

# Commercialization of Forest Biotechnology: Economic Targets for Enhanced Global Competitiveness of the U. S. Pulp and Paper Industry

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**Abstract:** Current economic analyses show that in the U. S., fiber costs represent up to 40% of the total cost for paper manufacturing. In countries located near the equator, these costs are dramatically lower. Commercialization of biological technologies that lead to genetic improvement of tree growth rates, wood and fiber qualities promise to significantly lower raw material costs and to maximize processing efficiencies, minimize environmental impacts, and improve product performances. A multidimensional cash flow model was constructed to estimate the value of changes in growth, wood and fiber properties of loblolly pine on linerboard production. Of the traits modeled increases in fiber tensile strength, specific gravity, and growth were found to be more valuable than reduced lignin content. If trees with a 20% increase in specific gravity captured 20% of the loblolly pine seedling market in the U. S. A., then the overall value of this wood quality improvement just for linerboard production alone was estimated at \$300 million per year. These results strongly support the forest industry goal of using biotechnology to improve tree growth and wood quality.

**Keywords:** Linerboard, profit, specific gravity, microfibril angle, growth rate, *Pinus taeda*

## INTRODUCTION

Commercial interest in forest tree biotechnology comes from the potential to dramatically improve the productivity of plantation grown trees by increasing growth rates and disease resistance as well as by enhancing the efficiency of converting trees into solidwood, pulp and paper products and biomass derived energy and new biobased products (Sedjo, 2004). The commercial success of genetically engineered crop plants that increase yield and require less chemical and energy inputs provides a roadmap to forest products and forest tree biotechnology firm's application of biotechnological methods to improve select tree species. Like crop biotechnology, forest biotechnology is composed of a suite of technologies. For forest trees these technologies include methods used for clonal or mass vegetative propagation of superior individual tree genotypes, molecular breeding and genetic engineering. These advanced technologies complement traditional breeding programs and share the same primary goal: to create faster growing trees that better resist insects and other pathogens and have wood properties that improve conversion into valuable products (Williams, 2001; Campbell, 2003).

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Only a few economic analyses have been published that quantify the potential cost savings for chemical pulp production which could come from increased volume growth and specific gravity, a key wood quality trait. For pines an analysis from the 1970s investigated changes in rotation age and specific gravity of loblolly pine using a linear programming model developed to optimize net profit of a mill that met specific paper quality standards (Van Buijtenen, 1987). The analysis compared 14 different cases for linerboard production and showed that selecting trees with increased volume growth and specific gravity improved mill profitability; however the amount of profit increase was not determined (Van Buijtenen, 1987). More recently Lowe et al. following the method of Borralho (Barralho, 1993) estimated changes in profitability associated with increases in loblolly pine growth rates and specific gravity for unbleached kraft pulp production (Lowe, 1999). They concluded that deploying seedlings from parents selected for higher specific gravity increased pulp mill profits by about ten fold over parents selected solely for fast growth (Lowe, 1999). This analysis assumed that unbleached kraft pulp was the final product and estimates for the impact of genetic improvements on the profitability of linerboard were not determined.

A research project to identify applications of forest biotechnology that have the greatest potential to enhance the global competitiveness, enterprise effectiveness, and environmental safety of U.S. pulp and paper companies is underway with funding by a Sloan Foundation Center for Paper Business and Industry Studies. The objectives for the first phase of this research program are: (1) cost/benefit comparisons of altering specific softwood fiber traits, (2) biological feasibility of increasing wood growth, improving wood and fiber properties, as well as uniformity of fiber supply through biotechnology, and (3) identification of the potentially most beneficial targets for forest biotechnology research.

