

**Summary of Recent Test Results
Of New Technology
Utilizing Small Diameter Ponderosa Pine
From Northern Arizona**

A series of tests on small diameter Ponderosa pine from Northern Arizona were conducted for the purpose of identifying technologies that can add value to the timber resource. The test results of five different technologies provide baseline information to help determine the feasibility of investment in new or upgraded manufacturing facilities within the region.

Small diameter Ponderosa pine logs from the Flagstaff, Arizona area were processed through a high tech, small log mill. Lumber produced from the primary log breakdown was then forwarded on to new technology manufacturers for materials testing. A mix of sawdust, chips, shavings, and bark produced from primary manufacturing was sent to Sorbilite for product development. These tests are of interest for the Central Oregon region as they demonstrate the potential for utilizing small logs that may be available from forest fuel reduction and restoration projects in the region. It also provides a demonstration of the type of testing required for other Central Oregon tree species.

Small Log Processing

The purpose of the mill trial was to determine the potential for processing small diameter Ponderosa pine logs from restoration sites on modern, efficient small log processing systems, and to provide lumber produced from these logs for further technology testing employing E-Grader, FiRP, Sorbilite, and Indurite technologies. To facilitate this test, Grand Canyon Forest Partnership entered into a memorandum of understanding with Kinzua Resources of Pilot Rock, Oregon. Kinzua was selected because they currently process Ponderosa Pine small logs from inland Western states and they have a CAE/McGehee, SL 2000, single pass, small log processing system.

In December 2001, 2 truckloads of logs were shipped from Northern Arizona to Kinzua Resources' mill in Pilot Rock, Oregon. These logs were selected as a representative sample of small logs in the 6"-9" small end diameter (sed) range with a taper of 1.5" to 2" in 16 feet. The logs were taken from the GCFP restoration site outside of Flagstaff and all but 3 logs were bucked to 16 feet in length. According to the logger, the logs were a mix of 30% from small diameter timber (< 9" dbh) and approximately 70%, second segment logs, from larger diameter timber (9"-16" dbh). No significant processing differences were noted in any of the logs.



5" to 9" 16' logs on log deck at Kinzua



CAE/McGehee SL2000

Procedure:

On January 28, 2002, Kinzua processed the logs through their small log processing line. The logs were processed in the same manner they process Ponderosa Pine from the Inland Pacific Northwest. Other than separating the logs and lumber for inventory and tracking purposes, the logs and lumber were processed along with their normal pine run.

After processing the trial logs through the sawmill, 10 sample boards were pulled for shipment to New Zealand for the Indurite Test and approximately 3 cu. yds. of residue was collected for the Sorbilite test. All remaining lumber was dried in steam dry kilns along with Pine from the Inland Pacific Northwest. No special schedules were used. After drying the lumber was pulled from the dry kiln and set aside for the planer test.

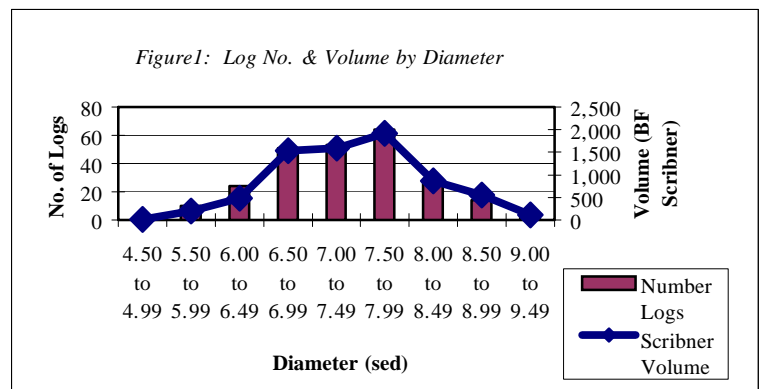
The lumber was put through the planer mill in separate runs using standard planer settings. Lumber was run and samples were selected for the E-Grader and FIRP Tests.

