Introduction

The global demand for forest products is increasing. This increase in demand coincides with diminished wood supplies in many established wood-producing countries of the world. Restrictions on harvesting from public forest lands in the United States (U.S.), particularly in Washington, Oregon, and California, have predictably exacerbated global timber supply shortfalls and increased demands on forests of the Southern U.S.

The Southern U.S. region is well positioned in terms of long-term timber supply and the forest products manufacturing infrastructure to meet a portion of the projected increase in demand. In fact, the South produces approximately 60 percent of the nation’s timber products, almost all of it from private forests. The South produces more timber than any other single country in the world and is projected to remain the dominant producing region for years to come.

A major challenge for the Southern U.S. is to extend the available wood resource by developing more efficient methods of processing and utilizing this wood and by developing new uses for that portion of the forest resource, including mill residues and unmerchantable trees, that currently is unused. The Forest and Wildlife Research Center (FWRC) receives funds to support a special research program on timber harvesting and wood utilization opportunities for the southern region. These funds provide opportunities for graduate students to complete their studies.

Results from the FWRC’s Wood Utilization Research Program are made available to the public and specialized user groups through publications in appropriate journals, short courses and conferences, and meetings with industry groups. Each year, thousands of inquiries (letters, telephone questions, facsimile and e-mail) are answered based on research funded by this program.
Research Program

The Office of Technology Assessment Report presented to Congress in August 1983 states policy options “designed to enhance the advantage of U.S. producers in international markets, to provide research and development in forest management, environmental effects of forestry and wood materials science, and to improve the productivity of the U.S. forests.” An important recommendation of this assessment was to establish Centers for Wood Utilization Research (WUR). Congress authorized the program and appropriated funds in 1985. Currently there are 12 universities that participate in the WUR program. The Departments of Forest Products and Forestry within Mississippi State University’s Forest and Wildlife Research Center were selected as program participants. Summaries of all current projects funded by the WUR program are included in this report.

www.fwrc.msstate.edu

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2007 annual report

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The objective of the timber harvesting and transportation research activity conducted by the Department of Forestry is to provide timely information on trends, technologies and economic factors affecting the logging industry and the industrial wood supply system.

**RESEARCH HIGHLIGHT**

- Many landowners are looking to carbon sequestration for increased revenues and to improve the environment. However, the financial trade-offs associated with changing production focus from timber to carbon are unknown. A project is looking at these financial trade-offs by analyzing net revenues generated from production of timber only, carbon only, and joint production of timber and carbon.
## Timber Harvesting and Transportation

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Economic and environmental effectiveness of water quality and forest sustainability on timber harvesting and wood utilization in Mississippi

L.A. Grace, R.P. Maiers, W.B. Stuart, C. Sun

OBJECTIVES:
1. Examine and review the evolution of forestry BMPs, their relationship to forest certification and the current use of BMPs in Mississippi;
2. Evaluate the economic costs and benefits of adopting BMPs on the wood supply system and associated communities in Mississippi;
3. Estimate the distribution of costs and benefits of implementing forestry BMPs among primary stakeholders in the wood supply system (forest landowners, loggers, and industry);
4. Develop a cost-effective, easy to implement method for evaluating the sediment budget at a watershed-scale;
5. Compare the relative effectiveness of forestry BMPs in reducing sediment-related non-point source (NPS) versus other land-use practices in the watershed.

PROGRESS:
A comprehensive literature review on sediment production as a function of forest management practices has been completed. Twenty-seven sub-watersheds approximately 2.2 ha in size have been monitored for gross sediment movement pre- and post-harvest, using readily available, economic methods. In a completely randomized design containing three replications of two treatments (harvested vs. unharvested) and two slopes (<9% vs. >9%), twelve sub-watersheds have been randomly selected for intensive measurement of the sources and sinks of sediment after every major precipitation event. In-stream, bank and hill slope sediment movement are being measured. Relative rates of movement due to various silvicultural activities (e.g. road construction, water control and logging) are also being measured. The analysis of data comparing relative contributions of logging and natural erosional processes to increased sediment loads and changes has been delayed due to a medical leave of absence. Hopefully, the student will return this summer to complete the work. Alternate plans are being considered to finish the work this summer.

A welfare analysis has also been conducted using a Muth-type equilibrium displacement model with two production stages. Under the base scenario perceived as being the most realistic, consumers had the largest absolute welfare loss and loggers had the second largest loss in relative...
welfare loss. Industrial mills generally experienced little welfare loss from forestry BMP regulation. Their relative welfare change was close to zero in most cases.

As part of a larger scale analysis of the efficacy of traditional contractual arrangements on wood supply system performance, the effects of altered harvesting operational strategies on the performance of individual businesses as well as the procurement strategy for a wood manufacturing firm were studied. Preliminary results indicated that strategies such as “double-shifting” (logging businesses operating two 8-10 hour shifts in the woods) did increase the amount of wood delivered to a manufacturing facility, but at the expense of the long-term (3-5 year) viability of the logging business. The data collected for this part of the project have been used to develop a simple cost model which is currently undergoing verification.

A before-after-control-impact (BACI) study on the impact of forest harvest-related activity on sedimentation rates was conducted in a 121 ha watershed located in the sand-clay hills of central Mississippi. Twelve headwater catchments approximately 2.2 ha in size were randomly selected for intensive measurement of the sources and sinks of sediment, including sediment contribution from roads, hill slope sediment movement adjacent to incipient stream channels, and sediment movement within intermittent and ephemeral stream channels.

As a best-management practice, wing ditches were effective at trapping 76-92% of total suspended sediment input from road sources, however TSS concentrations in wing ditch runoff entering watersheds increased from 18 g/L pre-harvest to 111 g/L post-harvest. Erosional processes dominated along the toe-slope of wing-ditches; however during and up to one year post-harvest, sediment export due to erosion was offset by sediment input from roads. Rate of hill slope sediment loss was less than 1 cm per year under both harvest and non-harvest conditions. Sediment export from the watershed is being evaluated.

Preliminary results from the watershed-scale sediment budget study suggest that existing headwater BMPs are sufficient to reduce NPS sediment contributions during silvicultural operations, however a surfeit of water control structures in headwaters may adversely affect NPS control. This study provides data on the relative contributions of forest harvesting operations and BMPs (such as
wing ditches) versus natural processes of soil erosion in ephemeral drainages for purposes of BMP refinements.

**IMPACTS:** These results have implications for future forestry BMP programs. Water quality and control of non-point source pollution in forestry will continue to be an important issue in coming years. How to enhance current state forestry BMP guidelines, increase the implementation rate, and improve program monitoring efficiency and effectiveness will keep on challenging policy makers and stakeholders in forest management communities. Based on the evaluations of welfare distribution, future technical and financial assistance for forestry BMPs should clearly target those who have experienced considerable financial losses, such as landowners and loggers.

**GRADUATE STUDENTS:** Three graduate students have worked on this project.
The economic impact of implementing carbon sequestration management strategies on timber supply and the forest products industry in Mississippi and the southern region

R.K. Grala

065430C

September 15, 2005–September 14, 2008

OBJECTIVES:
1. Evaluate the feasibility of storing additional amounts of carbon through manufacture of long-life wood products with emphasis on Life Cycle Assessment (LCA) and better utilization of processing, harvesting and thinning residuals.
2. Assess technological capabilities of converting facilities to utilize larger-diameter logs and manufacture new wood products in response to predicted changes as well as examine economic feasibility of implementing potential technological adaptations.

PROGRESS: Most common forest management regimes in the Southern U.S. have been determined. Estimates of available merchantable and unmerchantable volumes, average tree diameters and accumulated carbon have been generated for seven commercial tree species and selected forest management regimes using the Forest Vegetation Simulator. Land Expectation Value was used to determine optimal management regimes based on revenues and costs associated with three production scenarios: timber production, carbon production, and joint production of timber and carbon. Amounts of carbon that potentially can be stored in long-life wood products as well as quantities of carbon emitted at thinnings and harvest have been estimated. Procurement areas for predetermined hauling distances and Mississippi’s road network have been established using GIS.

