth of particular species or to extending the climatic range of certain species. For example, the development of frost-resistant eucalyptus would allow for a much broader planting range for this desired commercial genus. Other improvement possibilities include, as in agriculture, the introduction of a herbicide-resistant gene to allow for more efficient use of effective herbicides, especially in the establishment phases of the planted forest. Besides ensuring establishment, survival, and rapid growth of raw wood material, tree improvement programs also can focus on wood quality. Wood quality includes a variety of characteristics, such as tree form, fiber quality, extent of lignin, improved lignin extractability, and so forth. Furthermore, the desired traits vary by end product. Wood quality

Figure 3: Tree Improvement Programs

Important Attributes:

- **Growth rates**
- **Disease and pest resistance**
- **Climate range and adaptability**
- **Tree form and wood fiber quality:** straightness of the trunk, the absence of large or excessive branching, the amount of taper in the trunk.
- **Desired fiber characteristics may relate to ease in processing:** for example, the break-down of wood fibers in chemical processing.

may involve one set of fiber characteristics for pulping and paper production and another set of characteristics for milling and carpentry. Wood desired for furniture is different from that desired for framing lumber. In addition, some characteristics are valued not for their utility in the final product, but for their ease of incorporation into the production process.

For pulp and paper production there are certain characteristics desired to facilitate wood handling in the early stages of pulp production. For example, the straightness of the trunk has value for improving the pulp and paper products in that less compression—which is a characteristic of straight trees—generates preferred fibers. Also, straight trees are important in pulp production, since they allow ease of handling and feeding into the production system. Also, paper production requires fiber with adequate strength to allow paper sheets to be produced on high-speed machines. Ease in processing includes the breakdown of wood fibers in processing and the removal of lignin, a compound found in the tree that is removed in the pulp-making process.

Other wood characteristics relate to utility in producing the final product. The absence of large or excessive branching, for example, influences the size and incidence of knots, thereby allowing for fuller utilization of the tree's wood volume. Also, desired characteristics or properties of final paper products include paper tear strength, surface texture, brightness, and so forth. These are all properties that relate in part to the nature of the wood fiber used. Other features relate to the utility of the wood for use in final wood products—for example, straightness facilitates production of boards or veneer in solidwood products, wood characteristics related to milling and use in carpentry, wood color, strength and surface characteristics. In addition, wood fiber is increasingly being processed into structural products such as strand board, fiberboard, and engineered wood products, which have their own unique set of desired fiber characteristics.

In recent years pulp producers have begun to move away from simply producing standardized "commodity" pulp into the production of specialized pulp for targeted markets. For example, Aracruz, a Brazilian pulp company, has asserted that it can customize its tree fibers to the requirements of individual customers. This requires increased control over the mix and types of wood fibers used. Customized products require customized raw materials. However, in the case of Aracruz, thus far the control has been provided through cloning, rather than genetically engineered alterations.

Anticipated Cost-Saving Innovations

A recent study (table 5) identified several innovations in forest biotechnology believed to be feasible within the next decade or two and estimated the possible financial benefits of their introduction.[8] The development costs of the innovation are not considered.[9] The innovations noted in table 5 suggest a potential decrease in costs and/or an increase in wood volume or quality. Rates of return have been estimated from many of them. For example, the 20% increased volume due to the cloning of superior pine is estimated to provide a financial return of about 15-20% on the incremental investment cost of $40 per acre. This assumes initial yields of 15 cubic meters (m^3) per ha per year and a stumpage price of $20 per m^3. Similarly, cost savings should be realized for improved innovations that reduce the amount of low-value juvenile wood or the difficulty of extracting lignin in the pulping process.

In another example given in table 5, the potential cost savings in a Brazilian planted forest due to the herbicide tolerance trait is estimated to generate an immediate reduction of $350 per ha in the establishment costs in the two-to-three- year establishment period. Obviously, this potential degree of financial benefit, which reduces initial establishment costs on the order of 40%, is substantial.

