# SMALL DIAMETER TIMBER— A VIABLE RAW MATERIAL SOURCE FOR THERMOPLASTIC COMPOSITE PRODUCTS

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## ABSTRACT

Pinyon-Juniper (P-J) stands in the American Southwest have grown unabated due to fire-suppression efforts for several decades. These stands are now impacting the ecology of the region by reducing soil moisture, grassed regions, and general bio-diversity. Juniper is a twisted small diameter tree with hard, oily wood that is difficult to use as a raw material for particleboard type products. This material is an acceptable furnish for thermoplastic composite panel products. Thermoplastic composites made from this raw material offer competitive mechanical characteristics combined with excellent moisture and durability properties.

The *Pressaire™* Process has many unique properties that allow it to produce a competitive thermoplastic/juniper composite from relatively unrefined raw wood and waste plastic. Use of a Universal Refiner will allow the wood to be field processed with minimum environmental impact. Composite properties are affected by factors such as panel density, particle orientation, particle packing, and plastic content. Commercial challenges to bringing this technology to rural communities include plastic shipment, code approval, and air permitting issues. These technical problems can be solved, and it only takes the will to bring this opportunity to rural communities. If it is there, use of this technology can help prevent catastrophic fires, improve the environment, and enhance the quality of life in western rural America.

**Keywords:** Juniper, Thermoplastic, Composite, *Pressaire™*

## INTRODUCTION

Over the last few years Rycair Incorporated, a Boise, Idaho based technology transfer and consulting company, has been involved with various groups in New Mexico who are looking for ways to productively utilize the vast stands of pinyon-juniper (P-J) that are prevalent in the area. As part of that effort we have attempted to help these groups evaluate the commercial opportunities and risks associated with this development. Most of these potential products are either panels or planks that will be required to perform in a wet environment. If widespread acceptance and use of these panels, planks, and crates made from juniper/thermoplastic composites occurred, the manufacture of these products would benefit rural communities in the southwest by adding needed employment to produce the products, restore P-J rangelands, harvest the juniper, and add manufacturing jobs to viable locally-owned industries.

## Significance of the Problem and Opportunity

There are 7 million acres of P-J stands on national lands in the American Southwest. The primary concern is that nearly 50% (3.5 million acres) of this land base represents watersheds in unsatisfactory condition. P-J stands have grown unabated due to the extent of natural fire control. The root system of a juniper tree extends far beyond the tree; this changes the ecosystem by causing grassed areas to die off. Lack of cover causes extensive runoff erosion and a general decline of the entire watershed. These same conditions exist on a larger scale on other federal, Indian, and private lands extending into the surrounding states and into Mexico. Figure 1 shows an example of the extent of the problem.

Figure 1.—The spread of pinyon-juniper stands have had huge ecosystem impacts in the Southwest. These stands are prevalent on sloped and flat lands in the region.

The Claunch-Pino Soil and Water Conservation District Special Vegetative Study, conducted in the mid-80's, suggested that the dense woodland stands of one-seeded juniper were removing tremendous amounts of water from the soil profile. Initial results from this study showed a fourfold increase in soil moisture and a corresponding fourfold increase in herbaceous ground cover when moderate to heavy P-J tree stands were removed. The return of these grassed areas ultimately enhances the biological diversity in the region.

Bringing the P-J stands and its ecosystem back into balance will require significant removals of juniper through harvesting, mulching, or fire. To avoid soil sterilization and the significant air pollution caused by high temperature fires, a multi-faceted restoration approach is advocated by the National Resource Conservation Service and the Forest Service Regional Forester.

The Rocky Mountain Forest and Range Experiment Station is currently conducting research on the effects of treatment methods within the Abo Ecosystem Management Unit of the Cibola National Forest. Their current findings indi-

**Published in *Small Diameter Timber: Resource Management, Manufacturing, and Markets* proceedings from conference held February 25-27, 2002 in Spokane, Washington. Compiled and edited by D.M. Baumgartner, L.R. Johnson, and E.J. DePuit. Washington State University Cooperative Extension. (Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912. MISC0509. 268 pp.**

cate that optimum watershed treatment methods may involve some form of vegetation manipulation, mulching, fire, and nutrient recycling. Some of these methods can create new opportunities for production of juniper wood fiber. This wood could be an important by-product of watershed restoration, and it has a good potential of yielding economic benefits that encourage investment, which would offset costs for watershed improvements.