Mill production reports and data were obtained and interviews with mill personnel were conducted. The following is a summary of the test results:

Results:

Log Scale and Quality:

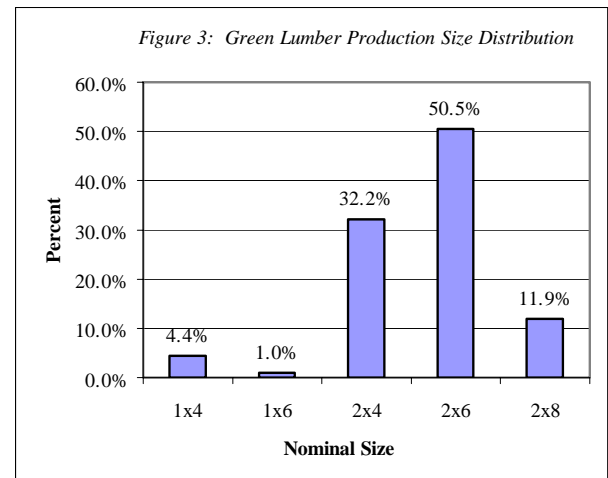
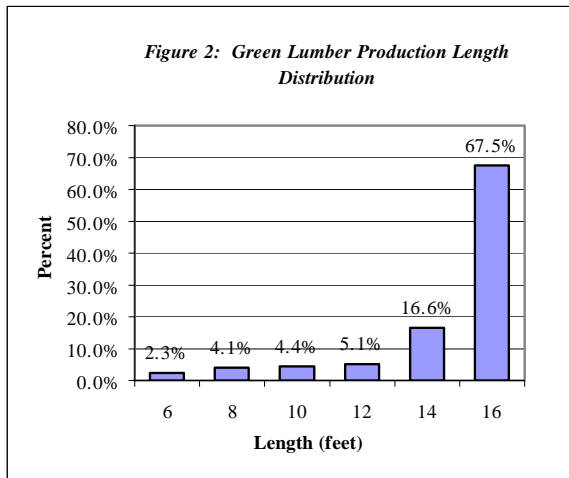
The logs were kept separate from the rest of the mill's log supply and scaled at Kinzua by the mill's certified scalers (NW Log Scalers) using Scribner, East Side Rules. A total of 249 logs were received. The Gross Scale for the logs was 6,780 BF. The net scale was 6,200 BF. Scaling defect was approximately 8.5%, which is relatively small for Ponderosa Pine. In general logs were relatively straight with an average diameter (sed) of 7.08". Mill personnel were impressed with the quality, taper, and straightness of the logs compared to the Inland Northwest logs they normally process. **Figure 1** shows the log distribution (number and volume) by diameter class.



Green Lumber Production:

All logs received were processed through the mill. No problems were experienced due to log form, quality, or size. A total of 249 log segments were processed. Net Log scale into the mill was 6,200 bf, Scribner, and 1,470.6 cu.ft.. Net lumber scale out of the sawmill was 9,435 bf lumber scale. Overrun of approximately 1.52 and a lumber recovery factor (LRF) of 6.42 bf/cf were realized. These factors are similar to results from processing Inland Northwest Ponderosa Pine.

Mill personnel stated that the logs ran through the machine as easily as any of the pine logs from the Inland Northwest. The quality of the log appeared to be as good or better than most of the logs processed in the small log mill. Production rates through the mill were approximately 15 logs per minute, typical for this operation. Due to the straightness of the log and the small amount of taper, a greater volume of longer and wider boards were produced than originally anticipated. **Figure 2** is the length distribution and **Figure 3** shows the size distribution from the green end.

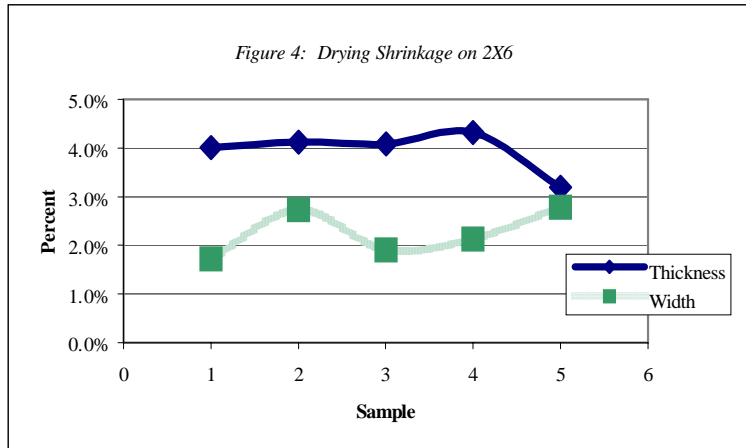


Drying:

Drying was accomplished in standard softwood dry kilns with dry bulb/wet bulb controls. The test lumber was placed in the kiln along with similar sizes of Ponderosa Pine from the Inland Northwest Region. A standard kiln schedule was used requiring 72 to 96 hours for drying. Lumber was dried to 12% to 16% moisture content. No significant drying defect was noted beyond what would normally be expected. A little warp in top boards and some additional splitting and twisting from drying were noted.

