

Use of cold tolerant eucalyptus species as a partial replacement for southern mixed hardwoods

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ABSTRACT: During the last several years, the increasing cost and decreasing availability of mixed southern hardwoods have resulted in financial and production difficulties for southern U.S. mills that use a significant percentage of hardwood kraft pulp. Traditionally, in the United States, hardwoods are not plantation grown because of the growth time required to produce a quality tree suitable for pulping. One potential method of mitigating the cost and supply issues associated with the use of native hardwoods is to grow eucalyptus in plantations for the sole purpose of producing hardwood pulp. However, most of the eucalyptus species used in pulping elsewhere in the world are not capable of surviving in the southern U.S. climate. This study examines the potential of seven different cold-tolerant eucalyptus species to be used as replacements for, or supplements to, mixed southern hardwoods. The laboratory pulping and bleaching aspects of these seven species are discussed, along with pertinent mill operational data. Selected mill trial data also are reviewed.

Application: The use of cold-tolerant eucalypt species obtained from plantations in the southern United States potentially could stabilize hardwood supply and raw material costs within southern U.S. pulp mills.

Traditionally, the pulp and paper industry in the United States has relied on native stands of hardwood to supply its demand for hardwood pulp. Over the last several years, increasing hardwood pulpwood stumpage costs [1] and a series of extremely wet winters have resulted in low hardwood pulpwood availability and escalated costs [2]. Pine availability has not been affected as drastically as hardwood because of the use of plantation-grown pine in the pulp and paper industry [3]. Typically, commercial pulpwood plantations within the southern United States only plant softwood species because it requires a longer growing time to produce a quality native hardwood tree suitable for pulping [4]. Hardwood removal rates currently are projected to exceed growth in Mississippi and South Carolina through 2040 because of the conversion of natural forest management-type plots to pine plantations [5]. Investment in hardwood productivity is fairly limited and the area of hardwood forest coverage is declining in the southern United States [6]. For a hardwood plantation to be economical for the pulp and paper industry, the growth time for the wood must be less than 15 years. Currently, eucalyptus plantations in Central and South America use a 5-9 year rotation [7]. Short rotation eucalyptus plantations in Spain typically follow a 13-18 year rotation [7].

Test plantings of cold-tolerant eucalyptus species in the southern United States have suggested that some eucalyptus species potentially could be grown and harvested in a plantation setting with less than a 12-year rotation. By establishing short-rotation eucalyptus plantations, it might be possible to

partially substitute eucalyptus for mixed native hardwoods. By performing a partial substitution of mixed native hardwoods with eucalyptus, the mill wood supply would be less prone to the weather and price fluctuations associated with current hardwood supply methods. This study evaluates the suitability of various cold-hardy eucalyptus species with respect to pulping and pulp physical properties, at the laboratory and mill scale.

EXPERIMENTAL

Cold-hardy species chip procurement

Seven different cold-hardy eucalyptus species were grown in the southern United States and harvested in late 2008 and 2009 for this study. These species were *Eucalyptus macarthurii*, *E. benthamii*, *E. urograndis*, *E. camaldulensis*, *E. dunnii*, *E. viminalis*, and *E. dorrigoensis*. In addition to these eucalyptus species, a sample of mill debarked and chipped mixed southern hardwood was obtained from the mill in Evadale, Texas, and used as a control. All of the species used in this study were grown in the United States and the maximum age of any of these samples was 9 years.

The *E. macarthurii* wood was collected from a plantation in Allendale County, South Carolina. The seed for this planting came from a Sappi Corporation seed orchard in South Africa. Ten trees were cut at age 7 years. The sample trees had an average diameter of 7.4 in. and average height of 58.6 ft.

The *E. benthamii* wood was collected from a plantation in Colleton County, South Carolina. The seed for this planting came from a collection in a native stand in the Camden area

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of New South Wales, Australia. Six trees were cut at age 7 years. The sample trees had an average diameter of 8.5 in. and average height of 67.3 ft.