## **MODELING APPROACH**

The value of changes in growth, wood and fiber properties for linerboard production costs and mill profitability are being estimated with a multidimensional cash flow model, consisting of a forest cost model and a theoretical Greenfield, vintage 1995, integrated Kraft pulp and linerboard mill cost model developed by Jaakko Pöyry Management Consulting (JPC) under contract to the Institute of Paper Science and Technology (IPST) (Figure 1). This mill model has been enhanced by addition of a module to calculate energy recovered when black liquor amount and composition change. To minimize errors due to fluctuations in spot prices for all forest and mill inputs and for the sale price of linerboard, we used real prices obtained from trend price regressions. The linerboard costs and mill profits are projected for year 2020, where the real price of linerboard is expected to drop from current values. Trait modeling predictions were based on empirical pulping and papermaking relationships obtained from the literature and when not available on mass and energy balances. To date all modeling has been conducted with the following basic assumptions: 1) the mill owns the forestland reflected in the lack of transfer pricing for softwood logs, 2) softwood logs are loblolly pine trees grown clonally, 3) all softwood logs for the mill come in as roundwood from company owned land, 4) hardwood (roundwood and chips) and recycled paper are purchased on the open market, and 5) linerboard production is held constant.

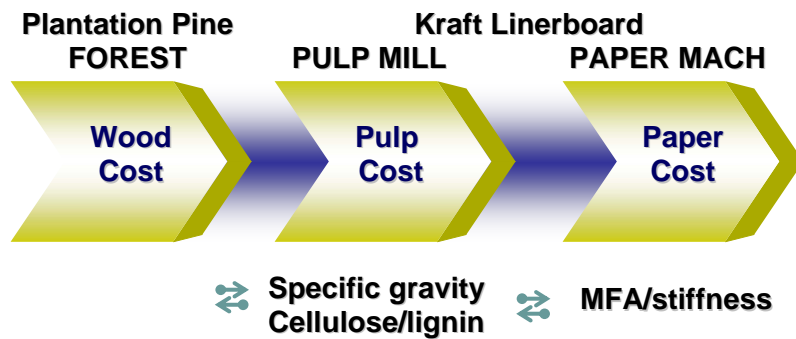


Figure 1. Approach to model growth rate, wood and fiber properties on the cost of slush pulp, linerboard and mill profitability

To interpret the modeling results it is important to understand the key assumptions and constraints made in developing the forest and mill models as well as the logic that we have followed in estimating the impacts on final costs for the trait changes investigated.

## FOREST COST MODEL ASSUMPTIONS

1. Plantation comprises solely Loblolly pine
  - Seedling cost is fixed at \$0.05
2. Land is located in the lower coastal plain of the Southeastern US
3. Base site index (SI) is 65 (max height in ft. at 25 yrs)
4. Intensive management improves SI from 65 to 78 for the unthinned scenario and 80 for the thinned scenario
  - Shear, rake, pile, bed and hardwood pretreatment
  - Herbicide treatments at planting and year 2 for unthinned scenario and brush control one year after thinning age
  - Fertilizer treatments at years 1, 6, and 10 for unthinned scenario and years 1, 6, and two years after thinning age
5. The land value is fixed and all land is owned by the mill for the sole purpose of supplying wood to the mill. For all rotations the opportunity cost associated with the land is assessed at a real discount rate of 8%.
6. Growth and yield equations for lower coastal plain were obtained from the Plantation Management Research Cooperative at the University of Georgia.
7. Tree diameter classes are estimated with the Weibull distribution function (PDF).
8. Harvesting outputs (efficiencies) are estimated with the Auburn Harvest Analyzer.
9. Transportation is estimated as a function of the distance and a derived hauling rate of \$2/mile/load.
10. The forest cost model optimizes the bare land value (BLV) of the plantation.
11. Silvicultural components of the model are constructed in MS-Excel with input variables of site index, trees per acre, cost per seedling, regeneration costs, stumpage prices, discount rate, and land cost. The harvesting and transportation components have multiple input variables.

12. Input variables for cost modeling are per acre land cost, specific gravity, trees per acre, growth (site index), and seedling cost.