The schedule for 2x4's raised the temperature to 170 degrees Fahrenheit in approximately 20 hours and then held a dry bulb/ wet bulb differential of approximately 50 degrees throughout the remainder of the drying time. For 2x6's, the temperature was raised to 150 degrees Fahrenheit in approximately 24 hours and then held a dry bulb/ wet bulb differential of approximately 30 degrees throughout the remainder of the drying time. These are typical winter schedules for the mill and may vary with climate changes and starting wood moisture content. The kilns are not equipped with steam injection for lumber conditioning. Dry bulb/wet bulb differential is maintained through control of the vents and fan speed.

Figure 4, shows the results of the shrinkage test that was conducted by the mill using 5 sample boards. The average shrinkage was 3.95% with a variance of 0.435% in thickness and 2.26% with a variance of 0.481% in width. This shrinkage is well within normal expected from Ponderosa Pine.



Planing and Finished Grading:

All of the lumber was processed through the planing mill using the same settings and grades that the mill uses on Inland Northwest Pine. Lumber was graded by the mill's certified graders and separated by grade on the sort chain. Lumber was inventoried by size and grade. Lumber that met 2 common grade was measured as 6/4 common while the remainder of the lumber was measured as standard dimension lumber.

Kiln and trim loss was approximately 11.21% for the entire production. This did not account for the paper loss of approximately 25% from measuring dimension lumber as 6/4 lumber. The sizes are the same, only 6/4 lumber is measured as 1.5" while dimension lumber is measured as 2". Factoring in the paper loss, the actual kiln and trim loss for the test was approximately 3.5%. Using either method of calculation, the loss was within norms for Ponderosa Pine.



Finished Lumber Grading Station

Grade recovery for the test logs was good. Almost 80% of the lumber produced was graded as 2 & Btr. With approximately 30% grade as 2 common or better, the highest grade that would normally be expected from these logs. **Figures 5, 6, and 7**, Show the grade distribution for 2x4, 2x6, and 2x8 lumber, respectively. **Figure 8** shows the overall grade distribution for the run. Std.&Btr., 2Com, and 2&Btr have been combined in **Figure 8**.