Biotechnological innovations that modify wood fiber characteristics so as to reduce pulping costs also have been estimated. The value added from pulping is about $60 per m^3 or $275 per ton of pulp output. If these costs are reduced $10 per m^3, this provides a surplus

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[8] The distribution of the benefits of a patented innovation is complex. Initially, one would expect most of the benefits of the innovation to be captured by the price charged for the improved product.

Subsequently, however, the price charged for the new technology typically declines. At the end of the patent period, the technology becomes part of the public domain.

[9] As is well known, once the investment is made in innovation, it is a fixed cost and unrelated to the marginal cost associated with the distribution of the product.

Table 5. Possible Financial Gains from Future Biotech Innovations

Additional Innovation	Benefits[10]	Operating Costs
Clone superior pine	20 % yield increase after 20 years	\$40/acre or 15%-20% increase
Wood density gene	Improved lumber strength	None
Herbicide tolerance gene in eucalyptus (Brazil)	Reduce herbicide and weeding costs potentially saving \$350 or 45% per ha	None
Improve fiber characteristic	Reduce digester cost potential savings of \$10 per m^3	None
Reduced amount of juvenile wood	Increase value \$15 per m^3 (more useable wood)	None
Reduce lignin	Reduce pulping costs potential of \$15 per m^3	None

Source: Context Consulting.

(or effective cost reduction) of about $47 per ton of woodpulp (assuming 4.7 cubic meters per metric ton of pulp), assuming wood prices are not affected. This type of innovation would be important to the forest sector since a mill would be willing to offer a premium for low processing-cost wood fiber. If the improved fiber is common, then it would be expected to create processing cost savings that would eventually be passed on to the consumer. Thus, substantial cost savings could be generated.

V. A Crude Estimate of the Global Impact: A Case Study of Herbicide Resistance

This section examines the potential costs savings of a specific biotechnological innovation—the introduction of a herbicide-resistant gene on the costs of establishing future commercial forests and thus on the potential future timber supply. By inference, the likely effect on harvests from natural forests also is examined. The approach used is that of a crude partial

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[10] The actual cost savings experienced by the tree planter will depend on the pricing strategy used by the gene developer and the portion of the savings to be captured by the developer and passed on to the grower.

equilibrium approach,[11] which estimates the cost savings associated with the development of a specific innovation as applied to forestry—the herbicide resistant gene. The savings in plantation establishment costs are estimated on the basis of the data presented above. These savings are translated into the lowering of the supply curve for planting activity. This results in an incremental addition to plantings. Due to the delay between planting and harvest, the impact on volume and financial returns is delayed until e the harvest .[12]

Figure 4: New Plantation Starts

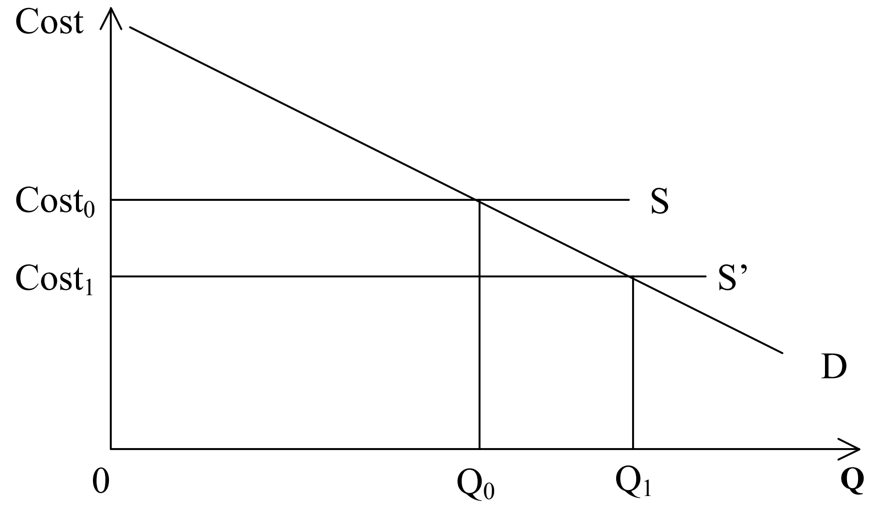

Figure 4 provides a schematic of the demand and supply for plantation forests. As the diagram shows, if the costs of plantation establishment decrease from Cost$_0$ to Cost$_1$, this is reflected in a downward shift of the supply curve from S to S', other things constant, and the quantity of plantations increases from Q_0 to Q_1. The economic benefits are the cost savings,

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[11] A more sophisticated modeling approach would involve integrating estimates into a forest sector systems model (for example, see Sohngen et al., 1999).