Future efforts will focus on determining aggregate amounts of carbon accumulated in Mississippi and the Southern Region. Average tree diameters will be determined and technological capabilities of local and regional mills to process larger logs will be examined. Additional increases in carbon sequestration through storage of carbon in long-life wood products will be estimated.

IMPACTS: Potential net revenues generated from production of timber only, carbon only, and joint production of timber and carbon have been estimated for selected commercial tree species and forest management regimes. Financial tradeoffs associated with changing production focus from timber to carbon have been established.

GRADUATE STUDENTS: A doctoral student has been working on this project. An additional graduate student will provide assistance in 2008.
Improving the performance of the wood supply system

L.A. Grace, W.B. Stuart

OBJECTIVES:
1. Identify characteristics that define wood supply system performance and develop measures to monitor those characteristics over time, emphasizing transparency, consistency, quality of product, productivity, quality of work life, innovation, and most importantly—profitability.
2. Conduct a critical analysis of the entire system to identify points where costs have been built in that: are artifacts of earlier wood supply structures, are unnecessary in today’s world, are constraints that were implemented to counter earlier challenges, and that serve functions outdated by modern technology.

PROGRESS: Work continues on the expansion of the logging cost and productivity and load-by-load delivery databases, with the intent to document long-term performance of the wood supply system as well as address the role, structure and development of the current system as tools for improving performance.

Information was collected and maintained on the production in tons per year, and costs, both annual and quarterly when available and summarized into six broad cost categories. Crew size, equipment make, model, and size, procurement practices and other relevant information was also collected for each participating firm. The cost and productivity database has been developed for multiple years for 41 of the 42 firms. This allows for year to year comparisons within firms and across years. The majority of the firms have participated for 10 years or more allowing long-term comparisons.

Recent pressures on the wood supply system have brought about changes that can be considered ‘false economies’. The cost information that has been collected as part of the logging cost and productivity survey indicate a growing trend among logging businesses to reduce investments in equipment—the dominant form of equity for these firms. Overall, the forty firms participating in the survey spend only 15 cents of every dollar of cost for equipment. The amount spent in 2005, in unadjusted dollars, was the same as that spent in 1995. Inflation over that period has reduced the purchasing power of the dollar by 30%.

Since 2005, scientists have been cooperating with a lumber manufacturer on an analysis directed at improving the performance of their wood supply system through information sharing, management and innovation. Efforts to date directed at reducing the variability in daily and weekly production from their core contractor force have been successful at stabilizing wood flow
and increasing contractor annual production without additional investment in equipment or crew size. Gains like this must withstand market forces before they can be considered sufficiently robust to be applied on a broader scale. This next year, with the decline in demand for lumber, rising fuel costs, and altered harvest schedules by the mill, will test these gains. As the manufacturing firm initiates operational changes, they are providing data to test the robustness of earlier modifications to their wood supply system on the economic viability on their contractor force.

The next phase of the cooperative effort will be directed at increasing truck transport efficiency and reducing truck turn-around-time.

Presentations during 2007 resulted in considerable interest in the development of a business plan template for logging firms. A non-thesis graduate student has been assigned this project and a potential group of loggers have been identified that are willing to participate in the project.

IMPACTS: The contractors serving the cooperating mill have all seen an improvement in their business performance as measured by production. Increases from year to year are significant at the 95% to 99% level. It is difficult to reveal dollar value gains because of confidentiality agreements with the cooperating firm and cooperating contractors.

GRADUATE STUDENTS: Two master’s students have worked on this project as well as one doctoral student.
Researchers in the Department of Forest Products are using cutting edge technology to search for solutions to upgrade lumber products and strengthen their market value.

**RESEARCH HIGHLIGHT**

- A real-time sensor to measure volatile organic compounds and hazardous air pollutants has been developed. Real-time measurements allow kiln operators to adjust the drying process to reduce emissions. Reducing emissions by 50 percent could result in the elimination of 168 tons of hydrocarbon emissions for a site producing 150 million board feet of kiln-dried lumber per year. There are 100 such sites nationwide.
# Lumber Manufacturing and Processing

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<td>065390G</td>
<td>Development of machine vision technology for lumber and panel products</td>
<td>J. Zhang, P.H. Steele, M.G. Kim</td>
<td>8/15/04–8/14/07</td>
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<tr>
<td>065430F</td>
<td>Wood drying research and breakthrough technology</td>
<td>R. Shmulsky</td>
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<td>065480C</td>
<td>Classification of hazardous air pollutants from drying southern pine lumber</td>
<td>R. Shmulsky, L.L. Ingram Jr</td>
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Development of machine vision technology for lumber and panel products

J. Zhang, P.H. Steele, M.G. Kim

OBJECTIVES:
1. Develop a device for detecting knots in logs moving at high speed through electrode sensors, and
2. Develop a real-time after-press radio-frequency device to detect moisture content and specific gravity.

PROGRESS: A device titled the “Through-Log Density Detector” (TLDD) was patented based on the research performed in this project. The TLDD is capable of detecting the juvenile wood core and knots located within pine logs. The TLDD is an Electrical Impedance Tomography (EIT) application that utilizes a current passed into materials from electrodes. Complex software analyzes voltage outputs to develop a finite element map of anomalies that influence the current passing through the material.

A lab scale proto-type RF scanning device was developed for measurement of moisture content and specific gravity for after-press oriented strandboard (OSB).

IMPACTS: The development of the TLDD was assisted by Dr. William Lionheart, professor, University of Manchester. Dr. Lionheart is one of the foremost experts in the EIT field and continues to collaborate on the development of the TLDD. The TLDD was utilized to scan fast-grown radiata pine shipped from Australia to determine the best scanning method for detection of resin pockets. These images were compared to those from CT and MRI scans. The resin pockets were clearly visible in the TLDD images.

The developed RF panel scanning device can be used to measure OSB inplane specific gravity and moisture content variation.

GRADUATE STUDENTS: One graduate student and one doctoral student worked on this project.
Wood drying research and breakthrough technology

R. Shmulsky 065430F September 15, 2005–September 14, 2008

OBJECTIVES:
1. Research and develop commercially viable technology to significantly reduce volatile organic compound (VOC) emissions from pine lumber drying so that major pine lumber producers would fall below pollution source threshold levels, i.e., 100 tons per year.
2. Research and develop technology that vastly and fundamentally improves dimensional stabilization during wood drying thereby eliminating costly warp especially as crook and twist.

OUTPUTS: A prototype, commercially viable, real-time sensor for VOC and hazardous air pollutant (HAP) emissions has been developed in cooperation with Seacoast Science and AMEC Co. The best possible source of emissions control is postulated to be a feedback system based on real-time measurement of air pollution streams. A refined prototype device to improve dimensional stabilization during the drying process is currently being fabricated. The revised device eliminates the use of complex, bulky, and heavy pneumatic cylinders in favor of a low pressure, smaller, and simpler diaphragm-driven device.

IMPACTS: The approach to air pollution control from lumber kilns has been investigated. It appears the optimal method of pollution control is through temperature, humidity, and air velocity control during the drying process. Investigators are pursuing this avenue.

GRADUATE STUDENTS: One graduate student worked on this project.
Classification of hazardous air pollutants from drying southern pine lumber

R. Shmulsky, L.L. Ingram Jr. 065480C September 1, 2006–August 31, 2008

OBJECTIVES:
1. Determine if methanol, acetaldehyde, acrolein, benzene, formaldehyde, or phenol occur in measurable concentrations in green southern pine.
2. Determine if there is a concentration difference of these compounds in heartwood vs. sapwood.
3. Determine if storage duration or conditions impact the emission of these compounds during drying.
4. Determine if drying schedule impacts the emission levels of these compounds.