Figure 5

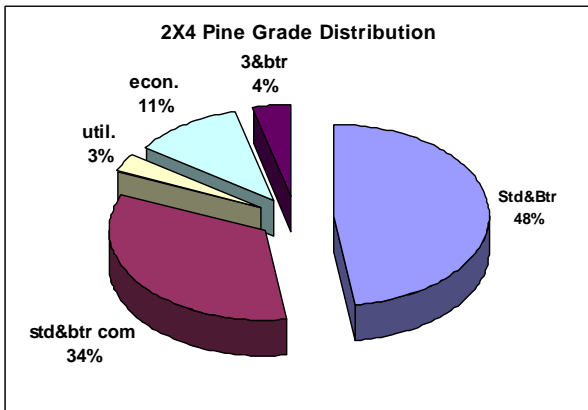


Figure 7

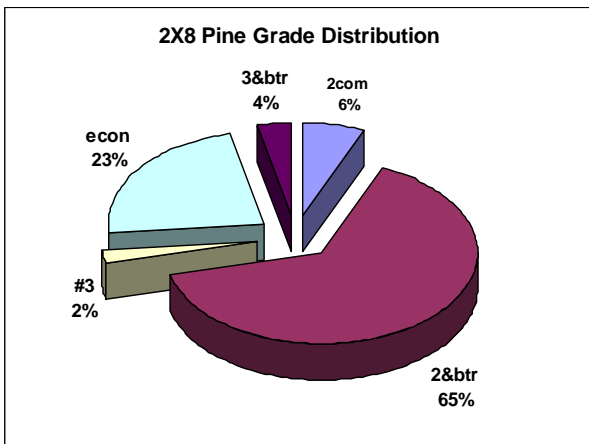


Figure 6

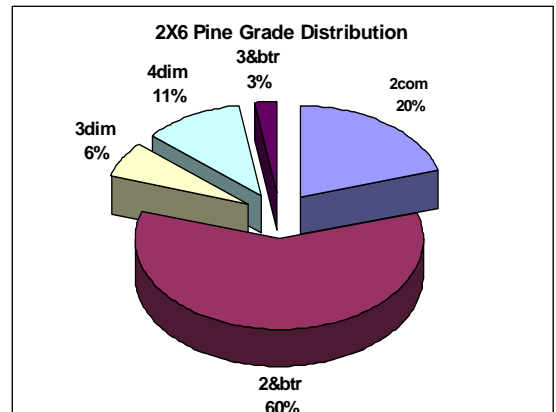
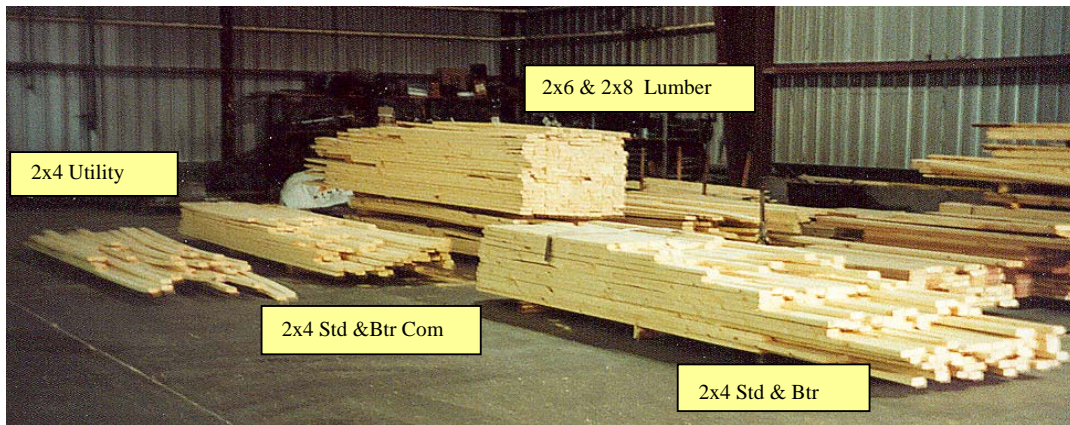
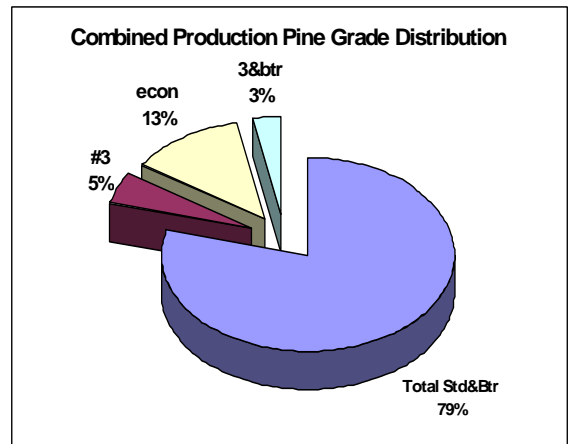


Figure 8



Finished Lumber

Overall Production:

The overall results of the test indicated that the Arizona Ponderosa Pine produced similar results to processing Inland Northwest Pine. Overall Net Overrun was approximately 1.35 not adjusted for 6/4 measure and approximately 1.47 adjusted to dimension measure. Net Lumber Recovery Factor (LRF) was 5.7 and 6.19, non-adjusted and adjusted, respectively. These factors are typical for small log Ponderosa Pine production. A summary of the overall production results is as follows:

<i>Description</i>	<i>Non-Adjusted</i>	<i>Adjusted</i>
No. of Logs Processed	249	
Total Log Gross Scale (lbf Scribner)	6,780	
Total Log Net Scale (lbf Scribner)	6,200	
Total Log Cubic Volume (Cu.Ft.)	1,470	
Total Green Lumber Produced (bf)	9,435	
Green Overrun (bf/lbf)	1.52	
Green (LRF) (bf/cf)	6.42	
Net Lumber Produced (bf)	8,377	9,103
Percent Kiln and Trim Loss	11.21%	3.5%
Net Overrun (bf/lbf)	1.35	1.47
Net LRF (bf/cf)	5.70	6.19
Average Market Value of Lumber	\$300/Mbf	

Conclusions:

The small diameter Ponderosa pine logs from Arizona were similar to the logs processed at Kinzua from the Inland Northwest. Lumber recovery and overrun were typical for the industry. The drying and planing of the lumber presented no problem and required no special treatment or scheduling.