## **PULP AND PAPER MILL MODEL ASSUMPTIONS**

1. Hypothetical, vintage-1995, Greenfield Kraft linerboard mill located in Southeast U.S.
2. The forest model is based on a yearly mill production of 483,000 ADMT/y unbleached Kraft pulp.
  - Produces 337,000 ADMT/yr (air-dried metric tons per year) of softwood Kraft pulp (70% of virgin fiber needs) at 70 Kappa for top ply and 105 Kappa for bottom ply.
  - Produces 146,000 ADMT /yr of hardwood kraft pulp (30% of virgin fiber needs) at 60 Kappa.
3. Mill also produces 127,000 ADMT/yr of recycled paper pulp.
4. The single paper machine produces about 590,000 MT/y (metric tons per year; 6.5% moisture) of 42 lb linerboard.
  - Top ply is 50% softwood and 50% hardwood
  - Bottom ply is 58% softwood, 10% hardwood and 32% recycled.
5. Black liquor solids and heating values are estimated separately for each pulp.
6. Capital is depreciated over 20 years for all equipment.
7. Inputs prices are based on trend price predictions obtained by linear regression of price data for the last 10-20 years.
8. Model is constructed in MS-Excel as an integrated set of worksheets with a base and proposed case format. All significant input prices and machine variables can be changed manually to determine the effect on production costs and mill profitability.

Table 1 shows a summary of the mill operating parameters, wood and pulp compositions and outputs used in the base case operations for the softwood and hardwood pulps and the top and bottom plys.

Table 1. Base Case Wood Properties and Pulping Conditions

Scenario	SW Wood Lignin Comp. (%)	SW Wood Density (BD kg/green m <sup>3</sup> )	SW BS Pulp Kappa	SW Wood Comp.: Cellulose/ Hemi/ Lignin/ Extr (%)	SW BS Pulp Comp.: Cellulose/ Hemi/ Lignin/ Extr (%)	SW BS EA, as Na <sub>2</sub> O (% on wood)	Sulfidity (%)	SW BS Pulp Yield (%)	SW BS HHV (BTU/ lb BLS)
Thin	29	458	105	39 / 23 / 29 / 9	63 / 17 / 16 / 4	10	25	60.3	6705.663
Unthin		471							
Thin-LC		458							
Unthin-LC		471							

Scenario	SW Wood Lignin Comp. (%)	SW Wood Density (BD kg/green m <sup>3</sup> )	SW TS Pulp Kappa	SW Wood Comp.: Cellulose/ Hemi/ Lignin/ Extr (%)	SW TS Pulp Comp.: Cellulose/ Hemi/ Lignin/ Extr (%)	SW TS EA, as Na <sub>2</sub> O (% on wood)	Sulfidity (%)	SW TS Pulp Yield (%)	SW TS HHV (BTU/ lb BLS)
Thin	29	458	70	39 / 23 / 29 / 9	68 / 17 / 13 / 3	13	25	53.5	6490.115
Unthin		471							
Thin-LC		458							
Unthin-LC		471							

Scenario	HW Wood Lignin Comp. (%)	HW Wood Density (BD kg/green m <sup>3</sup> )	HW Pulp Kappa	HW Wood Comp.: Cellulose/ Hemi/ Lignin/ Extr (%)	HW Pulp Comp.: Cellulose/ Hemi/ Lignin/ Extr (%)	HW EA, as Na <sub>2</sub> O (% on wood)	Sulfidity (%)	HW Pulp Yield (%)	HW HHV (BTU/ lb BLS)
Thin	20	515	60	51 / 27 / 20 / 2	68 / 25 / 7 / 0	12.5	25	58	5592.102
Unthin		515							
Thin-LC		515							
Unthin-LC		515							