The *E. urograndis* sample was obtained from an ArborGen planting near Loxley, Alabama. These trees were 2.5 years old.

The *E. camaldulensis* was from a 5-year-old planting in Texas and contained wood that had been downed by Hurricane Ike in 2008. Stain and decay was apparent in the *E. camaldulensis* samples.

The other species, *E. dunnii*, *E. viminalis*, and *E. dorri-goensis*, were sampled from a 9-year-old test planting near Summerville, South Carolina. The *E. dunnii* trees sampled at the South Carolina site had experienced multiple top die-backs caused by winter freezes. Some decay was apparent in the *E. dunnii* samples.

Unless otherwise specified, five representative trees of each species were cut for this study. Each tree was sawn into 4-ft bolts from the top, middle top, middle bottom, and bottom; these bolts were sent to the University of Maine for chipping and screening. In addition, unscreened mill hardwood chips were sent from Evadale to the University of Maine and screened using the same settings as the eucalyptus chips.

Laboratory pulping studies

After the chips were screened, they were pulped in a laboratory digester at the MeadWestvaco Corporation (MWV) facility in Raleigh, North Carolina. The liquor-to-wood ratio was kept constant at 4.0, the sulfidity at 30%, the time-to-temperature at 45 min, and the top temperature at 168°C. The active alkali charge was 175% on oven-dry wood. H-factor was varied by changing the time at temperature to produce a series of pulps with kappa numbers in the 14-35 range. In addition, *E. macarthurii* and *E. benthamii* chips were blended with mill hardwood chips at 25:75, 50:50, and 75:25 ratios, and the same pulping program was carried out for each chip blend. Four to six cooks were performed on each set of chips and chip blends.

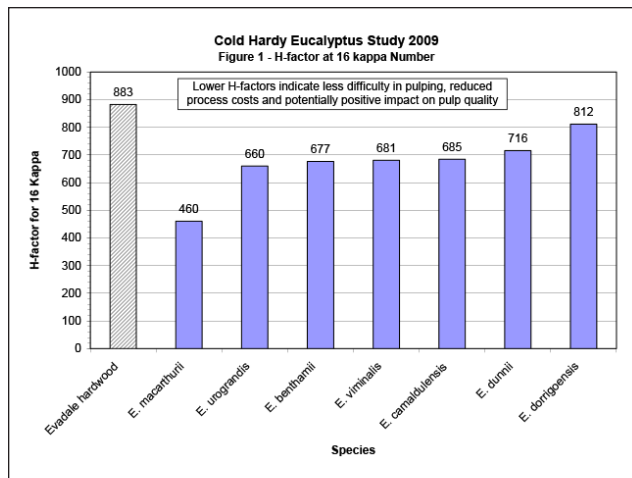
The resulting pulps were characterized as to kappa number, total pulp yield, and screened pulp yield. Screening work was carried out using a shaker-type laboratory flat screen fitted with a 10-cut (0.010 in.) slotted screen plate. Residual sodium hydroxide and residual active alkali charge in the black liquor from each cook also were determined.

RESULTS

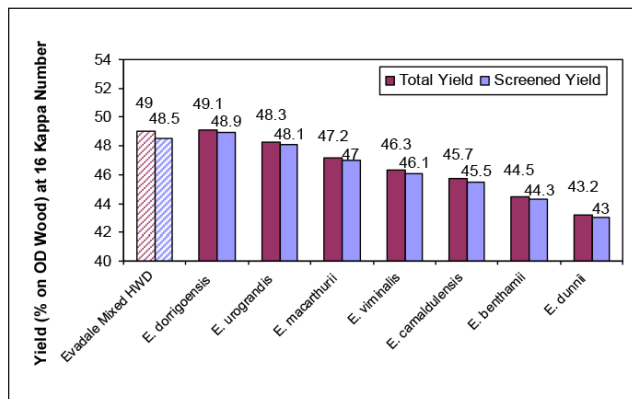
Pure species pulping laboratory results

Ease of pulping

One important aspect of evaluating any new species for potential use by a mill is its ability to be pulped. For instance, a wood species that required an extremely low or an extremely high H-factor would be undesirable to use as a partial replacement for mixed native hardwoods. Ideally, the desired cooking conditions required to obtain a target kappa number would be similar to the cooking conditions required for the