OUTPUTS: An air pollution sensor that measures and specifies hazardous air pollutants in real-time has been partially developed.

IMPACTS: None to report at this time.

GRADUATE STUDENTS: Three graduate students have worked on this project.
Researchers of wood-based composite materials continue their work to improve adhesive systems, gather data on fatigue damage and perform extensive tests on engineered wood.

**RESEARCH HIGHLIGHT**

- A research project identified two synthesized compounds for wood adhesion. While the compounds did not provide the water repellency and stabilization desired, they did show characteristics deemed useful for manufacturing of new wood adhesive resins. Test of the resins have indicated good wood composite bonding properties with very low formaldehyde emission potential. Research can now build on these molecules to develop new wood adhesive resins.
## Wood-Based Composite Materials

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<td>Development of functional water repellents for wood and wood composites</td>
<td>M.G. Kim</td>
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<td>065430E</td>
<td>Effect of high temperatures on adhesive bond durability in engineered wood products as well as its effect on the production of toxic chemical compounds in the smoke emitted</td>
<td>S.Q. Shi, L.L. Ingram Jr.</td>
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<td>065430H</td>
<td>Mechanical property enhancement of wood-plastic composites using carbon nanotubes and ceramic nanoparticles</td>
<td>J. Zhang, H. Toghiani, C. Pittman, Y. Xue, S. Shi, M.G. Kim</td>
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<tr>
<td>065480B</td>
<td>Development of novel wood-polyurethane composite foam products (wood-pu foam) for high-end applications</td>
<td>S.Q. Shi, R.D. Seale, J. Zhang</td>
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<td>Proposed for 2008</td>
<td>Dielectric behavior modeling of OSB composites</td>
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<tr>
<td>Proposed for 2008</td>
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<td>S.Q. Shi, H.M. Barnes, S. Lee</td>
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<tr>
<td>Proposed for 2008</td>
<td>Rendering hardwood fiber utilizing the TimTek™ process</td>
<td>R.D. Seale, H.M. Barnes, S. Shi</td>
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Development of functional water repellents for wood and wood composites

M.G. Kim 065390C August 15, 2004–August 14, 2007

OBJECTIVES:
1. Synthesize a series of potential functional water repellents for wood composites;
2. Evaluate the effectiveness in OSB and particleboard using southern wood species in the laboratory; and
3. Obtain optimum application parameters for industrial implementation.

PROGRESS: The two synthesized compounds identified as potential water repellent and stabilization agents were tested by impregnating in southern pine wood specimens and measuring the swelling in thickness and width dimensions in water. The compounds showed some effectiveness in the width direction only and were found to be less effective than available industrial wood treatment materials. However, the compounds showed characteristics deemed useful for manufacturing of new wood adhesive resins and tests of the resins have indicated good wood composite bonding properties with very low formaldehyde emission potential. It was included in a 2007 patent application.

IMPACTS: This research provides the wood composite products research community a platform of molecules from which new wood adhesive resins can be developed. Usefulness of some of the compounds in synthesizing wood composite adhesive resins has been shown and published in the patent application.

GRADUATE STUDENTS: One graduate student and one post-doctoral research associate worked on this project.
Effect of high temperatures on adhesive bond durability in engineered wood products as well as its effect on the production of toxic chemical compounds in the smoke emitted

S.Q. Shi, L.L. Ingram Jr.  
065430E  
September 15, 2005–September 14, 2008

**OBJECTIVES:**
1. To investigate the elevated-temperature behavior of adhesives used in engineered wood products.
2. To identify the chemical compounds contributed to the smoke by the adhesives used in engineered wood products.

**OUTPUTS:** A method using dynamic mechanical testing was developed to evaluate the heat durability of the cured adhesive resin film. Also, the chemical emission from the smoke affected by the adhesive has been analyzed.

**IMPACTS:** The research will have direct impact on building fire safety.

**GRADUATE STUDENTS:** One graduate student has worked on this project.
Mechanical property enhancement of wood-plastic composites using carbon nanotubes and ceramic nanoparticles

J. Zhang, H. Toghiani, C. Pittman,
Y. Xue, S. Shi, M.G. Kim

065430H September 15, 2005–September 14, 2008

OBJECTIVES:
1. Investigate the reinforcement effects of several nanosized materials, including carbon nanotubes and nanofibers on the mechanical properties of wood-plastic composites, and
2. Develop processing methods to disperse properly these small reinforcing phases into the plastic and then produce wood-plastic products for structural applications. Organic resin/carbon fiber nanocomposites used in wood-plastic materials may exhibit superior stiffness and creep resistance properties.

OUTPUTS: Maleated polypropylene and vapor-grown carbon nanofibers were formulated into polypropylene/wood flour composites. The composite components were mixed using a melt blending (182-190°C) process in either a Brabender or an extruder. Composite panels were then prepared by hot-press molding. Composite flexural strengths and flexural moduli were measured using a three-point bending test.

IMPACTS: The effects on mechanical properties were evaluated by fabricating and testing the polypropylene-wood flour composites with maleated polypropylene and carbon nanofiber as additives. The maleic anhydride groups in maleated polypropylene can react at wood fiber surfaces to enhance wood/polypropylene adhesion. The addition of maleated polypropylene (1.0-5.0% by weight) to the composites was found to improve the composite flexural strength and flexural moduli significantly for composites that were mixed by either the Brabender or the extruder. The addition of carbon nanofibers (0.6-4.6% by weight, ~0.35-2.6% by volume) to pure polypropylene via a Brabender was found to improve composite moduli. Polypropylene/wood flour/maleated polypropylene/carbon nanofibers composites mixed only by the Brabender affected the composite flexural moduli that were related to the wood flour concentrations. The composite moduli were further increased when the composite components were blended first using the Brabender, followed by extrusion (versus blending with the Brabender only). However, no flexural modulus improvements occurred upon addition of carbon nanofiber when the composite components were only mixed by extrusion. The reason for these phenomena is not clear, but nanodispersion and deaggregation of carbon nanofiber “nests” is important.

GRADUATE STUDENTS: One post-doctoral associate and one graduate student worked on this project.
**OBJECTIVES:**
1. To investigate an appropriate process to incorporate wood flours into polyurethane foam products for high-end applications;
2. To study the effect of incorporation of wood on the durability, flammability, and other properties required by high-end application for developed wood-polyurethane foam products.

**OUTPUTS:** The research is directed toward incorporating wood fiber/powers into rigid polyurethane foam products (polyurethane woodfoam) for different applications, such as tooling board, sign board, and etc. Initial polyurethane woodfoam products have been made with different wood content. The effect of wood particle size on the compressive strength properties of the polyurethane woodfoam has been studied. Investigation using the bio-based polyol for the polyurethane foaming process is also being pursued.

**IMPACTS:** This project will expand the wood utilization market.
Dielectric behavior modeling of OSB composites

J. Zhang, P.H. Steele, B. Martin  Proposed for 2008  July 1, 2008–June 30, 2010

Radio frequency (RF) scanning technology has been successfully used in automated softwood lumber grading through detecting defects. However, this technology has not been adopted for wood-based composite manufacturing process control in oriented strand-board (OSB) production. This is due to the lack of understanding of composites and their responses to RF signals. OSB consists of small wood building blocks such as chips, particles, and other add-ons such as resins and wax. Because of the in-homogeneous composition and geometric complexity of OSB, there are no effective models in existence to characterize the electrical properties (permittivity and conductivity) of OSB composites. Generation of this new knowledge base (accurate characterization of OSB electrical properties) is necessary to support the development of RF scanning technology for OSB manufacturing process control. RF scanning technology can be used to develop devices for process monitoring, in-plane moisture content and density distribution mapping of pre-press mat and post-press panel, and potential monitoring of hot press processes.