## RESULTS

Base Case. Table 2 summarizes the major outputs from the forest and mill models for the base case of growth rate, wood and fiber properties using two forest cost models, for the unthinned model all of the wood goes to the mill as pulpwood and for the thinned model where harvested trees are segregated by stem diameter into three product classes pulpwood, chip-n-saw, and saw timber. In one set of scenarios the opportunity cost of the land is included in the computation of the cost of growing timber (Thin-LC and Unthin-LC). For each forest model the bare land value is calculated the same, the maximal bare land value for all four forest models was 18 years (Table II). In the thinning models, age 10 was the earliest age at which all stems met the minimum pulpwood diameter and stands were thinned to 50% of the trees per acre. Other constraints included were as follows, 20 tons/acre as minimum volume to remove, 65 ft<sup>2</sup>/acre as minimum residual basal area, and 6.5 in. as minimum Dq (quadratic mean diameter), the minimum age for harvesting solid wood products is 18 years, planting densities less than 400 TPA were not considered sawtimber due to more conic stems, broader crowns, and larger branches. The average specific gravity of the wood coming into the mill is estimated from forest tree biometric data and for the thinned cases is a weighted average of the specific gravities of the 10 and 18-year-old trees. The growth rate is indicated as mean annual increment (MAI) and the land area required for a sustainable supply of all of the softwood needs for the mill is calculated. About one third of the cost of wood comes from tree production while the other two-thirds of the total wood cost come from harvesting and transportation to the mill. Overall the greatest portion of wood is the cost of harvesting the logs. Use of trees for pulpwood, chip-n-saw and saw timber products (thinned) decreases pulp and paper mill profitability by ~20%. The lower mill profit in the thinned scenarios is due to elevated roundwood costs incurred by a higher forest production costs and by increases in the in the haul distance. In this work no attempt was made to estimate the increased profit in the forest that would result from selling a portion of the trees as higher value chip-n-saw and saw timber logs.

Table 2. Summary of Forest Cost Model for the Base Case Data

Forest Cost Model	Rot. Age (Yr)	SG	MAI (m3/hect/yr)	Land (Hec)	Wood Cost (\$/grn ton)	Liner Cost (\$/MT)	Op. Profit (Mil. \$)
Thin	18	0.46	21.55	235,475	15.30	274	27.95
Unthin	18	0.47	21.51	85,688	13.27	267	34.23
Thin-LC	18	0.46	20.63	246,342	16.73	278	25.79
Unthin-LC	18	0.47	22.03	85,393	14.67	271	31.67

**Effect of Reducing Basis Weight on Mill Profits.** Reduced linerboard basis weights were analyzed because less damage to the fibers during pulping or decreases in cellulose microfibril angle should increase the tensile strength of fibers and thereby permit basis weight reductions without wet pressing. In this analysis up charges on linerboard sale prices commonly given to high performance linerboard grades were used with our base case wood prices and mill parameters. Figure 2 shows the impact of reduced basis weight on the mill's profitability can be

quite high. As expected when total annual production is fixed, decreases in basis weight increase mill profitability for both the thinned and unthinned scenarios. The percent increases in mill profit (Figure 2) are greater for thinned forest scenarios because the thinned wood is more expensive, due to increased haul distances (Table 2).

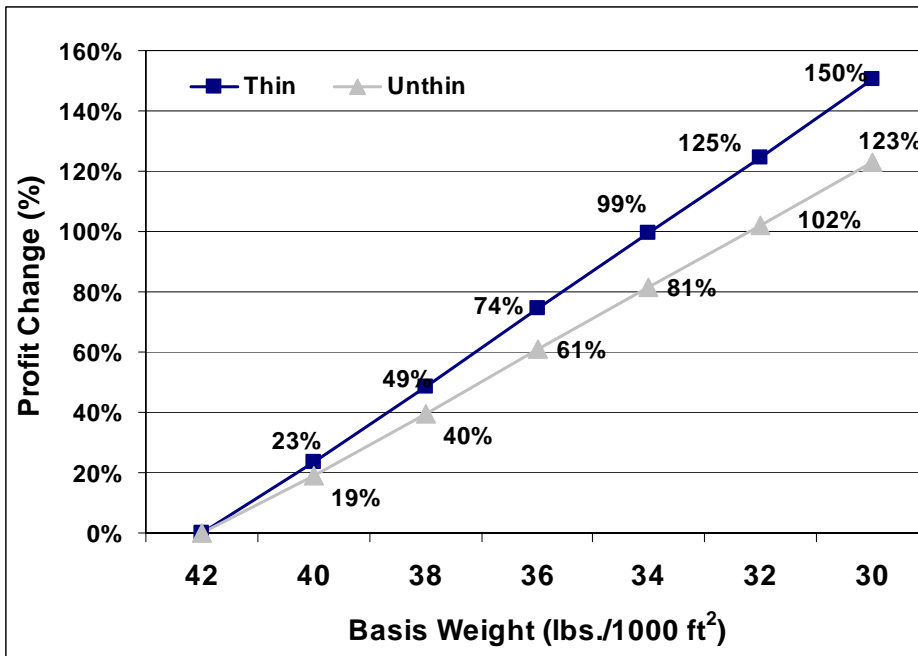


Figure 2. Effect of Decreased Basis Weight on Profit under Base Case Conditions (Note: Thin and Unthin Labels apply to scenarios both with and without land costs.)