1. Ease of pulping as measured by the H-factor required to obtain a 16 kappa number with all other cooking parameters held constant.

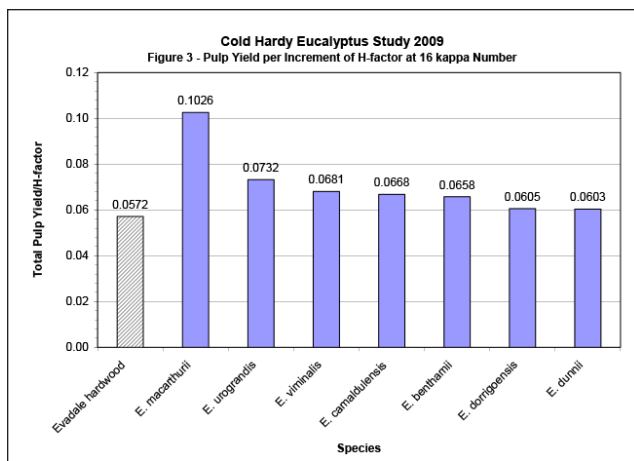


2. Total yield at 16 kappa for the species examined. (Note: the yield of *E. camaldulensis* and *E. dunnii* might have been affected negatively by poor chip quality.)

mixed hardwoods. To determine the ease of pulping for this study, we determined the H-factor required to obtain a target of 16 kappa for each species with all other cooking conditions held constant. **Figure 1** shows each of the eucalyptus species in order of increasing H-factor required to obtain a 16 kappa brownstock. The *E. macarthurii* was significantly easier to pulp than the other species. The *E. dorri-goensis* was the hardest eucalyptus species to pulp, though slightly easier to pulp than the native mixed species mill hardwood chips.

Pulp yield

Another important aspect of evaluating new wood species for pulping performance is the digester and screened yield of the resulting pulp. **Figure 2** shows the digester or total yield of each of these species at 16 kappa. *E. urograndis*, *E. dorri-goensis*, and *E. macarthurii* exhibit total pulp yields in the same range as the mill hardwood. The *E. benthamii* produced a relatively low pulp yield. The *E. camaldulensis* and *E. dunnii* trees used for this study had significant amounts of rot and decay, which might have negatively affected results.



3. Total pulp yield divided by the H-factor required to obtain a 16 kappa number, an estimate of species suitability.

The *E. camaldulensis* trees had been knocked down by Hurricane Ike and allowed to lay on the ground for several months before being collected for this study. The *E. dunni* samples also had a significant amount of decay in the wood samples because of repeated die-backs of the tree tops resulting from freezing conditions in South Carolina.

An evaluation of the screen rejects produced in a subset of these cooks showed that the eucalyptus species had about 0.2% rejects at 16 kappa, compared with about 0.5% rejects for the Evadale native mixed hardwood (Fig. 2). Those are only estimates, however, because the determination of screen rejects from such small cooks can vary considerably.

Pulping qualitative analysis

To rank each of these species with respect to yield and ease of cooking, we divided the total pulp yield by the H-factor required to obtain a 16 kappa cook. Ideally, this analysis shows how the degree of pulping required to achieve the target kappa number affects the pulp yield. **Figure 3** shows the results of this analysis.