The objectives of this research are:
1. to experimentally measure the dielectric properties of composite building blocks considering effects of wood chip sizes, specific gravity, moisture content, adhesive, and other add-ons;
2. to develop 3D macroscopic numerical models characterizing dielectric properties of wood chip orientations and geometric structures of wood composites; and
3. to experimentally verify the developed 3D models.
Inorganic nanoparticle impregnated wood fibers for wood thermoplastic composites

S.Q. Shi, H.M. Barnes, S. Lee

Proposed for 2008

July 1, 2008–June 30, 2010

Wood fiber is a cellulosic material with micropores in its cellular structure. The presence of micropores in the cell wall may cause many problems for different applications. For example, in wood fiber/thermoplastic composites, these micropores may induce some manufacturing defects which possibly lead to interfacial failure, such as air pockets in the composites. Wood fiber is also a hydrophilic material, which absorbs moisture from its surroundings. It will be subjected to dimensional and mechanical property changes with changes in moisture content. In wood fiber/thermoplastic composites, compatibility of the hydrophilic wood fibers and the hydrophobic polymer matrices, such as polyolefins, is a major concern. Incorporating nanoparticles has proved to be a promising technique to improve the physical and mechanical properties of the polymeric composites. However, practically, it is difficult to impregnate commercial nanoparticles (such as nano-particulated clay and carbon) into the micropores of the cell wall. This research will focus on the impregnation of inorganic nanoparticles into the wood fiber which may not only reduce the void volume in the cell wall, but also increase the hydrophobicity of the fibers, and thus improve their compatibility with the polyolefin matrices. In addition, the impregnation of inorganic nanoparticles would minimize the moisture sensitivity of the composites, and the attraction conductivity of the fibers to the polymer matrices could be improved.

The objective of this project is to develop a framework for inorganic nanoparticle impregnation into the wood cell wall structure to make wood fiber-thermoplastic composites. The specific objectives are to:

1. develop inorganic nanoparticle impregnation technology in wood cell walls using two ionic salts;
2. examine the compatibility (such as attraction force) at the interphase between the nanoparticle impregnated wood fibers and the hydrophobic polymer matrix;
3. explore the nanoparticle efficiency on the property enhancement of nanoparticle impregnated wood fiber/thermoplastic composites; and
4. evaluate the durability of the resultant composites.
The upholstered furniture industry in Mississippi and surrounding states has converted from hardwoods to softwood plywood and OSB as a primary raw material source for making upholstered furniture frames. Traditionally, relatively low value species such as yellow poplar, sycamore, hackberry and sweet gum are used to make upholstered frames. Computer numerical control equipment has replaced hardwood rough mills in most upholstered manufacturing plants and the demand for hardwood lumber has decreased. Case goods furniture manufacturers moving production facilities to China also impacted the hardwood lumber industry in a highly negative way. Since the demand for hardwood lumber has decreased by furniture manufacturers, many acres of hardwood timber have no viable economic utilization uses.

The TimTek™ Process, which started as Scrimber in Australia, was brought to the U.S., and a pilot line exists on the campus of Mississippi State University. The pilot line has been used to successfully render fiber from pine plantation thinnings and produce stiff, high strength beams for residential and commercial applications. The pilot line was used to produce rendered fiber for 160 beams that were tested by an ISO-approved laboratory, and a code application report was produced. The first step of the process is to render fibers on a series of rollers that have various profiles designed to reduce the fibers to long strands. The pilot line process utilizes small diameter logs approximately eight feet long and produces small mats of “scrim”, the rendered fiber. This project will investigate the viability of rendering fiber from alternative hardwood species by utilizing the crush and scrim mills of the pilot line.

The objective of this research is to evaluate rendering fiber from hardwood raw material sources that could subsequently be used to produce either panels or engineered lumber products. The rendering process will be evaluated on major hardwood species found in north Mississippi and will include but not be limited to red oak, white oak, sweet gum, sycamore, and cottonwood.
The Department of Forest Products is targeting research and development of safer and longer lasting preservatives that will enhance the marketability and performance of lumber and wood composites.

**RESEARCH HIGHLIGHT**

- A study successfully demonstrated that several new generation preservative systems could be used to treat and protect engineered composites and other wood-based materials in service. Treatment technologies like vapor boron, in-process addition, and treatment of furnish prior to gluing were all successful. This information could be used by producers to manufacture new generation wood composites with enhanced durability.
## Protection and Preservation of Wood

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<th>Project Investigator</th>
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<td>065390A</td>
<td>Increasing the durability of engineered wood composites</td>
<td>H.M. Barnes, R.D. Seale, T.L. Amburgey</td>
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<td>065390D</td>
<td>Development of treatments to improve the weathering of southern pine lumber</td>
<td>D.D Nicholas, T.P. Schultz</td>
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<td>Molecular explorations into the expression and inhibition of wood decay enzymes</td>
<td>S.V. Diehl, M.L. Prewitt, D. Braasch, D.D. Nicholas</td>
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<td>Proposed for 2008</td>
<td>Inhibition of enzyme and mucilage production by wood decay fungi</td>
<td>M.L. Prewitt, S.V. Diehl, D.D. Nicholas, H. Borazjani</td>
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<td>Development of environmentally-benign organic wood preservative systems</td>
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**Increasing the durability of engineered wood composites**

H.M. Barnes, R.D. Seale, T.L. Amburgey  
065390A  
August 15, 2004–August 14, 2007

<table>
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<tr>
<th>OBJECTIVES:</th>
<th>IMPACTS: This study successfully demonstrated that several new generation preservative systems could be used to treat and protect engineered composites and other wood-based materials in service. Treatment technologies like vapor boron, in-process addition, and treatment of furnish prior to gluing were all successful. Blending of some biocides with resin before application was unsuccessful. The use of powdered biocides can be problematic. This information could be used by producers to manufacture new generation wood composites with enhanced durability.</th>
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<tbody>
<tr>
<td>1. Evaluate methods for applying new generation biocides/additives to engineered wood composites;</td>
<td><strong>GRADUATE STUDENTS:</strong> Two graduate students worked on this project.</td>
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<tr>
<td>2. Evaluate the impact of biocide addition and methods of addition on the properties and processing of engineered composites; and</td>
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<td>3. Evaluate the durability in and suitability for components used in the housing market.</td>
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**PROGRESS:** The most significant outputs for this project have been the publications and presentations made to international audiences. Under objective one several approaches for applying biocides were tested and confirmed with effects being described. Negative effects on composite properties were identified. Long-term tests are ongoing which indicate enhanced durability of composites treated using the chemicals and methods evaluated in this study.
Development of treatments to improve the weathering of southern pine lumber


OBJECTIVES: Develop cost effective treatments to impart dimensional stability to wood. A model for this objective is redwood which weathers well even though it has only limited natural dimensional stability.

PROGRESS: A second set of decking, quartersawn laminated boards made from southern pine sapwood, was manufactured, treated with a waterborne resin acid solution, and then placed outdoors in a severe above-ground exposure. Matched samples were untreated or treated with 3% wax as a positive control. These samples and earlier solid wood sapwood pine decking samples that were treated with the waterborne resin acid or untreated, were inspected periodically for splitting, warping, and weight gain/loss following rainstorms and subsequent drying. The resin acid solution reduced weight gain following rain by about one-third, with splitting and warping reduced by about half. With the solid untreated decking, the extent of splitting was significantly correlated to the amount of water gained following rain. Although not part of this study, it was noted that five of the 12 untreated quartersawn samples had decay after 9 months of exposure, with the samples that had decay being those that picked up the most water following rainstorms. An additional study was thus initiated in which a large number of untreated southern pine sapwood decking boards was obtained and exposed outdoors to determine the variation in wetting and splitting, with sub-sections exposed in a ground proximity test to determine decay susceptibility and unexposed samples saved to analyze the natural extractives in the sapwood to determine the effect of the extractives on the above properties. Previously, it was found that pine sapwood has an inherently large variation in hydrophobic terpenoids and fat/fatty acid extractives, which likely affects the decay susceptibility, extent of water gained after rain and subsequent splitting.