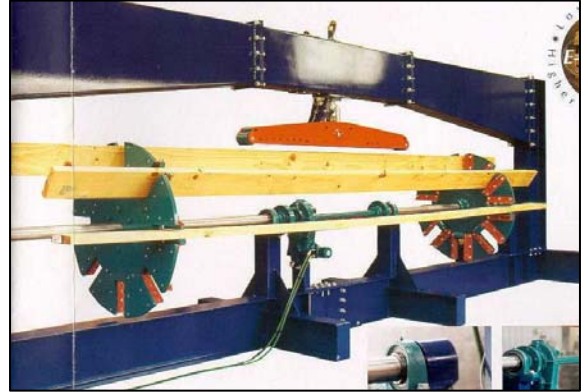
The logs were processed through the Kinzua small log system without any changes from the mill's normal practices. Mill personnel observed that no unusual problems were experienced in processing the Arizona logs. They did note the higher density of the suppressed Ponderosa Pine but that did not cause problems in processing.

The general impression of the mill personnel was that these logs were as good or better than the Ponderosa pine they currently process. They went as far as saying, if they could get these logs to their mill at reasonable price they would take all they could get.

<i>E-Grader</i>

Once the Arizona Ponderosa pine was sawn into lumber at the mill, a 1,000 board-feet of the 2 x 4 lumber was separated out and visually graded and stamped as Standard & Better (Std&Btr). These 140 pieces of lumber, in lengths of 8', 12', 14', and 16', were shipped to a facility with an E-grader machine and tested to compare the grading results.

The E-Grader is a small, affordable automated machine for measuring actual lumber strength during in-line processing, with a significantly lower price than competing equipment. This machine accurately identifies lumber that can be certified for structural applications (and sold at a higher price), and essentially augments human visual grading. Visual grading, of necessity, is very conservative, but the use of this mechanical system has resulted in increases of higher grade lumber compared to visual grading. The following are the results:



Results:

Of 140 pieces of visually graded, 2 x 4 lumber were processed through the E-Grader. Based on the results, 30% or 42 pieces could have been upgraded to a higher strength grade.

<i>Visual Grading</i>	<i>Machine Grading</i>
140 pcs graded Standard & Better – 100%	24 pcs upgraded from Std&Btr – 17% * 95 pcs remained at Std&Btr – 68% 21 pcs downgraded to Utility – 15% **

* *These pieces were upgraded to a structural use that is heavier than light framing, but the actual grade was not specified in the test results. According to the testing consultant however, “many of the higher E pieces were actually double what we might expect from Standard & Better product.”*

** *These pieces were downgraded to utility grade primarily due to visual defects such as skip and warp that were not separated out at the mill.*

Conclusions:

With proper manufacturing, a 30% increase in grade, using the E-Grader in the process line, may be realistic for the regions' resource.

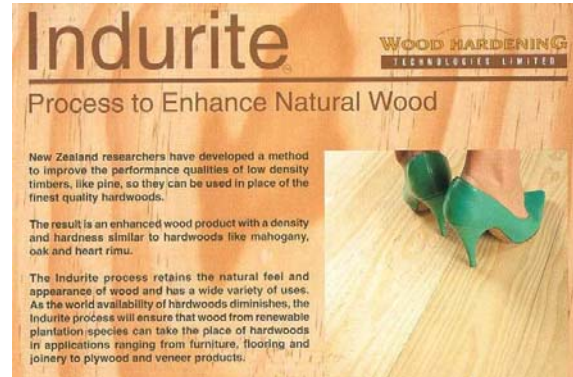
The E-Grader not only adds grade value to lumber but can provide the mill with feedback on its production parameters—especially if the mill is trying to saw for higher value structural grades. The higher strength wood identified by the E-Grader is ideal for reinforced glulam beams and “makes this Arizona’s Ponderosa pine an attractive option.”

Indurite

Indurite is an environmentally safe treatment fluid made from soy and corn starches that can harden wood and increase its fire resistance. This new treatment process, which can use existing pressure treating equipment, is especially beneficial for softwoods that heretofore could not be used for products such as flooring. The potential increased fire resistance, when boric acid is added to the solution, may be highly beneficial in opening up additional structural markets where fire resistance is critical.