A species that is easier to cook (low H-factor) and gives a higher pulp yield would be the best option from a pulp mill perspective, and a species that is harder to cook and gives a lower yield would be the least desirable option. From Fig. 3, it appears that *E. macarthurii* is the best option, followed by

E. urograndis. Because the decay present in the *E. camaldulensis* and *E. dunni* species examined in this study might have negatively affected this pulping evaluation, caution should be used when drawing absolute conclusions from these data. Results for the other eucalyptus species appear to be similar; all of them rank as good as or better than the native mixed mill hardwood.

Several studies have examined the effect of wood composition on the ease of pulping and pulp yield [8-10]. These studies examined the effect of wood composition variability, both within species [8] and between species [9,10], on ease of pulping and pulp yield. These studies found that wood containing a higher syringyl lignin content pulped easier than wood containing more condensed lignin structures. Overall, the studies showed a rough correlation between yield and cellulose or carbohydrate content. They also found a roughly negative correlation between yield and lignin content. These correlations were fairly good within a species, but tended to break down somewhat between species [8]. Attempts to correlate specific hemicelluloses or specific constituent carbohydrates to pulp yield gave poor correlations, even within a specific species. Because we mainly were attempting to determine whether the cold tolerant species grown in the southern United States could be used as a partial replacement for native hardwoods, the individual effects of pure species components on the pure cooking and yield characteristics were not studied further. The wood constituents were analyzed for the mixed Evadale mill hardwood, *E. macarthurii*, and *E. benthamii* samples used as part of the mill scale blending study described later in this paper. **Table I** shows these results. Based on statistical analyses with only three data points, it appears that the lignin content of the wood was the only wood component that correlated with yield.

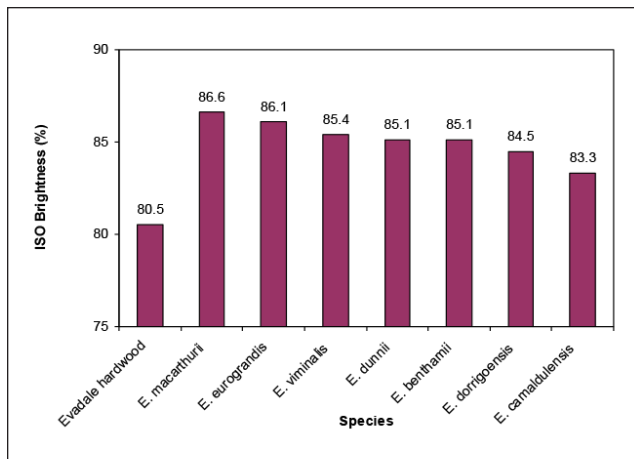
Bleach response screening

Pulp samples of 16-18 kappa number were bleached with a constant XD(EP)DD bleaching sequence. Each pulp was bleached with the same percent applied chemical under identical bleaching conditions. **Figure 4** shows the final brightness of each of these pulps. For this screening study, we wanted to try to determine whether the pure species eucalypts examined could be bleached to the same or higher brightness as the mixed mill hardwoods. Because of the large number of

Species	Water Extractives	DCM Extractives	Ash	Uronic Anhydride ¹	Arabinan	Galactan	Glucan	Xylan	Mannan	Cellulose (cal)	Hemicellulose (cal)	Lignin	Yield
Mixed hardwood	3.45	0.36	0.66	4.74	0.52	1.25	42.69	19.43	2.26	41.4	30.0	27.6	49.0
<i>E. macarthurii</i>	4.58	0.48	0.74	4.98	0.48	1.92	43.04	15.62	0.73	42.6	24.5	31.7	47.2
<i>E. benthamii</i>	4.47	0.39	0.73	5.10	0.39	1.91	42.63	15.11	0.78	42.2	24.3	32.4	44.5
Calibration sample used					0.64	0.46	77.14	8.92	6.25				
Calibration standard data					0.7±0.14	0.5±0.11	77.2±2.30	8.9±1.09	6.5±0.65				

¹ Uronic anhydride analysis was conducted to determine cellulose and hemicellulose content.