Rycair Incorporated participated in a grant issued by the Cibola National Forest Service, which demonstrated that exterior sign grade material could be made from the P-J resource by using the fiber as the primary constituent in a thermoplastic composite. Further work done in cooperation with the USDA's Small Business Innovative Research Program demonstrated that numerous exterior grade wood-substitute products made from P-J fiber and small diameter ponderosa pine can offer commercially viable market alternatives while providing a powerful management tool for restoring P-J rangelands.

## Why Plastic/Lignocellulose Composites?

Research by Rycair Incorporated and the USDA Forest Service, Forest Products Laboratory (FPL) indicate that recycled plastics, such as polyethylene and polypropylene, can be combined with waste wood fiber to make useful composites. Advantages associated with these composite products include competitive stiffness, strength, and weight coupled with excellent durability and moisture resistance properties. These composite products can be delivered at costs equal to, or lower than, products made from wood or plastic alone.

The characteristics of P-J wood offer significant challenges when it is considered as a wood source for *commercial* wood applications. The tree is quite twisted, and it has very short branches. In addition, the wood has a high oil content. This oil content enhances its durability, but it also makes it difficult to glue to. Figure 2 shows a typical juniper tree. The nature of the tree precludes the possibility of harvesting dimensional lumber from it. This means that the only method currently available for utilizing this fiber as a wood substitute is to turn it into chips, flakes, strands or dust and make a particle composition board out of it. When this option is considered, the glue-ability of the wood using conventional thermoset adhesives makes the P-J wood source an unattractive option because of the properties of the composite panel produced with these adhesives or because of the cost of more exotic thermoset variants. Tests by Rycair Incorporated indicate that value-added juniper/thermoplastic composites made with the *Pressaire™* process overcome these objections. These tests also seem to show that the P-J fiber is durable, and it is particularly well suited to the *Pressaire™* process' method of manufacture of these composites. Table 1 lists the properties of some of these P-J composites.

## THE *PRESSAIRE™* PROCESS

Key components in making a *competitive* thermoplastic/lignocellulosic composite are the *plastic cost*, the *percentage of plastic* in the composite, *cost of additives*, and the *machine cycle time* required to make the panel.

There are a number of ways to produce a thermoplastic/lignocellulose composite. These include extrusion/injection-molded technologies, melt-blend technology, and air-laid mat/compression molded technology. All of these methods have a place in the emerging world of thermoplastic/lignocellulose composites, but Rycair Incorporated believes that its process is best suited for processing fiber from P-J rangelands into useful products. The reasons for this conclusion are contamination issues, plastic content, composite strength, and composite processing time, which are all related to the *commercial* viability of the P-J composite.

Figure 2.—The juniper tree will yield little or no commercial dimensional lumber.

Table 1.—Properties of Random Oriented Juniper Flake/ Polyethylene Composites - no additives.

| Property | ASTM Test | Density (pcf) | Plastic % | Value |
|---|---|---|---|---|
| Bending Modulus of Rupture (MOR) | D-1037 | 54 | 50 | 3300 psi (22.6 MPa) |
| Bending Modulus of Elasticity (MOE) | D-1037 | 54 | 50 | 270 ksi (1.85 GPa) |
| Internal Bond | D-1037 | 54 | 50 | 110 psi (0.75 MPa) |
| Thickness Swell | D-1037 | 54 | 50 | 4 % |
| Linear Expansion (50%/90% RH) | D-1037 | 54 | 50 | 0.07% |
| Water Absorption | D-1037 | 54 | 50 | 14.3% |

In order to produce a competitive thermoplastic/lignocellulose composite product, two major obstacles have to be overcome. First, an efficient method to mix the highly viscous thermoplastic with the lignocellulose fiber must be employed. Second, the manufacturing process used must be able to raise the composite mixture to roughly twice the temperature needed to make a wood/thermoset composite, such as Oriented Strand Board (OSB), in the same cycle time. The *Pressaire™* process satisfies these criteria.