Results:

A limited proof-of-concept treatment test was conducted on a few samples of Ponderosa pine from Northern Arizona using the Indurite wood modification chemistry. The purpose of this small-scale test was to quickly assess the potential for using Indurite treatment to harden, strengthen, and improve fire resistance in the pine lumber. Indurite treatment can allow a weaker wood to be substituted for a stronger wood, and it also allows a wood to be used in products that benefit from fire protection: e.g. doors, trusses.



Ten 3-foot long pieces of lumber, five 1 x 4 dimension and five 2 x 4 dimension, were sent to Engineered Wood Systems Ltd. (EWS) in New Zealand. EWS dried the boards and took measurements of density and side hardness. EWS then experimented with several formulations of soy and cornstarch-based Indurite treatment solutions on a single pine piece before settling on a formulation that would best infuse throughout the wood. This formulation was then used on the remaining pine pieces.

Before and After Tests:

Several strength tests and a fire resistance/flame spread test were performed on the pieces following immersion and treatment in a pressure vessel. Prior to testing, the green (wet) lumber pieces had to be dried down to 20% moisture content to increase uptake of the Indurite hardening solution. After treatment, the **1 x 4 boards were shown to have absorbed twice the hardening solution as the 2 x 4 boards** due to the higher percentage of heartwood observed in the 2 x 4 samples. (The hardness tests described below demonstrated that the increase in hardness was less in heartwood than in the sapwood.) The following chart represents the average results of 10 samples each of 1 x 4 and 2 x 4 boards.

Thickness	Weight before drying	Weight after drying	Moisture before	Moisture after	Basic density	Hardening solution uptake
	Grams	Grams	%	%	Kg/m³	Kg/m³
2 x 4	753	698	30	20	357	256
1 x 4	507	466	23	13	425	509

For comparison purposes, the **documented density of Ponderosa pine in standardized tests is 426 Kg/m³** (“The Wood Handbook” - U.S. Forest Products Laboratory, 1974).

Hardness Test:

The hardness test was conducted on multiple wood samples, and natural variation in hardness was examined between the sapwood (outer rings) and heartwood (inner rings). The **treated Arizona Ponderosa pine meets industry requirements for wood flooring in New Zealand**, where flooring is required to have a density of over 600 kg/m³ and a hardness of over 4,000 N.

The Indurite solution increased the hardness of 1 x 4 and 2 x 4 boards by 89% in the sapwood regions and 29% in the heartwood regions (the lower permeability of heartwood has been observed in Radiata pine as well).

The permeability of Ponderosa pine requires use of a viscous hardening solution, and therefore the pine must be dried prior to treatment to a maximum of 20% content. The 1x4 boards absorbed more solution than the 2x4 boards because they had half the moisture content prior to treatment and a lower percentage of heartwood. This increased density and hardness in 1x4 boards to 509 Kg/m³ and 4,220 N respectively; up from 425 Kg/m³ and ~2,500 N.

Janka Hardness, N (newtons)			
Value represents the mean of all samples			
Sample type	BEFORE HARDENING	After hardening	Percent change
Heartwood	2,964	3,752	+27%
Sapwood	2,227	4,220	+89%
All samples	2,522	4,033	+60%

For comparison purposes, the **documented Janka Hardness of Ponderosa pine is 1,400 N when dried to 12% moisture content and 2,000 N when green. The untreated Arizona pine samples averaged ~2,500 Newtons, harder even before treatment.** (“The Wood Handbook” - U.S. Forest Products Laboratory, 1974).

The wood in the core of the Ponderosa pine, or heart center, is less absorbent (of hardening solution) than the outer sapwood. The appearance of heart center can be reduced if logs are sorted by diameter and selected diameters are cut for value by adjusting lumber cutting pattern. Lumber with a high percentage of sapwood provides the most options for value-added products such as glulam beams, other structural products, and flooring.

Fire Resistance Results:

Indurite treatment clearly improves Spread of Flame and Heat Evolved but has minimal effect on Ignition time or Smoke Developed. Treated Ponderosa pine showed superior results in the Spread of Flame and Heat Evolved tests when compared to treated Radiata pine, and superior results in Spread of Flame compared to all wood species.