**Effect of Changes in Growth Rate on Mill Profit.** To evaluate a difference in mill profitability as the growth rate of trees increased or decreased by a certain percentage, the site index within the forest cost model was varied by the respective percentage. As the trees' rate of growth increased, the production, harvest, and transportation costs decreased due to constant, yearly mill consumption. The decreased cost of wood translated into a higher mill profit. The impact of tree growth rate on profitability is illustrated in figure 3. In figure 3 the percent profit change was predicted when growth rate varied from a -20% to +30%. When the site index is increased by 30% (65 to 84.5) timber growth increases ~25% and mill profitability is predicted to increase by 5-10%

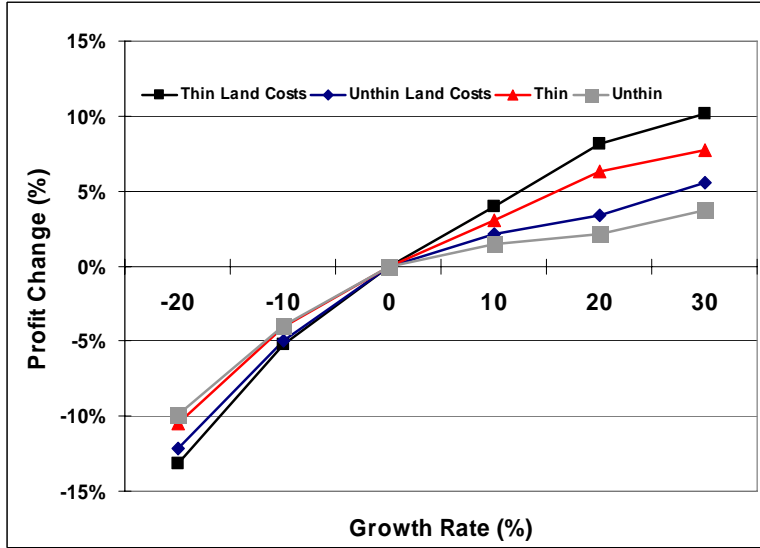


Figure 3. Effect of Change in Growth Rate on Profit

**Effect of Changes in Wood Lignin Content on Mill Profit.** The impact on mill profitability of processing wood with reduced lignin contents was modeled by increases in softwood pulp yield. Because no empirical data relates pulp yield with reduced lignin contents, increases in softwood pulp yields were estimated with a mass balance approach by assuming a fixed chemical composition of the base and top ply pulps. Since the yearly mill production of pulp was held constant, the yearly mill wood consumption declined with increases in pulp yield. This decreased wood consumption meant a lower wood cost and reductions in land area required to sustain production. The lower wood cost translated into a higher mill profit. Figure 4 shows the effect of softwood lignin content, at a fixed base case growth rate, specific gravity, and hardwood yield, on mill profitability. In figure 4 the percentage profit change is measured as the lignin content in the wood reduces from 29% to 15%. While there is less than a 1% increase in profit at a lignin content of 25% for all four scenarios, the two thin scenarios show a 7% profit increase at a lignin content of 15%, half of the natural lignin content. While dramatic reductions in wood lignin content lead to large increases in pulp yield, the value to the mill is mitigated by the loss in bioenergy production and the need to purchase more power.