The *Pressaire™* manufacturing process appears deceptively simple. It involves mixing low bulk density thermoplastic, or thermoplastic fluff, and lignocellulose at ambient temperature, injecting hot air through the mixture to melt the plastic, pressing the mixture into a mat, transferring this mat, which is the consistency of warm bread dough, to a cold press that completes forming the panel while consolidating and cooling the material, and ejecting the finished panel from the cold press. Figure 4 shows a schematic drawing of the process.

A key element to the process is to dry mix thermoplastic fluff with relatively low-density lignocelluose slivers or flakes. The thermoplastic fluff effectively *suspends* the lignocellulose particles and thereby allows complete coating of the lignocellulose to be accomplished during the mat formation. Figure 3 shows a close-up photograph of a typical dry mixture of wood and thermoplastic fluff before it's processed into a panel. When hot air is injected into the mixture, the white thermoplastic melts almost immediately and attaches itself to the wood. Each white thermoplastic piece turns into a very small dot of glue. By using thermoplastic fluff we're able to evenly distribute the thermoplastic glue throughout the thermoplastic/lignocellulose matrix. This allows us to reduce the amount of relatively expensive thermoplastic glue needed to bond the wood into a flat or formed board, if the product definition will allow such a reduction.

A key innovation of the *Pressaire™* process is the use of hot air to rapidly melt the thermoplastic fluff while bringing the thin discrete lignocellulose slivers or flakes up to a temperature that allows them to merge with the thermoplastic. This heating takes place very quickly, and the process cycle is similar to other engineered wood-composite manufacturing cycle times.

Figure 3.—Dry mix of thermoplastic fluff (white) and wood (brown). The close-up shows expanded thermoplastic fluff, but any low- density fluff can be used, such as plastic film or chopped strands.

Another key element of the *Pressaire™* process is the separation of the heating and cooling functions. By heating one mat while simultaneously consolidating and cooling the previously heated mat, we are able to drastically reduce cycle time. Generally for thin panels (1/4–3/4 inch thick) the heating and cooling times can be balanced. As the panel thickness increases, the laws of thermodynamics cause the cooling time to become longer than the heating time. This can be mitigated by only cooling the board in the consolidation press until about a third of the heat in the board's core has been removed. At this point the shell of the cross section has cooled sufficiently to contain the internal stresses caused by consolidation of the lignocellulose fibers, which are trying to blow the board apart. Use of a multiple opening consolidation press (Fig. 4) can be used to balance the heating a cooling parts of the process. The *Pressaire™* process can also be made into a continuous process by having a continuous heated press followed by a continuous cooled consolidation press. In this iteration, the heating and cooling times can be exactly matched by simply extending the length of the cooled consolidation press.