[12] It should be noted, however, that the anticipation of greater future supplies will affect current actions, including current harvests (see Sohngen et al., 1999)

which are represented by the area between the two cost curves and bounded by the demand curve on the right and the vertical axes on the left.

Table 6: Herbicide Resistance Benefits:

$35/acre ($87/ha) cost reduction for fast-growing softwoods[13]

$160/acre ($400/ha) cost reduction for fast-growing hardwoods

***Source*:** Context Consulting.

Table 6 presents estimates of the cost reduction in plantation establishment for the herbicide resistant gene used in this study. Forest plantation establishment involves incurring of substantial costs in an early period in order to generate larger but discounted benefits at some future time. High-yield plantation forestry involves plantations with harvest rotations from 6 to 30 years. To the extent that costs of establishment can be reduced, net benefits can be achieved. Experts estimate that herbicide resistance would reduce the costs of plantation establishment by an average of about $35/acre for fast-growing softwoods (reduced costs of 15%) and an average of $160/acre for fast-growing hardwoods (reduced costs of 30%) through the elimination of the costs of other pest mitigation activities.[14] In North America, about 4 million acres are planted annually: If 98% (3.9 million) are softwood and 2% (0.1 million) are hardwood, the potential cost reduction at current rates of planting would be $136.5 million for softwoods and $16 million for hardwoods, or a total savings of $152.5 million annually.

Worldwide, about 10 million acres of plantation forest are planted per year. If the plantings are roughly split between conifer and hardwood and the plantings remain unchanged, the potential saving from the introduction of the herbicide resistant gene is $175 million for softwoods and $800 million for hardwoods, where the development of the clonal prerequisite is largely developed (table 7). Thus, the potential global cost savings is about $800 million annually with enabling technology that is essentially available today for hardwoods and roughly $975 million annually, once low-cost conifer cloning has been perfected. Thus, the near-term

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[13] It should be noted that, for many conifers, low-cost clonal forestry is not well developed. Thus, the wide-spread application of GMOs to conifers is not feasible at this time. However, New Zealand appears to have a workable system for *pinus radiata.*

[14] The percentages are based on an update of plantation establishments costs as found in Sedjo (1983).

Table 7: Potential Cost Saving from Herbicide Resistant Gene

(Millions of US$)

North America		**Total Global**
Hardwood	$136.5	$800.0
Conifer *	16.0	175.0
Total	$152.5	$975.0

* Assumes successful development of enabling commercial clonal technology.

potential benefits are quite large, even if softwoods are not considered. Another issue is the extent to which lower establishment costs would increase total plantation establishment. Of the 10 million ha of forest planted annually, we assume that about 1 million ha represent new industrial plantations.[15] Assume that the actual costs to the industry were reduced by the full amount of the cost reduction realized through the innovation—for example, that the innovation was priced at marginal cost. This would be an average reduction of 22.5% in plantation establishment costs. Under these circumstances, what increase would be expected in the annual rate of plantation establishment? The expected amount would be dependent in part on the responsiveness of demand to price changes. This responsiveness is captured in the economist's use of price elasticities.[16] To examine this question, we develop and estimate the impacts from three scenarios: the maximum impact, an intermediate impact, and a low impact (Table 8).