IMPACTS: A major consumer concern with lumber in above ground exposure such as decking is the poor dimensional stability that leads to warping, splitting, and checking. Development of improved, cost effective water repellents would be very beneficial to manufacturers of these products.

GRADUATE STUDENTS: One graduate student worked on this project.
**OBJECTIVES:** The overall objective of this project is to develop data to understand and predict the relationship between moisture content and temperature and their interactive effect on the long-term serviceability of wood-based materials.

**OUTPUTS:** Data is being analyzed.

**IMPACTS:** This research addresses a major national need for improving long-term service-life of wood products and homes. It will improve the ability to accurately relate materials performance with building serviceability and it will allow engineers to more effectively identify, then design, to avoid conditions conducive to deterioration and effectively mitigate wood deterioration if it occurs. It will also result in better performance of U.S. housing during man-made and natural disasters, such as inappropriate humidity control, moisture leaks or ingress, and floods.

**GRADUATE STUDENTS:** Two graduate students and two undergraduate students have worked on this project.
Molecular explorations into the expression and inhibition of wood decay enzymes

OBJECTIVES:
1. Develop the methodology for detection and quantification of the wood decay genes by reverse transcription real-time polymerase chain reaction;
2. Evaluate the Beckman-Coulter Genome Lab GEXP system for use in expression profiling of wood decay genes; and
3. To test one expression profiling technique in a more complex, yet controlled environment such as the laboratory accelerated decay test system. Knock out technology for the regulation of lignin degradation by Phanerochaete chrysosporium. The goal is to evaluate knock out technology as a plausible means for reducing wood decay caused by the white and brown rot fungi.

OUTPUTS: The methodology for detection and quantification of the wood decay genes has mostly been accomplished, with a few enzymes yet to be tested by real-time polymerase chain reaction. The expression profiling technique is just beginning using the laboratory soil block test system. Good target sequences have also been identified within the transcript genes involved in the lignin degradation pathway.

IMPACTS: The methods have been developed for extraction of RNA from wood and decay fungi; the synthesis of cDNA from the RNA; and for a few decay enzymes RT-qPCR have been successfully run. There are still several enzymes that have not been tested by RT-qPCR but that should easily come with time. The greatest hurdle which was the extraction of RNA and conversion to cDNA has been accomplished. The soil block system has been set up and decayed wood from these test systems are being used for gene expression. A series of individual fungi and fungi combinations will be tested to see how competition alters the expression of the decay genes. An assay method for lignin peroxidase detection is needed to validate gene knock out and this has been developed. The next step is to induce lignin peroxidase production by the white rot fungus in order to evaluate objective one. This is currently in process.

GRADUATE STUDENTS: Two graduate students worked on this project.
Development of near infrared spectroscopy of rapid assessment of wood decay

P.D. Jones, D.D. Nicholas

Proposed for 2008

July 1, 2008–June 30, 2010

Rapid assessment of wood decay is critical when testing the efficacy of wood preservatives. The sooner it can be determined that decay and degradation of wood has begun, the sooner alternative preservatives can be tested. Current testing procedures require approximately 20 days to determine the ability of a preservative to stave off wood destroying organisms. Controlling moisture content and temperature of testing samples may accelerate wood decay in ineffectively treated samples.

To bolster this accelerated decay process, a method to detect decay earlier than previously available needs to be examined also. Near infrared spectroscopy will be examined to determine if changes in wood chemistry by fungi can be detected earlier than other methods. Also the ability of near infrared spectroscopy spectra will be examined to determine strength loss associated with decay.

The specific objectives of this study are to:

1. Determine whether near infrared spectroscopy can be used to measure the extent of wood decay in a soil block test.
2. Determine whether controlling the moisture content and temperature of above ground test samples will accelerate wood decay.
3. Compare dynamic moduli of elasticity, static bending and near infrared spectroscopy as methods for evaluating wood decay in an accelerated above ground decay test.
Wood decay is predominately caused by insects and microorganisms and results in billions of dollars loss to consumers annually. Traditional wood preservatives are broad spectrum pesticides that often lead to environmental concerns. Therefore, there is a need to develop more effective and environmentally benign wood preservatives. To accomplish this, a better understanding of the microbial wood decay mechanism is required. It has been established that basidiomycete fungi are the primary wood decomposers because they produce a suite of enzymes that work synergistically to decay wood. The enzymes are produced inside the cell and secreted through the hyphal tip into an extracellular matrix called mucilage. Mucilage is composed of a polymer of β-D glucans with a β-(1, 3) linked main chain and β-(1,6) linked side chains. Proteins and lipids may also be found in mucilage. It has been suggested that mucilage not only provides a matrix for enzymes but may also play a role in wood decay. Two compounds, Brefeldin A and cytochalasin, have been shown to inhibit mucilage production in other fungi. Known wood decay fungi will be exposed to Brefeldin A or cytochalasin under optimal and non-optimal conditions in order to measure their effect on mucilage production and decay enzyme expression. Mucilage production will be determined quantitatively and by Transmission Electron Microscopy. Proteins will be extracted from solutions containing decay fungi and inhibitor exposed and unexposed treatments under optimal or non-optimal conditions and separated by isoelectric focusing and 2-D gel analysis. Unique protein spots appearing in the inhibitor-free and not in the inhibitor exposed will be excised and analyzed both quantitatively and qualitatively by mass spectrometry. This proposal seeks to determine if Brefeldin A and cytochalasin can reduce mucilage production by wood decay fungi. If these inhibitors are successful in reducing mucilage production, then this research will determine if mucilage reduction leads to a reduction in decay enzymes and wood decay by initiating an accelerated decay test using various concentrations of inhibitors on wood. If these inhibitors are successful in reducing the mucilage production and subsequent enzyme expression and wood decay, this would provide a basis for a new research area to develop alternative wood preservatives.

The objective of this study is to evaluate the effects of Brefeldin A and cytochalasin on the inhibition of mucilage and enzyme production (through protein expression) and wood decay by selected wood decay fungi.
Subterranean termites cause extensive damage to wood products. Protection against termite degradation employs various bioactive compounds. However, many of these compounds negatively impact other non-target organisms, persist in the environment, and may migrate into ground water. Therefore, in the past decade many bioactive compounds have been voluntarily withdrawn, which has accelerated the need for environmentally friendly, non-biocidal termite control technologies. Many studies of the effect of heartwood extractives on termites have separately shown that the same classes of extractives have both termite toxicity/repellency and free radical scavenging (antioxidant) properties. That extractives have both antioxidant properties and affect termites may be due to coincidence or evolutionary design.

Wood products used in outdoor exposure can also be degraded by fungi. To prevent this degrade, wood is treated with biocides. Biocides for residential lumber are currently the new second generation copper-rich preservatives, but these new systems have environmental concerns. Organic biocides have two major problems: a relatively high cost compared to metallic biocides and biodegradation over the long service life.

This project will continue studies on employing butylated hydroxytoluene and other antioxidants to protect wood against attack by subterranean termites, and to continue to study the efficacy and biocide depletion of ground proximity samples that were recently treated with two promising organic wood preservatives, with and without the economical and non-biocidal additives butylated hydroxytoluene and/or metal complexing resin acids.

The objectives of this research are:
1. conduct laboratory AWPA E-l termite tests with other selected antioxidant compounds; inspect the outdoor field termite studies installed last year at Saucier, MS, and install additional termite outdoor wood-protection and soil perimeter tests as appropriate; and
2. analyze and inspect samples installed at Saucier, MS and Hilo, HI. These ground-proximity samples employ two organic biocides that are promising wood preservatives, both with and without butylated hydroxytoluene and/or resin acids co-added to determine the effect of the additives on biocide efficacy and depletion; and
3. approach commercial entities to determine their interest in licensing these technologies.
Scientists in the Department of Forest Products are researching ways to use wood to develop fuel. With increased demand for fuel and reliance on foreign supplies, the need to develop fuel from natural resources is a top priority. Scientists also are studying ways to clean-up wood preservatives in ground and water sources.