Test measure	Radiata pine untreated	Radiata pine treated, 1994	Radiata pine treated, 1997*	Ponderosa pine treated, 2002
<i>Ignition time, minutes</i>	6	6	6.4	5.7
<i>Spread of flame, secs</i>	25	76	115	(> 230 secs)
<i>Heat evolved, Kj/m²</i>	220	144	127.9	95
<i>Smoke developed % obscuration</i>	3.8	3.7	3.6	Different units, not comparable**

* This later treatment used an improved formulation.

** The test lab clarified that the Smoke developed results are similar to the treated Radiata pine.

The spread of flame results for treated Ponderosa pine were superior—at the highest possible standard index for any wood species. Treated Ponderosa pine exceeded treated Radiata pine flame spread time by greater than 115 seconds at which point the standard test was terminated.

Both the Spread of Flame measure and Smoke Developed measure are used in determining a material's fire resistance and compliance with fire safety standards.

The following table shows the fire resistance index developed for the AS/NSZ1530 standards used in this test series. **The lower the number, the better the results.**

Index <i>(the lower, the better)</i>	Radiata pine (untreated)	Radiata pine (treated, 1994)	Radiata pine (treated, 1997)	Ponderosa pine (treated)
Ignitability, (0 – 20)	14	14	14	14
Spread of Flame, (0 – 10)	8	6	4	0
Heat Evolved, (0 – 10)	8	5	5	3
Smoke Developed, (0 – 10)	3	3	3	3

Conclusions:

This initial “proof” testing had limited samples to work with. Further tests with a higher sample count are needed to determine the best possible combination of moisture content and formulation to increase hardness and density. The promising flame test results were also based on a few samples; tests on more samples are recommended to demonstrate consistent results. Code testing will be required prior to introducing this material into the fire rated materials market. Many samples of both 1x4 and 2x4 pieces need to be tested for consistent verifiable results. Fire test results can vary from sample to sample due to knots, resin pockets, sapwood and heartwood percentages, and inconsistent absorption of solution.

Increasing the hardness of Ponderosa pine may be the answer for improved pine glulam beams. Indurite treatment not only hardens the wood, also improves overall mechanical strength characteristics. A menu of standard strength tests would provide the data needed to determine if hardened pine can be used for the top and bottom layer of glulam beams.

The wood hardening results – especially for the sapwood – would increase the value of the wood for use in furniture and flooring manufacturing. The treated 1x4 boards adequately meet industry standards for wood flooring, or 600 Kg/m³ and 4000 N respectively. However, additional analysis will be required to determine market potential and economic feasibility.

Sorbilite

A small scale system that combines wood waste (sawdust, bark) with recycled plastic to produce a solid material that can be molded into high value parts such as cabinet doors, doors, furniture components, moldings, and other complex items.

Results:

Sorbilite was sent 35+ lbs of wet residue in a large garbage bag. The mixture was consciously prepared 'dirty' with particles and shreds of all sizes so as to provide a 'worst case' wood waste material. Sorbilite had the material dried to 12% moisture content and ground to a 40-mesh particle size. Sorbilite then mixed it with styrene in a 60-40 ratio of styrene to wood residue; test technicians at the Sorbilite test facility determined this ratio (instead of typical 50-50).

The sample pine residue required an increased ratio of recycled styrene plastic to wood waste because of drying difficulties at the test facility; the ground material was scorched. The ratio increased from an expected 50-50 to 60-40.

Three samples of high value products/parts were produced from 35 pounds of a wet Ponderosa pine bark, hog fuel, and sawdust mixture from the Oregon mill trial site. The resulting parts, two types of cabinet panels and a moulding, were smooth, hard and dense and coffee brown in color. One sample was veneered with high grade Black cherry; the other two were partially primed to demonstrate the coverage and adherence of an off-the-shelf primer. All three samples produced were dense and had a hard surface similar to other samples that have been provided by Sorbilite from other materials.

The unprimed Sorbilite samples of Ponderosa pine Mater Engineering received were a dark brown, chocolate color and had a hard smooth surface. They were quite different in appearance and finish than other Sorbilite samples sent in that were made of pure pine sawdust and polystyrene in a 50-50 mixture. These were a pale pinewood color and had a matte eggshell surface. According to Les Litchfield of Sorbilite, the dark color "happened during drying because the material was scorched." He explained that the contractor they used to dry the material did not have the proper dryer, and that this was not typical.