I. Wood component percentages (%) for mixed hardwoods and two selected eucalypt species studied.



4. ISO brightness response when 16-18 kappa number pulps were bleached under constant total applied chemicals bleaching conditions using an XD(EP)DD bleaching sequence.

	Refining Time (min)	CSF (no load) (mL)	Length-weighted Fiber Length (mm)
Evadale, TX, USA mixed hardwood	11.66	689	0.872
<i>E. dorrigoensis</i>	4.28	468	0.538
<i>E. urograndis</i>	1.43	550	0.618
<i>E. macarthurii</i>	4.15	557	0.572
<i>E. viminalis</i>	1	499	0.542
<i>E. camaldulensis</i>	5.05	547	0.598
<i>E. benthamii</i>	3.1	569	0.617
<i>E. dunni</i>	1.14	555	0.62

II. Refining and fiber properties. Length weighted fiber length determined at 1.35 cm³/g handsheet bulk. Freeness determined before refining.

	Tensile Index (Nm/g)	Tear Index (g/m ²)	TEA (J/m ²)	Bending Stiffness (nNm)	Sheffield Smoothness	Modulus of Elasticity (TSI/bulk)
Evadale, TX, USA mixed hardwood	71.7	11.6	204	2.19	178	6.81
<i>E. dorrigoensis</i>	69.7	8.3	197	2.06	119	7.03
<i>E. urograndis</i>	73.8	10.2	180	2.22	114	7.42
<i>E. macarthurii</i>	76.0	10.8	226	2.18	126	7.17
<i>E. viminalis</i>	70.4	7.8	177	2.09	118	6.92
<i>E. camaldulensis</i>	75.1	9.6	251	2.09	119	6.87
<i>E. benthamii</i>	76.1	11.3	203	2.22	125	7.48
<i>E. dunni</i>	78.7	9.7	250	2.29	121	6.92

III. Physical properties evaluated at 1.35 cm³/g bulk.

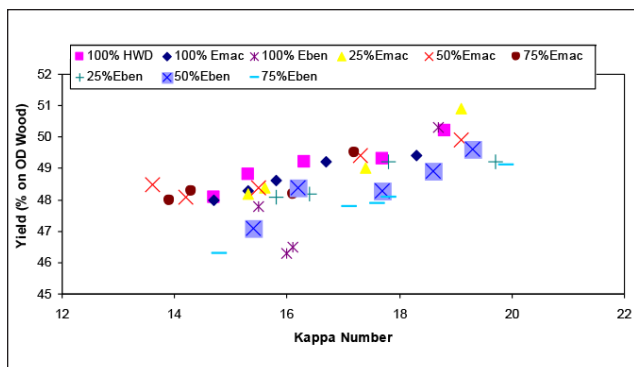
samples involved in this study, we did not attempt to bleach each pulp to a constant brightness. Our screening study was performed simply as an indication of potential bleach plant problems, not as a unique pulp-to-pulp comparison. As shown in Fig. 4, a higher brightness was obtained for each of the eucalypt species studied, as compared with the brightness of the control mill pulp. Thus, we determined that blending a portion of eucalyptus into the mill furnish should not cause low brightness problems in the bleaching sequence.

Physical and fiber properties

The screened pulp was laboratory bleached and subjected to refining in a Valley beater. Samples were collected at four different times and tested for fiber freeness and fiber length. These pulps were made into 120 g/m² handsheets and tested for tear, tensile, tensile energy absorption (TEA), and bending stiffness. Physical property data were interpolated and the results were tabulated at 1.35 cm³/g bulk. The fiber lengths of all the species examined were determined using a fiber quality analyzer. **Table II** and **Table III** show the results of these tests. Table II shows the refining and fiber properties, and Table III displays the physical properties.