**RESEARCH HIGHLIGHT**

- Researchers have successfully reduced the oxygen content in raw bio-oils with a hydrodeoxygenated treatment. Successful development of this treatment will allow production of an upgraded bio-oil that can be input to existing petroleum refineries for refining into fuels. This has the potential to be the best route to diesel and gasoline fuels from lignocellulosic biomass.
## Wood Chemistry

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<td>065430B</td>
<td>Development of immobilized sequence-specific oligonucleotide probes (SSOPs) for rapid identification of important wood-inhabiting fungi</td>
<td>S.V. Diehl M.L. Prewitt W.J. Diehl</td>
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<td>065430G</td>
<td>Development of fuels and value-added chemicals from pyrolysis of wood/waste-plastic mixtures</td>
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<td>Fuels and chemicals from catalytic hydrodeoxygenation of pyrolysis oils</td>
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## Wood Chemistry

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### Microbial populations associated with accelerated soil contact decay test

**M. L. Prewitt, T. McElroy, D.D. Nicholas, S.V. Diehl**  
065390E  
August 15, 2004–August 14, 2007

**OBJECTIVES:**

1. Evaluate the microbial breakdown of chlorothalonil-treated wood stakes exposed to a soil mixture from two common field sites and on the wood alone,
2. To compare the associated microbial communities (and identify the key microorganisms) in the wood and the soil mixture with and without the ‘acceleration’ inoculate added, and
3. If degradation is observed by high performance liquid chromatography analysis, to determine through laboratory bioassays which microorganisms are responsible for the breakdown.

In addition, the fungi and bacteria from the two soil sites will be identified (as much as possible) using the molecular database and fatty acid identification systems.

**PROGRESS:** The study is complete. Chlorothalonil breakdown was observed, but it occurred very rapidly (by the second month) and focus was shifted to evaluate the breakdown products.

**IMPACTS:** Preservative treatment led to increased microbial species richness, diversity and turnover in early exposure that decreased over time. These increases may have led to the rapid depletion of the preservatives in this study. Chlorothalonil treated wood samples are being further analyzed to determine the concentration, if any, of 4-hydroxy-2,5,6-trichloroisophthalonitrile, a common chlorothalonil breakdown product. Due to the fact that chlorothalonil or butylated hydroxytoluene was not detected in soil samples, neither of these compounds leached out of the treated wood, but were broken down
by the microbes. The addition of compost to the soil had an effect on total fungal communities in this study, but not the basidiomycete community. The addition of compost increased the rates of decay in treatments, either by enabling the microbes to overcome the adverse effects or providing an alternative food source for the microbes than the treated wood. There were fluctuations in soil moisture in the later months of this study which may have influenced low numbers of basidiomycetes encountered. The majority of test samples had decay characteristics more indicative of soft rot than brown or white rot, not only in later sampling but throughout the test. Some white mycelium was noted on wood surfaces, but the wood surfaces were extensively pitted and water soaked. It seems that soft rot fungi may have greatly contributed to degrade these samples. An important point to be made from the results of this study is the lasting impacts of the preservatives on the community structure and patterns of strength loss. Preservatives were completely degraded within the first month of exposure, but the microbial communities exhibited differences in species composition until 10 months into the study and longer in some cases. Differences in strength loss were apparent even after 12 months exposure, which suggest that the initial 30 days of this test somehow influenced the durability of the test samples.

**GRADUATE STUDENTS:** One doctoral student worked on this project.
OBJECTIVES: The objective of this research is to identify and separate chemical products from bio-oil produced from softwood woody biomass.

PROGRESS: Bio-oils from southern pine, red oak, white oak, sweetgum and cottonwood have been produced. Bio-oils from 4-year-old whole tree feed stocks have been produced from pine and cotton wood saplings and their bark, clear wood, leaf or needle components. A major study of the potential for collection of harvest residue with a slash bundler was performed to determine the collection efficiency, economics and aging properties of the slash bundles resulting from the process. It was found that a harvest residue volume equivalent to 20% of merchantable stand volume can be collected on the first thinning, second thinning and clearcut mature stand. The bio-oil produced from this biomass had quality equal to that from clear pine wood. Ash content was slightly higher at 1.75% compared to 0.4% but this was considered acceptable for fuels production. Bio-oils made from pine and oak feedstocks have been tested as a wood preservative alone and as a co-biocide. Bio-oil fractions have been utilized as a substitute for phenols in the production of oriented strand board.

IMPACTS: Pine bio-oils produced by this project were provided to Dr. Sandun Fernando, who developed a transesterification process that will allow burning the upgraded bio-oil in a furnace for space heating. A laboratory-scale demonstration project will demonstrate small scale semi-batch reactor production of 40-liter volumes. The upgraded product will be used to heat the Mississippi State University Combined Heat and Power light industry simulation laboratory.

GRADUATE STUDENTS: One graduate student worked on this project.
Development of immobilized sequence-specific oligonucleotide probes (SSOPs) for rapid identification of important wood-inhabiting fungi

S.V. Diehl, M.L. Prewitt, W.J. Diehl

OBJECTIVES:
1. Align and design species specific oligonucleotide probes for important wood decay fungi based on internal transcribed spacer (ITS) sequences,
2. Develop identification membranes for specific field sites containing the sequence-specific oligonucleotide probes for fungi important to that site and
3. Develop functional gene specific oligonucleotide probes for important enzymes associated with decay or biocide deactivation for specific fungal species.

The secondary objective of this project is to continue to train research personnel in new molecular procedures, so the biodeterioration research can expand into new and progressive directions, but not at the expense of its current personnel.

OUTPUTS: Scientists have aligned and designed sequence-specific oligonucleotide probes for important wood decay fungi based on internal transcribed spacer (ITS) sequences. Functional gene specific oligonucleotide probes for important enzymes associated with decay or biocide deactivation for specific fungal species are being developed.

IMPACTS: Decaying wood samples from two study sites in Mississippi were collected over a 14 month period. Wood samples consisted of southern yellow pine untreated, treated with different preservatives, and exposed either above ground or in ground contact. Fungi were isolated from these wood samples and cultured until pure. DNA was extracted from all samples and the ITS region of DNA amplified and prepped for sequencing. The fragments were sequenced. Sequences were compared to the NCBI database for identifications. This produced a list of fungi found on wood from these sites as well as sequence information. Primers were designed and the amplification protocols worked out for some of these fungi considered important to wood decay. Additionally, gene specific primers have been designed for several of the important wood decay enzymes and probes for quantitative real time PCR are being designed.

GRADUATE STUDENTS: One graduate student and two undergraduate students worked on this project.
Development of fuels and value-added chemicals from pyrolysis of wood/waste-plastic mixtures

P.H. Steele, L.L. Ingram Jr. 065430G September 15, 2005–September 14, 2008

OBJECTIVES: The objective of this research project is to develop improved fuels and value-added chemical products from the co-pyrolysis of plastic and wood mixtures.

OUTPUTS: Bio-oil produced from woody biomass polymerizes during storage, is corrosive due to organic acid content, is high in density, and low in heat content relative to petroleum fuels. The objective of this research was to determine if rapid copyrolysis of pine and oak wood with three plastics: polystyrene, polyethylene and polypropylene would produce bio-oil with improved properties. Pyrolysis gas chromatography mass spectrometry analyses were performed with wood feed stocks to determine the relationship of temperature, residence time and heating rate to the chemical species produced. The pyrolysis gas chromatography mass spectrometry temperature, residence time and heating rate that best simulated fast pyrolysis product types and distributions for wood were determined to be 450°C with 10 s residence time and 10°C/ms heating rate. This temperature and residence time were applied by pyrolysis gas chromatography mass spectrometry to copyrolyze wood and plastics in 0:100, 25:75, 50:50, 75:25, 100:0 wood-to-plastic mass ratios. Researchers have previously observed that co-pyrolysis of wood and plastic produced an upgraded raw bio-oil with increased hydrogen content. Based on the pyrolysis gas chromatography mass spectrometry results, 50:50 mass ratios of pine wood and the three plastics were copyrolyzed separately to bio-oil in a two kilogram per hour laboratory scale auger reactor. Elemental analyses of the bio-oils indicated higher carbon content and significantly lower oxygen content compared to pine bio-oil. Heat of combustion values of these bio-oils were higher and water content, acid value and viscosity were lower compared to pine bio-oil. These results indicate potential for fuel production from bio-oils produced by copyrolysis of wood and waste plastics.