Scenario A: Maximum Impact:

Given an initial total annual global planting rate of 1.0 million ha and assuming an infinite supply elasticity and a unitary demand elasticity for forest plantation plantings (a derived demand), the estimated impact would be the establishment of an additional total planting area of 225,000 ha per year. This assumes that the additional planting would reflect current mix of planting; for example, the additional planting would be divided evenly between conifer and hardwood. Furthermore, if we assume growth rates on plantation forests would average 20 m^3

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[15] Sedjo (1999) estimated this to be about 600,000 ha for the tropics and subtropics, while the model of Sohngen et al. (1999) estimated new plantations to be about 850,000 ha annually. The somewhat higher figure used in this study reflects the inclusion of new plantation establishment in the temperate regions and anecdotal evidence suggesting that these earlier estimates were on the modest side.

[16] Price elasticity is simply the percentage change in quantity divided by the percentage change in price.

per ha per year for softwoods and 30 m^3 per ha per year for hardwoods, the result of the additional plantings would result in a future addition to total annual production at harvest of 2.5 million m^3/yr. If these increases in plantings were realized each year for a 20-year period, about 100 million m^3/yr of additional industrial wood production would be generated annually after 20 years.[17]

Scenario B: Intermediate Impact

Suppose the same conditions obtained as in Scenario A, except that the supply elasticity was 1. In this case, a total of 112,500 additional ha planted per year would result in a total increased production at future harvest of 2.5 million m^3/year. After 20 years of planting this would generate about 50 million m^3/yr of additional continuous production.

Scenario C: Estimated Minimum Impact

The assumption is that supply elasticity remains a +1.0, as in Scenario B, but that the demand elasticity is –0.7.[18] In this case, we estimate a total of 78,750 additional ha planted per year with an increase in total production at harvest of 1.969 million m^3 per year. After 20 years of planting at this rate, the additional continuous wood production would be about 39.375 million m^3 per year.

Table 8: Scenario Summary

Scenario	**Additional Plantings**	**One year Additional m^3**	**20 years Additional m^3**
Scenario A	225,000	5 million	100 million
Scenario B	112,500	2.5 million	50 million
Scenario C	78,750	1.97 million	39.4 million

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[17] At the 0.5% annual increase consumption, on a 1997 production/consumption base of 1.5 billion m^3, global industrial wood consumption would be expected to increase about 7.5 million m^3 annually.

[18] This is approximately the recent FAO estimate of –0.67 for the elasticity of demand for industrial roundwood.

VI. Benefits of Forest Biotechnology: A Summary

Economic Benefits

As noted, a distinguishing feature of the introduction of technology is increased productivity, such as in output per unit input. From a societal point of view, this implies that society gets more output for its expenditure of inputs; for example, there is a societal increase in efficiency. The above analysis suggests that the annual economic benefits in reduced costs associated with the introduction of only one transgenic gene, the herbicide resistance gene, could reduce the global costs of the establishment of planted forests by as much as $1 billion annually. This cost reduction implies an increased rate of tree plantation establishment into the indefinite future and more industrial wood at lower prices in the future. Of course, substantial additional economic benefits could be derived from the host of other biotechnological innovations, including the variety of additional transgenic trees with various other economic advantages.

Furthermore, the increased biological and economic productivity of planted forests has important positive spillovers to the environment. Increased planted forest productivity implies the creation of a larger number of low-cost plantation forests and a lower-cost industrial wood associated with those plantations. Wood from planted forests develops a greater comparative cost advantage over wood harvested from natural forests. Thus, while harvests from planted forests increase, production from natural forests declines. In short, plantation wood is substituted for natural forest wood, thereby leaving the natural forests for other uses, including ecosystem and biodiversity preservation.[19]

Environmental Benefits of Forest Biotechnology

The above discussion has focused on the economic or financial benefits of biotechnology to forestry. These financial benefits are manifest through reduced costs and/or higher production of wood, and through enhanced quality due to improved traits and wood characteristics, suitable for both solid wood products and pulp and paper products. Additionally, as discussed below and summarized in table 9, biotechnology in forestry can be used to achieve several environmental

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[19] The argument that plantation wood substitutes for wood from natural forests is substantially different from the issue of land involved in grain production in that forestry compares a foraging with a cropping activity. A recent FAO study (1996) estimated the global demand elasticity of industrial wood at - 0.67.