Freeness values were determined for the unrefined brownstock. It was determined that the freeness of the eucalyptus fiber was considerably lower than the freeness of the mixed native hardwoods. The mill hardwood and the highest freeness eucalyptus pulp differed by more than 100 mL, and the freeness of the mill hardwood and the lowest freeness eucalyptus pulp differed by 221 mL.

All of the eucalyptus pulps required significantly less refining energy (in some cases up to 90% less refining energy) to obtain the desired bulk value of 1.35 cm³/g. Within the eucalyptus species, *E. viminalis*, *E. dunni*, and *E. urograndis* were easier to refine than the other species. All of the eucalyptus species evaluated had a significantly reduced fiber length compared with the mill native hardwood pulp. The mill hardwood length-weighted fiber length was 0.873 mm;



5. Yield versus kappa number relationship for blends of *E. macathurii* and *E. benthamii* chips with mill hardwood ranging from 0% to 100% eucalyptus.

all of the eucalyptus species length-weighted fiber lengths were between 0.538 mm and 0.620 mm. A result of the lower eucalyptus fiber length is that sheets of the same bulk made with the eucalyptus fibers produce a smoother sheet (lower Sheffield value) than sheets made with mixed native hardwoods. Table III shows the Sheffield smoothness results.

As would be expected from the short fiber length of the eucalyptus pulps, the mill native mixed hardwoods exhibit a higher tear index than any of the eucalyptus fibers. The mill hardwood produces sheets with a rougher surface (lower smoothness) than the eucalyptus pulps. Results varied for tensile index, TEA, bending stiffness, and modulus of elasticity for the mill hardwoods and the eucalyptus fiber strength. In several instances, specific eucalyptus species exhibited better strength properties than the mixed hardwood. *E. camaldulensis* and *E. dunnii* both exhibited superior TEA compared with the mill hardwood; even though the chips for both of these wood species had a significant amount of decay. Because the decay in the wood chips could have affected yield and ease of pulping, and based on their superior TEA test results, it would be important to retest these two species before committing further to alternate species.

Blended chip pulping trials

Because the cold-tolerant eucalyptus will be used as a partial replacement for the native mixed hardwoods, we decided to perform an analysis of two different eucalyptus species blended in different ratios with mill hardwood chips. *E. macathurii* and *E. benthamii* were chosen for this effort. Samples of

each of these species were blended with mill hardwood in 25%, 50%, and 75% eucalyptus to mill hardwood ratios. These blended chips were pulped over a range of cooking conditions in the same manner as for the pure species work described previously. **Figure 5** shows the kappa number and yield relationship for each of these blends. As can be seen in Fig. 5, the *E. macathurii* chip blends from 25% to 100% eucalyptus produced about the same kappa yield relationship as the 100% mill hardwood. The *E. benthamii* chip blends tended to produce a slightly decreased yield compared with the 100% mill hardwood chips.

Unbleached fiber from the 100% mill hardwood and the two 50% blend cooks were made into 120 g/m² handsheets and tested for physical properties. Additional samples were tested for fiber properties with a fiber quality analyzer. **Table IV** shows the fiber and physical properties. The partial substitution of eucalyptus for mill hardwood chips had little or no effect on the physical properties of the resulting pulp. The one exception was a slightly negative effect on fiber stiffness.

Mill-scale trials – partial substitution

The blended chip studies suggested minimal to no impact for partially substituting eucalyptus chips with mill hardwood, so it was decided to perform a mill-scale pulping trial. Significant quantities of *E. macathurii* were harvested from four different operational-scale test plots in South Carolina. The trees ranged in age from 8 to 11 years old. The logs were debarked, chipped, and screened at a satellite chip mill and transported by truck to the MWV mill in Evadale. All chip processing was performed within three weeks of tree harvest. Two distinct 24 h trials were performed. The first trial consisted of substituting 42% of the mill hardwood chips going to the digester with the eucalyptus chips. The second trial decreased the substitution level to 33% because of the limited volume of chips available for the trial. For both of these trials, the eucalyptus and mill hardwood chips were mixed at the chip screens and sent to the digester as a blended product. No changes in the standard mill pulping or bleaching conditions were required to process these blended chips. Samples of the pulp produced from these trials were sent to John D. Hankey and Associates in Appleton, Wisconsin, for independent testing to verify the eucalyptus content in the final pulp.