The veneered panel had a very high quality Black Cherry veneer that adhered well to the panel front and back, and completely hid the dark brown material except along the edge of the panel. The veneer itself was unfinished.

The white primer used to partially cover two of the samples adhered well to the surface and was a smooth brilliant white. This primer is epoxy based and made by Sherwin Williams under the brand name XIM Primer. This primer is recommended by Sorbilite because it adheres and covers well.

Conclusions:

A quality product can be produced from the Ponderosa pine residual. The plastic-to-wood ratio can be adjusted by modifying the type and particle size of wood waste used, and production can accommodate varying relative supplies of recycled plastic and wood waste. A full market and economic feasibility analyses will be required to determine the potential for molded products manufacturing in the region.

<i>Fiber Reinforced Plastic (FiRP)</i>

Fiber Reinforce Polymer (FRP)glulam beams are glulam beams that have a thin ribbon of Kevlar fiber laminated to or sandwiched in the lowest beam layers to significantly increase beam strength. This reinforcement layer allows the use of low-grade lumber (e.g. knotty) and lower strength species (e.g. Ponderosa pine) that are less expensive than conventional laminate grade lumber. The reinforced beams are glued up with a new adhesive (Greenweld) that is strong, fast setting, does not require expensive heating or radio-frequency equipment for curing.

**Results:**

In this sample, the reinforced Ponderosa pine glulam beams significantly exceeded the unreinforced Ponderosa pine beams in all strength tests:

- Twice the load-bearing capacity, up from 8,165 lbs to 15,413 lbs;
- 2.4 times the bending strength, up from 975 psi to 2,364 psi;
- Twice the Modulus of Rupture, up from 2,780 psi to 5,716 psi.

When compared to standard, non-reinforced, Douglas fir glulam beam, the reinforced Ponderosa pine beams demonstrated nearly identical bending strength: 2,304 psi for Douglas fir and 2,364 psi for this pine sample.

<i>Comparison of Ponderosa pine and Douglas fir in Reinforced Glulam Beams (2x6 lams)</i>				
Characteristic	Ponderosa pine (unreinforced)	Ponderosa pine (reinforced)	Douglas fir¹ (reinforced)	Douglas fir² (unreinforced)
Total Load (lb)	8,165	15,413	25,021	
Bending, F_J (psi)	975	2,364	2,725	2,304
Modulus of elasticity, (psi)		960,000		
Deflection at failure (in.)	3.1	7.1		
Modulus of rupture (psi)	2,780	5,716	6,988	

¹ This value is from a tested glulam beam made with all L1 (high grade) lumber

² This value is from National Design Standards (NDS) table for a Douglas fir glulam beam made with L1 for the lower layer only. Note: neither Ponderosa pine beam had L1 grade for the lower layer.

The table above might be considered an ‘unfair’ comparison of low grade Ponderosa pine with reinforced high grade (L1) Douglas fir glulam beams. Of the random mix of lumber sent from the Kinzua mill, only 5% to 10% were high L1 grade, which was insufficient for the construction of ten identical beams. All

the lumber used in the test beams was #1&Better and #2 Common grade... medium to medium-high quality.

It is important to note that because there were no L1 bottom pieces for the beams, the Kevlar fiber reinforcement ribbon was laminated to the bottom of the beam for greater strength. If the ribbon had been sandwiched-in by a high quality L1 “bumper” lam on the bottom, much higher strength results could be expected. The bottom “bumper” lam mechanically protects the Kevlar ribbon and reduces shear forces under high loads.

The inherent safety factor determined in the beam strength tests was between 2.8 to 3.0; this is higher than the 2.1 safety factor required for structural applications. The higher safety factor provides leeway for reducing costs by reducing the Kevlar reinforcement fiber in the beam. A combination of less fiber reinforcement (from 0.58% to 0.25% by cross section) with the use of a higher-grade bottom layer can reduce the safety factor to 2.1 and also save costs. Ponderosa pine glulam beams can also be strengthened for higher load applications by the addition of a higher-grade top and/or bottom laminations.

Conclusion:

Ponderosa Pine from small logs can be utilized to make fiber reinforced glulam beams for structural purposes that meet or exceed structural safety factor requirements. Further testing is necessary to verify these results and to explore how to increase strength without increasing cost. FRP glulam technology is currently accepted as an engineered material under most building codes however, additional code testing will eventually be required to fully commercialize other Ponderosa pine, FRP products.