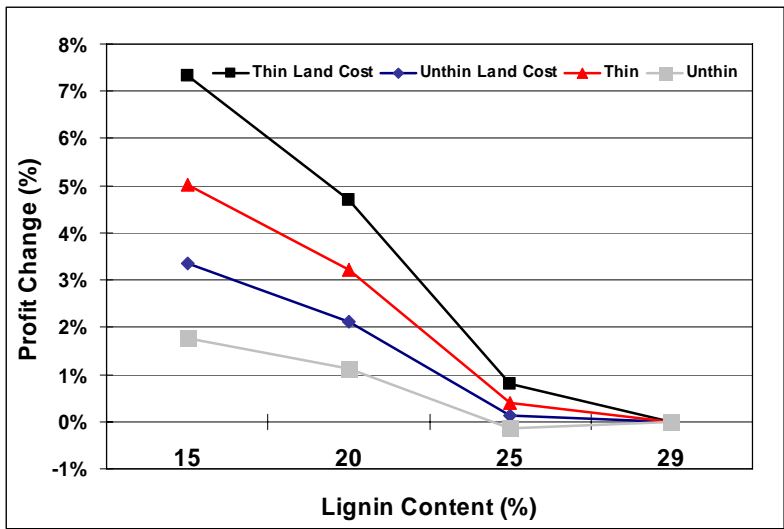


Figure 4. Effect of Change in Wood Lignin Content on Profit



**Effect of Changes in Specific Gravity on Mill Profit.** The impact on mill profitability of processing wood with changes in wood density or specific gravity was modeled by changes in softwood pulp yield. Regression equations relating changes in pulp yield at defined kappa values relative to changes in loblolly pine wood specific gravity were used to predict pulp yields (Kleppe, 1970a). The increases in pulp yield with increases in specific gravity are probably due to less degradation of carbohydrates during pulping in wood with higher specific gravity (Kleppe, 1970b). Since the total yearly production of pulp was held constant, at higher wood densities the yearly mill wood consumption declined. This decrease in wood consumption meant lower pulp mill costs and higher profitability. The impact of specific gravity on profitability is illustrated in figure 5. In figure 5 the percentage profit change is measured as specific gravity varies from 0.30 to 0.80 and can be fairly high. Again the thinned relative to the unthinned cases show a greater impact from changes in specific gravity due to the higher cost of wood that comes from hauling it further in the thinned cases.

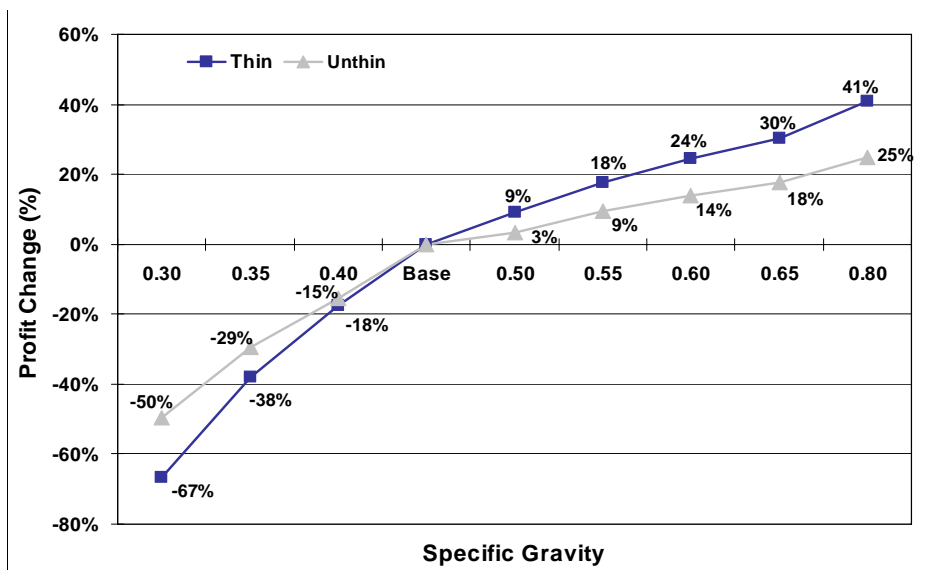


Figure 5. Effect of Change in Specific Gravity on Profit  
(Note: Thin and Unthin Labels apply to scenarios both with and without land costs.)

**Effect of all Biotech Changes on Mill Profit.** If we compare the four different changes to the trees, then the greatest increase on mill profits are reduced basis weight followed by increased specific gravity, increased growth rate, and decreased lignin content (Figure 6). The tree improvements that were chosen for Figure 6 are probably achievable through clonal selection or genetic engineering. A 10% reduction in linerboard basis weight, 42 lb. to 38 lb., shows a very good profit increase of forty to fifty percent.