Drainage on the brownstock washer and decker were neg-

Blend	CSF (mL)	Fiber Length (mm)	Fiber Width (μm)	Tensile Index	Stiffness (mN)	Tear (gram-force)
100% hardwood	465	1.085	19.6	8.87	95.2	218
50% <i>E. macathurii</i> /50%hardwood	460	0.760	15.8	9.09	86.5	197
50% <i>E. benthamii</i> /50%hardwood	460	0.751	16.1	9.30	84.9	216

IV. Fiber and physical properties of 100% mill hardwood and 50/50 mill hardwood/eucalyptus blends. *E. macathurii* and *E. benthamii* were the two eucalyptus species studied.

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Blend	% Fines – length Weighted	Length-weighted Fiber Length (mL)	Fiber Width (μm)	CSF (mL)
100% mill hardwood	12.86	1.04	18.5	582
67% hardwood/33% <i>E. macarthuri</i>	11.02	0.85	17.0	514
58% hardwood/42% <i>E. macarthuri</i>	11.29	0.85	17.1	534

V. Freeness and fiber properties of 100% mill hardwood and two *E. macarthuri*/mill hardwood pulp blends.

Blend	Refining Energy (kWh/metric ton)	Elastic Modulus (TSI/bulk)	Bending Stiffness (mNm)	Tear Index (g/m ²)	Tensile Index (Nm/g)	Smoothness
100% hardwood	4.87	5.14	1.80	11.1	45.2	223
67% hardwood / 33% eucalyptus	19.26	5.67	1.95	10.5	56.6	188
58% hardwood / 42% eucalyptus	28.58	5.62	1.66	10.1	53.7	183

VI. Physical properties of laboratory refined, mill produced pulps with various levels of eucalyptus substitution for native mixed hardwoods evaluated at 1.4 cm³/g bulk.

actively affected, with the eucalyptus blend experiencing slower drainage, especially on the decker. No noticeable pitch effects resulted from the presence of eucalyptus in the digester feed. No changes in brightness reversion were noted in the final bleached fiber. **Table V** shows the freeness, fiber length, fiber width, and fines content of pulp samples collected during the mill trials. The blended fiber had a lower fiber length and thinner fibers with a lower freeness compared with the typical mill hardwood pulp.

When the blended fiber was converted into board on the paper machines, no specific adverse effects were noted. The mill had no internal rejects and no field quality complaints related to the use of eucalyptus as a partial substitution for the mixed native hardwood. The resulting board did have a slightly improved smoothness and a slight improvement in stiffness as a result of the eucalyptus fiber in the machine furnish.

Laboratory refining evaluation of mill trial pulps

The trial pulps were collected from the mill and refined using a pilot-scale disc refiner. A series of freeness levels were generated by varying refining power at a constant intensity of 0.5 watt-seconds per meter, and each freeness level was sampled for further evaluation. Each freeness sample was tested using the fiber quality analyzer, and TAPPI board-weight handsheets were made (TAPPI T 205 sp-95, "Forming handsheets for physical testing of pulp, Appendix B - Board stock") for determination of pulp physical properties. Physical properties were interpolated at 1.4 cm³/g bulk (**Table VI**).