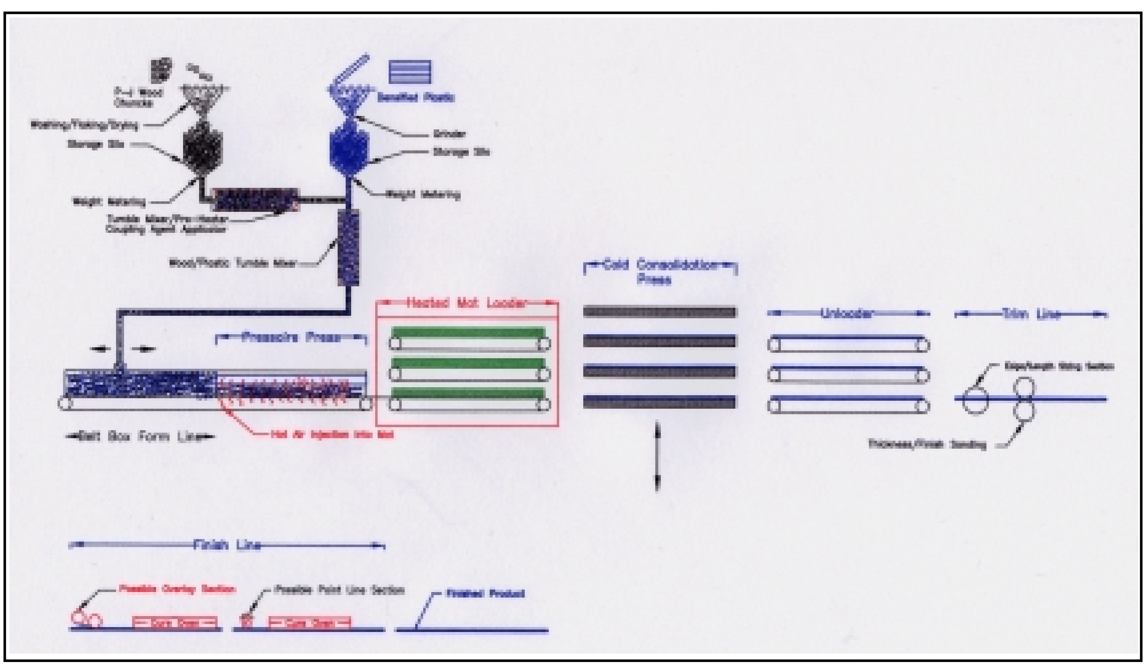


Figure 4.—The *Pressaire™* Process

## RAW MATERIAL REQUIREMENTS AND HARVESTING METHODS

By employing the *Pressaire™* manufacturing technology to make thermoplastic composites, it is possible to consider making useful wood substitute materials from a variety of lignocellulose raw material sources, including small diameter timber, urban wood waste, straw, sage brush, and pinyon-juniper.

In our USDA funded research, we used a Universal Refiner PDR-96-750 with a 2-1/2 inch screen to convert the raw branches into slivers. This machine is equipped with a 10 ft x 14 ft hopper, a 750 horsepower engine, and it can process 100 tons per hour of green waste material (Fig. 5).

Figure 5.—Universal Refiner PDR-96-750.

Field harvesting can be easily accomplished by cutting the trees and depositing them in the hopper with a front end loader. If the end product is to be slivers, an apparatus would need to accompany the universal refiner that sifted the overs and returned them to the hopper for further refinement in order to maximize the yield of acceptable furnish. If the final wood furnish is to be flakes processed on a Pallmann rotary flaker, then the Universal Refiner should be fitted with a 4 inch screen in order to allow the flaker to produce longer flakes (Fig. 6).

Figure 6.—Raw Material Components (l-r) — Slivers, Flakes, and Ground Plastic Film.

In our experiments we processed juniper branches and small diameter(4-6 inch) ponderosa pine logs with the bark left on. The juniper bark was relatively dry and it turned to dust when it went through the refiner. The ponderosa pine bark was fairly thick and it ended up as discrete particles about 1/4 inch in diameter. These bark particles could not be removed with a conventional screener, and they reduced the mechanical properties of the thermoplastic composite boards about 20% when the wood furnish was in the form of slivers. When these ponderosa pine slivers were further processed into flakes, the bark particles dulled the Pallmann flaker knives very quickly. Consequently, we concluded that the bark would have to be removed from the furnish before it is processed into thermoplastic composite material. Further research will be needed to determine the best way to accomplish this objective.

A good source of inexpensive plastic can be found in the municipal solid waste stream (MSW). The plastics industry annually disposes of about 19 million tons of plastic in the U.S. Of this amount, only 2.5–3% is recycled (U.S. Environmental Protection Agency 1998). The main reason that plastic recycling isn't widely used is that the cost of sorting, cleaning, and removing contaminates coupled with variations in color and purity makes the recycled product unacceptable for many traditional plastic end uses.