outputs that can improve the environment. In addition to the protection from harvests afforded natural forests by the substitution of the harvest of low-cost wood from forest plantations, biotechnology-improved trees can be modified to specifically provide certain desired environmental services. These would include modifications to allow trees to grow in previously unsuited areas, such as arid and degraded lands, where the trees could both provide restoration benefits to the lands, as well as traditional ecosystem services, such as erosion control and watershed protection. Absent transgenic trees with suitable characteristics, such ecosystem services might not be possible. Additionally, certain desired species could be modified to allow them to grow in areas previously unsuitable due to cold climate or frost prone conditions. This modification could not only increase wood outputs, but might be appropriate for environmental objectives.

Additionally, biotechnology provides the potential to restore species severely damaged by pests and disease, such as the American chestnut.[20] Finally, forestry has been shown to have substantial potential for mitigating the build-up of atmospheric green house gases—including carbon—believed to be the causes of anticipated global warming (IPCC 2001). Biotechnology applied to forestry could assist in enhancing the carbon sequestration ability of forests and thereby provide additional carbon mitigation possibilities.

Table 9. Environmental Benefits

Environmental Outputs	**Biotechnological Innovations**
Reduced pressure to log natural and old-growth forests	More productive plantation wood will substitute for wood from natural forests at lower costs.
Protection forests can be established on degraded, arid or lands.	Genetically improve trees with land protection and land restoration capabilities suited to poor sites.
Carbon sequestrating forest can be established on site previously not suitable to forestry.	Genetically improved trees capable of substantial carbon sequestration suited to biologically poor sites.
Species restoration	The potential species restoration of the American chestnut.

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[20] The American chestnut was decimated around the turn of the 20th century by an introduced fungus. However, the fungus acted only on the above-ground portions of the tree. Thus, live roots remain and could provide the bases for a restoration should the fungus be controlled through genetic modification. Appropriate genes appear to be available in the Chinese chestnut.

To summarize, the benefits of biotechnology in forestry can be viewed as coming in two groupings. First, biotechnology has generated a number of innovations that will significantly reduce costs and/or enhance the quality of the forestry outputs, thereby enhancing society's efficiency in resource use. Some portion of these benefits is likely to be transferred to the consumer in lower prices and we would expect the transfer to increase over time. Additionally, biotechnology has the potential to generate a number of environmental benefits through its effect on the competitive structure of the forest industry. In general, this will be through decreasing the competitive advantage of the harvest and use of natural and old-growth timber toward increased substitution and use of plantation wood, thereby imparting a degree of protection from commercial logging to the natural and old-growth forests, which are viewed as having more environmental value. Finally, the biotechnological modification of a tree can allow it to perform a broader and more useful set of both economic and environmental functions and services. These include, for example, enhanced carbon sequestration generally and potential for regions that have been degraded and are currently difficult for forestry. Biotechnology also can enhance other desired environmental objectives, such as restoration, watershed enhancement and erosion control in areas typically not suitable to forests and/or areas subject to cold, frost and drought.

VII. Potential Costs of Biotechnology in Forestry: Some Concerns

Transgenic biotechnology has become quite controversial when applied to agriculture (for an example, see Williams 1998). However, in drugs, medicines, and pharmaceutical applications, transgenic biotechnology is essentially without controversy. The nature of the controversy in agriculture has developed around at least five issues.

First, is the issue of ownership of the modified genes and the question of how much ownership/control the biotechnology companies have over their transgenic products after they have been distributed. An important element in the discussion relates to the ongoing controversy regarding the ownership of biodiversity and improved products. Are wild genetic resources the property of all of humanity or of the country in which they reside? Are developed biotechnology products the property of the developer or should they be available without royalty payment to all of humanity? (For example see, Kloppenburg Jr., 1988, Sedjo 1992.) This controversy manifests itself in the difficulties in interpreting and finalizing the "biodiversity treaty" coming out of the UNCED "Earth Summit" meeting in Rio in 1992.