IMPACTS: Upgraded bio-oils offer an efficient means to produce bio-fuels. Copyrolysis of waste plastics offers a means to utilize a waste stream from large volumes of waste plastics entering municipal landfills and producing an upgraded fuel from woody biomass. A large reduction in required landfill space would result.

GRADUATE STUDENTS: One graduate student worked on this project.
OBJECTIVES:
1. Develop techniques for both mild hydrogenation and hydrodeoxygenation treatments of bio-oils to a quality suitable for refining. Various catalysts, temperature, and pressure regimes will be tested.
2. Refine the hydrogenated bio-oils to develop light, medium and heavy distillate fractions suitable as fuels or value-added products.
3. Test the fuel values and analyze and explore the potential for producing value-added chemicals from the distillate fractions.

OUTPUTS: A novel catalyst has been developed that reduces the usual coking that occurs during hydrodeoxygenation treatment. Refinement of the catalyst composition is being pursued based on batch reactor experiments. Following optimization of the catalyst a continuous flow reactor system will be developed. The bio-oil with reduced oxygen will then be fluid catalytic cracked as in a petroleum refinery to determine fuels yield.

IMPACTS: Researchers have attempted for decades to reduce oxygen content in raw bio-oils with hydrodeoxygenation treatments. Heavy coking of the catalyst has prevented application of this process. Successful development of a hydrodeoxygenation system, assuming commercially viable yield, will allow production of an upgraded bio-oil that can be input to existing petroleum refineries for refining into fuels. This has the potential to be the best route to diesel and gasoline fuels from lignocellulosic biomass.

GRADUATE STUDENTS: One doctoral student worked on this project.
Regulation of selective delignification

S.V. Diehl, M.L. Prewitt, D.D. Nicholas, W.J. Diehl

Proposed for 2008

July 1, 2008–June 30, 2010

Wood and other plant biomass are currently the only worldwide sustainable sources of fuel and materials. DOE’s Research Roadmap ‘Breaking the Biological Barriers to Cellulosic Ethanol’ states that “lignocellulose recalcitrance to bio-processing is the core and limiting factor in creating ethanol production from lignocellulose.” The best biological system for understanding novel lignocellulose metabolism is the microbial wood decay community. Additionally, the global wood preservative market is a $120 million industry. Understanding the regulation of the decay process will allow for development of environmentally safe wood protection systems that could target the production or activity of enzymes and not simply act as a broad spectrum pesticide. Knowledge gained from this work could lead to improved regulation of pretreatment enzymes used in the conversion of biomass into fuels, improved bio-pulping and improved utilization of biomass for economic importance.

Although quite a bit is known about some of the decay enzymes in select wood decay fungal species, very little is known about regulation of these enzymes during the process of decay and what other metabolic events are occurring that are integral to the decay process. Why does a fungus ‘choose’ selective delignification over simultaneous decay or why does selective delignification target only lignin, when most of the lignin degrading enzymes are non-specific and attack all cell components?

In order to ‘control’ delignification or decay for biomass conversion to energy or for new environmentally friendly ways to protect wood products from decay, there needs to be a better understanding of regulation mechanisms.

The objectives of this research are to better understand the wood decay fungi’s regulatory mechanisms involved in selective delignification versus simultaneous decay and to lay the foundation for future studies in this area. The specific objectives are:

1. to determine what proteins are uniquely expressed by a wood decay fungus undergoing selective delignification versus simultaneous decay;
2. to compare levels of expression of the decay enzymes by this fungus undergoing selective delignification versus simultaneous decay to the protein results;
3. to track the changes that occurs when a fungus switches from delignification to decay; and
4. to confirm the levels of lignin removal by scanning electron microscopy.
There is a growing interest in processes that utilize a fast growing, low-value log to produce an engineered product with excellent modulus of elasticity and modulus of rupture properties and also dewatering of these type trees for burning purposes. For engineered products the process begins with first thinnings from plantations grown for paper manufacture. The individual stems are harvested and quickly transported to the manufacturing facility. After harvesting, the bark and inner bark are removed and the stems are conditioned with heat to soften the wood. Once properly conditioned, the stems are processed on the scrim line. The scrim line initially crushes and then separates the stems into long strands normally called scrim. The “resonated” scrim is assembled into a mat that is pressed into a billet that can later be re-sawn into desired pieces. The pressing process uses a steam chamber press. Scrim is heated in the press via steam for approximately half of the press cycle. The steam chamber press facilitates production of thick billets in a relatively short period of time. Three or four charges of wood are possible per hour. In a conventional steam injection press, the corresponding press cycle would be more than 1.25 hours per billet. It is anticipated that four to ten scrim plants will be built in the U.S. within the next eight years to produce this type of product with an estimated economic impact of over one billion dollars annually. A major environmental concern is process water containing wood extractives collected during the crushing cycle for this process and de-watering of wood for energy utilization. Little information is currently available on composition of this type process water as well as proper treatment before its discharge. At the same time, mechanical dewatering has been shown to be an effective means of increasing energy density of wood fuels. The process water from mechanical dewatering is similar to that from the crushed strand-based lumber.

The objective of this research is to identify and characterize compounds in process water and evaluate treatment technologies such as bio-treatment, co-composting, and phytoremediation using aquatic plant species.
Economic Evaluation and Technology Transfer

The Forest and Wildlife Research Center is a significant channel for transferring technical and economic information to the diverse members of the wood industry enabling them to become more efficient and more profitable.

RESEARCH HIGHLIGHT

- Furniture manufacturers often use a trial-and-error method to determine design loads for furniture components. A study has provided a numerical model to analyze internal forces and stresses acting at critical joints and members in sofa frames. This data provides clear design targets and provides material savings for upholstered furniture frames from 20 to 30 percent.
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<td>065480E</td>
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## Economic Evaluation and Technology Transfer

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Enhanced utilization technologies for increased productivity and profitability: Lean manufacturing initiative for the American furniture and wood-based industries


OBJECTIVES:
1. Determine profitability and other benefits of a newly designed lean manufacturing system variant, parallel pull flow, for the furniture industry;
2. Determine ergonomic benefits derived from lean manufacturing research that will eliminate or reduce work related muscular-skeletal disorders, thus lower worker chronic injuries and industry worker lost time injury, compensation costs; and
3. Determine the feasibility of lean production methodologies applied to the manufactured and modular home manufacturing industry.

PROGRESS: One hundred and twenty-six factory seminars have been given to 1,451 managers, engineers, technicians, and workers. These seminars included hands-on training on the factory floor and assistance to furniture and wood products manufacturing personnel. This assistance included Lean Production subsystems such as Parallel Pull Flow manufacturing lines and other modern manufacturing techniques.