A major advantage of the patented *Pressaire™* process is that it is almost immune to the problem of *plastic contamination* in the form of paper labels and etc. This type of plastic contamination creates havoc with conventional melt-blend plastic screw extruder processing methods. The *Pressaire™* process can handle particles up to six inches long. In contrast, screw extruder technology can only accept dust sized particles. With the ability to process such large particles, the concept of "plastic contamination" loses its meaning. Consequently, we are able to use thermoplastic derived from the waste stream as a raw material with very little preprocessing.

## FACTORS AFFECTING THERMOPLASTIC/ LIGNOCELLULOSE COMPOSITE PERFORMANCE

Thermoplastic/lignocellulose composites produced by the *Pressaire™* process are similar to other thermoset wood composite products such as Particleboard, Medium Density Fiberboard (MDF), and OSB. Many of the factors that impact mechanical and physical properties of these materials, such as board density, fiber geometry, fiber packing, and fiber alignment, also have a significant effect on the properties of a *Pressaire™* processed composite.

Perhaps the most important board property that affects the mechanical characteristics of these thermoplastic/ lignocelluose composites is board density. In the *Pressaire™* process, board density can simply be controlled by how much mass of material is pressed into a given thickness. When the specific gravity of the board is raised from 0.7 to 0.9, our tests indicate that there is about a 30% increase in bending strength (Modulus of Rupture) and stiffness (Modulus of Elasticity). There is a cost associated with board density since more material is required to make a given thickness, and it takes more pressure to consolidate the board. Typically, these materials are processed at a specific gravity of 0.7 to 0.9 (board density range equals 45 lbs/ft$^3$ – 55 lbs/ ft$^3$), although some of these composites can be processed up to about a specific gravity of 1.0. The consolidation pressure required by the *Pressaire™* process ranges from 250 psi to 600 psi (1.7 MPa – 4.1 MPa) depending on the wood fiber percentage, type of wood fiber, and target board density.

Figure 7 is a close-up of the types of material that can be made with the *Pressaire™* process. Note the large fiber geometry in the sample on the left, and the zoned geometry of the sample on the right. Large fiber geometry is unique to the *Pressaire™* process, and it allows composites produced by this method to have lower raw material processing costs and higher strength than thermoplastic/wood composites produced without additives by other means. These factors make composite materials produced by *Pressaire™* process more attractive commercially in comparison.

Figure 7.—Juniper/ thermoplastic composites made``` with the *Pressaire™* Process.

A characteristic of OSB is that the wood flakes are oriented parallel to the length of the panel. By doing this the panel's bending strength and stiffness are improved. A refinement of this approach is to place the longer particles near the surface and the smaller particles in the core of the board. This approach has been shown to enhance wood recovery and improve the board properties of thermoplastic/wood composites produced with the *Pressaire™* process. The trade-off is that it requires more expensive and sophisticated mat forming equipment and properties such as linear expansion are compromised.

Another device that can easily be employed to make *Pressaire™* processed thermoplastic/lignocellulose composites competitive is the process' ability to form the material into structural shapes that allow less material to be used to achieve specific mechanical performance criteria. Screw extruder technologies can produce more exotic shapes than the *Pressaire™* process, but both manufacturing processes can be used to reduce the amount of material needed for a particular application.

The use of chemical modifiers that enhance the interfacial bond between the hydrophilic lignocellulose and the hydrophobic thermoplastic have been shown to reduce the amount of thermoplastic needed to make a performance-based competitive composite or to increase the bending strength and stiffness by as much as 50% (Forest Products Society 1997; Kolosick et al. 1992; Krzysik and Youngquist 1992; Rowell 1993). One of the most common additives to enhance interfacial bonding is maleic-anhydride-grafted-polypropylene (MAPP). In the *Pressaire™* process MAPP is typically spray applied in concentrations of 1–2% by weight of the composite. There are a number of commercial and proprietary additives in this class, and they are relatively expensive. Increased board density tends to be a more cost-effective approach to reaching target mechanical properties, but in some specialized applications these additives can make economic sense.