The second issue in the overall controversy relates to the health, safety, and environmental aspects of transgenic products. Although there is little or no evidence that transgenic foods are unsafe, health concerns are raised due to the lack of long-term knowledge of and experience with such products. The health issue is not generally raised for trees as they are not usually viewed as a human or animal food source.

A third issue with transgenic plants is the question of genetic transfer to nearby domestic or wild tree populations. Coming on the heels of the animal comment, I was momentarily confused] populations. For forestry, the concern is largely with genetic transfer to wild populations. In many cases, plantation tree species would be exotic and thus exchange would not be a factor. In cases where genetic exchange could be a problem, a method to prevent or reduce their "escape" would be to promote sterility, which would prevent escape. Furthermore, sterile trees would not be a problem for future production as the seeds used in the next rotation would almost surely be technologically improved and thereby replace the current stock. (see DiFazio et al. 1999). The implications of gene escape are likely to differ depending on whether the gene would confer a selection advantage to the wild plants. This is likely to depend upon the nature of the genetic alteration.

A fourth issue relates to the impact of the biotechnology on the resistance of the targeted pest population. It is well known that pests adapt through natural selection to the introduction of pest-controlling chemicals. The same response to attempts at genetic pest control could be expected. As in agriculture (Laxminarayan and Brown 2000), in forestry the pest population could adapt to the modified gene, thereby undermining its longer-term effectiveness. The long period of forest growth would seem to exacerbate the problem, as it would allow many generations of insect populations to develop a resistance mechanism. Various approaches are being considered to overcome this problem, including the continuing development of new pesticides in agriculture and the use of refugia to dilute the development of resistance in the pest population.

The issue of whether biotechnology applied to agriculture will increase the demand for land, thereby putting increased pressure on natural habitats. Some recent work suggests this is likely to be the case if the demand for agricultural products is elastic (for example, Angelsen and Kaimowitz 1998).[21] However, this is unlikely to be a problem in forestry, where demand is

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[21] It has been noted that since cattle are increasingly being placed in feedlots where they consume grains, the total demand for grain—human and animal—may be elastic. This implies that if grain prices fall—for example, due to biotechnology—the total area of grains land could increase. However, it should be noted that where both grain and cattle are part of society's diet, the feeding of grain to cattle has resulted in a decline in pasture area. Thus, total agricultural land—grain plus pasture—may have decreased even if the area of grains land.

almost always estimated to be inelastic and productivity of planted forests considerably greater than that of natural forests.

In some ways, the biotechnology issues in forestry appear to be modest compared to those in food. Since wood products are not ingested they are unlikely to have any direct human health or safety effects, either in the short or long run. Also, the ownership issue associated with the use of seeds from transgenic plants to create subsequent crops is likely to be less important due to the long periods required for flowering in trees, since technical change is likely to make current stock obsolete.

A more pressing concern, however, relates to the potential for genetic transfer from the transgenic tree to the surrounding natural environment.[22] As noted, this is not a problem in cases where the tree is an exotic and no similar species of trees are found in the natural environment—for example, conifer species are not indigenous to South America so the accidental transfer of genes from exotic conifer to indigenous conifer trees is precluded. Where the species is indigenous, an approach may be the introduction of sterility to prevent the release of genes that might transfer to the natural environment. Note that the major reason for introducing a sterility gene into trees is not, as in agriculture, to retain control over future seed sources, but rather to prevent the escape of genes into the natural environment through the tree-flowering process.

Finally, if modified genes do escape, how serious are the "expected" consequences or the "worst case" consequences? In the case of the herbicide-tolerant gene, the consequences of release into the wild are probably small. Herbicides are unlikely to be applied to most of the natural environment. If herbicides are to be applied, types can be used to which the escaped genes do not confer tolerance. In the intermediate and longer term, the herbicide in question will almost surely be replaced periodically in the normal course of product change and development. Thus the presence of that modified gene in the natural environment appears unlikely to constitute any serious short- or long-term environmental problem. Similarly for genes that affect tree form or fiber characteristics, the release of this gene into the natural environment is unlikely to provide a competitive advantage in survival and therefore unlikely to have significant or adverse consequences.