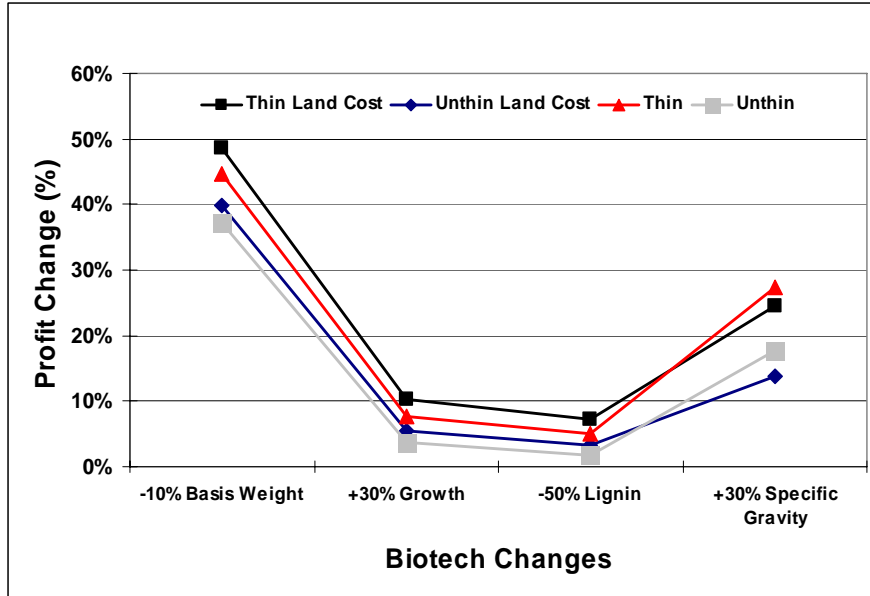


Figure 6. Effect of Percent Changes in Wood Properties from Base Case on Mill Profit

**Seedling Costs Reflect the Market Size and Potential of a Return for Investing in Forest Biotechnology.** In the above scenarios the seedling cost was fixed at the current market price of \$0.05. Table 3 shows what the maximum price for an improved seedling could be. This price was determined by increasing the seedling cost in the forest model to the point where the linerboard cost equals that for the base case and all of the cost savings in the mill due to the wood improvement goes into the seedling. These elevated seedling costs represent the value associated with changes in growth or a wood property and define the upper end of what might be expected in the open market for these improved seedlings. This higher seedling cost can be used to justify the magnitude of investment in forest tree biotechnology research and development. Currently there are over one billion loblolly pine seedlings planted annually in the SE US. If 20% of the seedling market were genetically improved, then the total potential value of the market based just on cost savings for linerboard would be \$100-300 million annually depending on the trait. It should be noted that this is a minimal estimate of the market size because it does not include any additional value that would come from reduced production costs of other paper grades or of solidwood products. If these additional cost savings were included, the market size would be expected to be substantially greater.

Table 3. Breakeven Seedling Costs for Growth, Wood Composition, and Specific Gravity within the Thinned Land Cost Scenario

Growth Rate	Breakeven Seedling Cost (\$/seedling)	Lignin Content	Breakeven Seedling Cost (\$/seedling)	Specific Gravity	Breakeven Seedling Cost (\$/seedling)
0	0.05	29%	0.05	0.458	0.05
+10%	0.25	25%	0.09	0.50	0.52
+20%	0.48	20%	0.29	0.55	1.09
+30%	0.63	15%	0.47	0.60	1.67

## CONCLUSIONS

The thinned scenarios have a greater impact on linerboard mill operating profit than the unthinned scenarios due to a higher wood cost. In all four scenarios, a reduction in basis weight provides the greatest profit increase given current biotechnology capabilities. An increase in specific gravity followed by an increase in the growth rate provides the next best value to the mill, respectively. A reduction in wood lignin content provides the least incremental benefit to the mill because of the loss of bioenergy and need to purchase more power.

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