Since a major component of thermoplastic/lignocellulose composites is thermoplastic, the panels made from these composites are heat sensitive, and they creep under load at elevated temperatures. Consequently, they should only be used in "non-structural" applications, such as siding, floor underlayment, fencing, molding, decking, pallets, and etc. The fire resistance of these composites is dependant on the plastic binder used. Some composites, such as those made of polyvinyl chloride, are self-extinguishing, while others made of polyethylene will burn about like wood. Smoke opacity, generation, and toxicity are directly related to the type and quantity of plastic in the composite. Ultra-violet degradation is also dependant on the type of plastic used; however, Rycair Incorporated as found that placing any barrier coating on the surface will prevent this degradation. In some cases, the wood in the composite will provide a sufficient barrier. If the composite is made of polyethylene, then surface treating will be required before the barrier coat can be applied. Typically, this surface treatment is in the form of flame treating or corona discharge.

Independently financed studies have indicated that the decay resistance of these composites is dependent on the type of wood in the composite. All of these composites have microscopic fissures between the wood and the plastic. Over a <u>very</u> long period of time water will migrate into the material through these cracks, and rot will develop. Soaked composites made of redwood or CCA-treated fir will be very long lived, while materials made of straw will deteriorate much faster.

## COMMERCIALIZATION CHALLENGES

The technology for harvesting small diameter timber for use as sliver or flake raw material in thermoplastic composites exists, and it is being used commercially. Since the machinery is trailer mounted and mobile, it appears to satisfy the requirements of foresters to remove excess fuel from the forest with minimum ecological impact.

The class of thermoplastic/lignocellulose composites produced by the *Pressaire™* process and its variants are just now emerging from a long stage-gate development activity. Some forms of these composites should be commercially available later this year. The market acceptance of these composites is unknown at this time, but we believe it will be favorable.

The manufacturing equipment required by the *Pressaire™* process is similar to the equipment used commercially in many other flake board composite manufacturing processes. Consequently, a considerable amount of off-the shelf equipment needed for raw material handling, material processing, heat generation, and panel finishing is readily available for inclusion in a *Pressaire™* manufacturing facility. There are, however, unique processing challenges that only operation of the commercial facility will demonstrate that a successful solution has been found.

The plastic material required for this class of composites is available in sufficient quantity to supply a relatively large manufacturing facility, but the infrastructure to deliver it to the plant in a timely manner is in an early stage of development. How efficient it is remains to be seen. Most of the plastic raw material is located near centers of large population. Consequently, locating a *Pressaire™* production facility in a rural area places a freight penalty on the product produced, because of the need to ship a component of the composite some distance. This can be mitigated somewhat by developing high value added products like molding, floor underlayment, tile backer, or specialty products like exterior window and door cores. The freight penalty can also be reduced by on-site production of low grade, low bulk density thermoplastic film or foam made from ground high bulk-density recycled plastic materials.

Virtually all manufactured products have to meet some industry standards, which require testing and independent approval before they can be marketed. Any product made from small diameter timber and thermoplastic would have to undergo this process. The choice of the product to be manufactured could limit the type of small diameter timber that is used in order to maintain an acceptable quality and consistency in the final product.

In this environmentally sensitive world, permitting a new manufacturing facility has become a major undertaking. Since the *Pressaire™* process heats the wood and plastic components to a high temperature, volatile gases are flashed off. The choice of plastic and wood used have a tremendous effect on the amount and types of gases that are generated. Generally the volatile gases in the wood are more of a problem that those in the plastic. The *Pressaire™* process can turn green wood directly into a plastic composite; it is an effective dryer. However, processing green wood increases cycle time and product variability. It is better to dry the wood before processing it into a composite. Depending on the locality, air-permitting requirements for wood dryers can be very expensive. Rural communities have an advantage in air permitting issues because they typically are in an attainment area.

The potential for utilizing marginal timber resources and helping rural communities by manufacturing thermoplastic composite materials is great. What is needed is a clear vision, a clearly defined opportunity created by the right product, a good development plan, community support, and a committed team of individuals willing to take the risks and accept the challenges. Solutions to the technical problems are available. It only takes the will to bring this opportunity to rural communities. If it is there, we can help prevent catastrophic fires, improve the environment, and enhance the quality of life in western rural America.

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