However, this situation could change if a survival gene is involved. For example, the release of a Bt gene, which provides protection again natural pathogens, into the wild could

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[22] See Mullin and Bertrand (1998) for a detailed discussion of many of these issues in a Canadian context.

constitute a more serious problem if it affects the comparative competitive position of pests associated with various types of similar natural vegetation. Ultimately, the seriousness of this problem depends on the probability of the transfer of a survival gene into the wild, on the scale of the transfer, and on the comparative change in the competitive balance within the natural habitat. This becomes an argument for the introduction of controlled exotics.

VIII. Some Implications of Biotechnology for Forestry: Assessing Benefits and Costs

The benefits of applying biotechnology to forestry are potentially huge. The estimates above suggest that the introduction of only one type of biotechnological innovation, a herbicide resistant gene, could generate benefits of as much as $1 billion annually in reduced forest plantation establishment costs and an expansion in the rate of plantation establishment by up to 225,000 additional ha per year. The increased production would not only generate increased social welfare through lower commodity prices but also would generate environmental benefits. Increased productivity from biotechnoligy would provide additional impetus to the well-documented gradual worldwide shift in industrial wood production from natural forests to plantations. Such a trend could have advantageous effects on native forests and biodiversity in that, as harvest pressures are relieved, native forests can be devoted to other purposes, including conservation. The more productive forest plantations are, the more they can deflect harvesting pressures from natural forests.

Additionally, biotechnology applied to trees offers an additional tool in dealing with specific environmental problems, including land and water protection, as well as presenting the potential to deal more effectively with global warming and atmospheric carbon mitigation.

The costs of biotechnology in forestry can be problematic. For many nonconifer species the potential financial costs of the introduction of biotechnology in forestry appear to be modest. Form and fiber modification and herbicide resistance appear to offer minimal potential damages. For most conifer species, however, the wide-spread low cost application awaits the development of low-cost cloning, which has yet to be achieved.[23] Furthermore, in many cases the financial benefits of biotechnology are only captured upon harvest while the costs are incurred in the

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[23] Currently, the development of conifer cloning at acceptable financial costs appears to be most well advanced for New Zealand radiata pine.

seedling. Thus, the financial benefits are delayed which, with positive discount rates, makes the investment far less attractive.[24]

The greater cost concern is probably related to the potential environmental damages that could be associated with the escape of modified genes into the natural environment. The costs associated with this are unclear, but in many cases would undoubtedly be negligible. Furthermore, as discussed above, most of any damages could probably be reduced substantially by the delay or elimination of flowering and/or by introducing the species into foreign environments where similar species are not found in the wild and gene transfer is highly improbable. However, the introduction of transgenic trees has been likened to the introduction of an exotic. In many cases the impacts are benign, but occasionally an invasive species can generate substantial economics and environmental damage.

Biotechnology in forestry takes many forms. Even if certain traits or types of transgenic trees are viewed as potentially risky, there are a host of genetic modifications that appear to offer negligible social risk.

IX. Summary and Conclusions

The benefits of biotechnology in forestry, both economic and ecological, are potentially enormous. The widespread use of a herbicide-resistant gene in forestry could result in annual savings of up to $1 billion. Admittedly, biotechnology in agriculture has come under attack for its potential health, safety, and environmental risks. However, the application of biotechnology to forestry poses somewhat different considerations than biotechnology's applications elsewhere. For example, direct health and safety risks appear nonexistent or negligible. The environmental risks that exist appear to relate largely to the potential for altered genes to move out of transgenic trees into the natural environment. The damages associated with the escape of many types of altered genes are probably negligible and are likely to be reduced substantially by the delay or elimination of flowering and/or by introducing the species into foreign environments where similar species are not found in the wild and gene transfer is highly improbable. Nevertheless, in s0me cases the risks may appear to be substantial. Where the risks cannot be adequately mitigated, certain selected types of biotechnological modifications could be excluded.

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[24] Traits like the herbicide resistant gene can reduce the costs of planting and therefore the cost savings can be realized early in the rotation. However, increased growth rates or improved fiber characteristical must await harvest.

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