No significant negative effects on the physical properties examined resulted from the inclusion of eucalyptus in the sheet. The inclusion of eucalyptus fiber in the mill hardwood did make the resulting pulp more difficult to refine. In general, blending of a longer fiber that is more difficult to refine with a shorter fiber that is easy to refine will result in an increase in the overall required refining energy. Refining is ef-

fectively a statistical impact of fibers with each other and with the refining bars. The more difficult to refine fiber will still require a significant amount of energy to be refined. Unfortunately, the shorter fibers blended into the fiber furnish statistically will reduce the number of impacts that the hard to refine fiber experiences. Compared with pure species, the hard to refine fiber will be hit fewer times as it passes through the refiner, requiring more applied specific energy to obtain the same degree of refining.

CONCLUSIONS

The inclusion of 33% to 42% *E. macarthurii* in the hardwood chip furnish at the Evadale mill did not lead to a significant change in important hardwood pulp properties, especially when the pulps were compared at constant bulk. No significant changes were required in the mill pulping and bleaching conditions to accommodate the inclusion of a significant percentage of eucalyptus into the chip furnish feeding the digester. The partial substitution of eucalyptus for native mixed hardwoods did result in decreased drainage on the brown-stock washers. Partial substitution of eucalyptus also decreased the unrefined freeness of the pulp produced and lowered the average fiber length and fiber width of the mixed hardwood fiber being produced. Pulping of pure species and blends of eucalyptus with mixed hardwoods in the laboratory has verified these trends. Specific eucalyptus species might have a negative effect on pulping yield. However, when blended with a large percentage of native hardwood, only minor changes were noted.

The initial laboratory work, in conjunction with the mill trials, suggested that several potential cold-tolerant eucalyptus species could be used as a partial substitute for mixed native hardwoods. Even in blends of up to 50% eucalyptus, pulp and paper (board) properties were not affected negatively. If it is possible to grow these species economically in a plantation

setting in the southern United States, it might be possible to reduce mill fiber supply costs and ensure a reasonable percentage of the mill fiber demands during the winter months when hardwood procurement tends to be difficult. **TJ**

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ABOUT THE AUTHORS

Over the last several years, hardwood pulp logs have been difficult to obtain during winter months. The price of these logs has escalated in conjunction with the difficulty in obtaining hardwood. Currently, hardwoods are being harvested at a faster rate than they are growing within several of the southern United States. The ability to supplement this hardwood supply with rapid growth hardwood plantations would be of great benefit to the mills, resulting in price stability and guaranteed raw material availability.

To our knowledge, the current work is the first to examine several different potential eucalyptus species that have actually been grown within the southern United States. These hardwoods have demonstrated their ability to survive over long periods under typical southern U.S. weather conditions. Full-scale mill trials were conducted with these trees and reported in the current work.

This research project has been planned and conducted over several years. The majority of the trees used in this study were planted 9-12 years before the beginning of the laboratory pulping studies. The current work provided several logistical challenges: the trees were cut in the south; shipped to Maine for debarking, chipping, and screening; then shipped back down south for pulping. The trees used in the mill-scale trials were cut in South Carolina, debarked and chipped at a satellite facility, then transported to Texas for pulping and bleaching.

The eucalyptus fiber produced from these pulping studies had an extremely short fiber length and a very low unrefined freeness. On first glance at these values, one would expect significant negative drainage issues on the brownstock washers and on the paper machines. When the mill trials were performed, a

minor drainage impact was experienced on the washers, but no problems were encountered on the actual paper machine or in the paper mill in general.

The initial laboratory pulping and mill processing studies have shown that cold-tolerant eucalyptus species can be used successfully as a partial replacement for southern U.S. hardwoods in demanding bleached board applications. By using these species in hardwood plantations, it may be possible for mills to successfully supplement their hardwood supply to ensure availability and stabilize raw material costs.

The next step in this work is to actually plant several hundred acres of cold-tolerant eucalyptus species and determine the optimum growing conditions for southern U.S. hardwood plantations. It is important to establish reliable plantation yield values in green tons or wood per acre per year to determine the overall economics associated with the establishment and use of cold-tolerant eucalyptus plantations in the southern United States.



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