IMPACTS: The impact of these efforts included the design and implementation of many lean production manufacturing cells, leaned flow lines, parallel pull flow manufacturing lines, and other leading edge techniques and methodologies. The Parallel Pull Flow manufacturing lines improved productivity roughly 50 percent over the archaic push system. Manufacturing cells and leaned flow lines had substantial productivity increases ranging up to 73 percent. Furniture assembly cycle time has been reduced 33 percent since utilizing lean production methods and techniques. Factory floor space has been improved by 15 percent. Ergonomically correct changes were incorporated to reduce or eliminate work-related muscular skeletal disorders in the various manufacturing areas. It was difficult to determine whether the various ergonomical changes were making significant impact since the workforce utilizing the new ergonomically changes were the same workers who had already, in many cases, sustained chronic injuries while working under the old manufacturing system. However, it is believed that, in a few years, there will be a leveling off or an actual reduction of new ergonomic-related injuries.
Analysis of bio-oil as an emerging wood use


OBJECTIVES:
1. Evaluate potential demand for bio-oils as a potential energy source for heating in Mississippi.
2. Evaluate potential supply for bio-oils as a potential energy source for heating in Mississippi.
3. Compare alternative forest management regimes that produce bio-oil outputs.
4. Assess the impacts of existing state and federal tax and cost share incentive structures on managing timberland for bio-oil outputs and alternative management regimes.

PROGRESS: All objectives have been met. One thesis and one peer-reviewed manuscript were produced from this research effort. In addition, another manuscript is in preparation.

IMPACTS: World instability and the United States’ heavy dependence on oil imports from the Middle East make it extremely important to investigate alternative sources of liquid fuels. The conversion of woody biomass with gasification and pyrolysis processing technologies makes this an intriguing option. Mississippi’s abundance of woody biomass, high profile forest sector, and location gives it an important position in advancing this technology and developing a woody biomass liquid fuel market. The results from this study will provide important information pertinent to Mississippi policy makers evaluating the viability of this energy source as an alternative fiber market for both industrial and non-industrial forest landowners. In addition, the results from this study will serve as a framework for addressing region wide issues on this topic.

GRADUATE STUDENT: One graduate student worked on this project.
An analysis of the structure, performance, capacity and future of the production forestry economic sector of Mississippi: A tool for economic development

R.K. Grala, R. Shmulsky, L.A. Grace, R.D. Seale, W.B. Stuart

065430D September 15, 2005–September 14, 2008

OBJECTIVES:
1. Assess the capacity, capabilities, and constraints of wood using manufacturing facilities in current (and planned) operation in the state, including raw material requirements;
2. Evaluate the capacity, capabilities, and constraints of the marketing raw material supply systems and production forces needed to procure that raw material, routing it to the appropriate manufacturing facility;
3. Describe the sourcing and legal constraints concerning the type, quality and availability of woody raw materials needed by the forest-products industry; and
4. Integrate these into structural models of the material, financial, information, and influence flows within the wood using sector.

PROGRESS: The wood supply system of the area continues to restructure following Hurricanes Katrina and Rita. There has also been a reduction in demand for building materials and the rise of interest and opportunities for cellulosic feedstocks. The survey of wood manufacturers was completed, and found that while the effects of the hurricanes were wide spread, the physical effects have been handled. However, the restructuring of markets and increased fuel prices continue to have an effect. One major market for hardwood logs in the central Mississippi region shut down their mill and entered the mulch business and another that had been dependant on mill residues for raw material was unable to compete with the prices paid for residues as fuel and had to develop sources based on residues from pine thinnings.

Work continues on developing a better description of the value chain associated with production forestry, especially the role it plays in rural economic sustainability.

Work continues on the state level project directed at quantifying the size of parcels of land classified as “uncultivated” on county tax rolls in a format compatible with GIS information concerning soil characteristics, road networks, low weight bridges, and other factors that affect the flow of raw materials. The data available extends across years, providing an opportunity to assess changes in ownership, uncultivated tract sizes, and land use post-Katrina. This information may prove especially useful for use in assessing the effects of increased bio-based energy production on wood supply, especially comparing alternate sites for production plants and for assessing the
potential impact on forest acreage of increased corn and soybean prices—how much of marginal land converted to forests over the last few decades will be returned to agricultural production as a result of rising commodity prices.

Increased fuel prices are having an effect on the wood supply system. Hauling costs, forest to market, are causing shrinkage of individual mill procurement areas, as gains in trucking efficiency are not able to offset the rising operating costs.

The results from load by load data for 12 contractors across the Mid-South region indicate that on any given day a logger may be moving wood to multiple destinations, ranging from a minimum of two for thinnings to over seven for chip and saw and sawtimber stands. The logistic and scheduling complexity affects the operations’ ability to produce in a region requiring “hot logging”, and get material to the market within days of severance.

Work is underway to look at the business structure of individual firms and how it affects the firm’s ability to accommodate changes in the demand for their services, and how that variability affects business performance.

Several distinct, knowing or unknowing strategies involving choices concerning investment strategies, response to growth opportunities, and personnel management are emerging.

**IMPACTS:** Information from this effort has been used by cooperating loggers and mill in reducing variability in productivity as a means of improving overall system improvement. All logging contractors involved have seen an increase in productivity without increased investment in equipment or crew size. The mill has seen reduced variability in daily and seasonal wood receipts, making it easier to manage mill site inventories. A longer “test period” is required before publicizing the work in total, but findings have been incorporated in presentations to forestry and logging associations across the South.

**GRADUATE STUDENT:** Two master’s students and one doctoral student have worked on this project.
Development of design loads for upholstered furniture frames

J. Zhang, Y. Xue, S. Hunter 065480E September 1, 2006–August 31, 2008

OBJECTIVES:
1. Development of analysis methods and procedures,
2. Frame structural modeling and analysis,
3. Deriving cycle load schedules for all structural components,
4. Deriving fatigue life curves based on available experimental data for structural components,
5. Deriving design loads, and
6. Performing structural design and carrying out frame performance tests for verifications.

OUTPUTS: Fatigue performance of 12 sofa frames supplied by a local furniture manufacturer were evaluated. Structural analyses of the frame construction using numerical finite element simulation technique was performed. Testing was also performed to evaluate strength performance of joints and members constructed with several different types of composites. Design loads of the structural frame design for sofa frames were proposed.

IMPACTS: Numerical simulation was proven as an effective method in analyzing internal forces and stresses acting at critical joints and members in studied sofa frames. Design loads were proposed for design of sofa frames considering fatigue effects. Base strength properties data of wood-based composites such as fastener direct withdrawal and lateral shear load capacity, surface adhesive bonding strength in tension and shear, are necessary for sofa frame strength design. With clear design targets or when using alternative engineered materials, developed design and analysis methods and engineering design data produce material savings for upholstered furniture frames from 20 to 30 percent.

GRADUATE STUDENTS: One graduate student worked on this project.
Domestic and global competitiveness of the U.S. wood products industry: A general equilibrium analysis

I.A. Munn, A. Hussain

065480G

September 1, 2006–August 31, 2008

OBJECTIVES:
1. Formulate a general equilibrium model of U.S. major regions (e.g., Pacific Northwest, Southeast, Southwest, Northeast, Midwest) juxtaposed in relation to the world major trading regions (e.g., Pacific-Asia, Scandinavia-Russia, Europe, Canada, South America, rest of world), that allows for appropriate representation of inter-industry linkages and associated transactions.
2. Simulate the impact of a set of policy scenarios including changes in corporate taxes, technological change, environmental regulations, and trade liberalization on U.S. forest products competitiveness.
3. Construct indices of net regional welfare, and discuss alternative management and marketing strategies that would optimize economic gains from forest products international trade.

PROGRESS: No progress has been completed this year.

IMPACTS: There are no impacts to report at this time.
Development of large-area inventory techniques for measuring forest landscape change

E.B. Schultz, T.G. Matney, R.C. Parker, D.L. Evans, K.L. Belli

061130

September 1, 2006–August 31, 2008

OBJECTIVES:
1. Investigate multi-spectral and Light Detection and Ranging (LiDAR)-based change detection procedures that will generate statistically efficient strata based on age and stand density classes for optimally allocating a random sample in a large-area inventory.
2. Develop models to accurately predict change caused by hurricane damage and describe its spatial extent using analyses of pre- and post-storm remotely sensed and GIS data.
3. Estimate below- and above-ground forest carbon sequestration for the promotion of carbon management as it relates to mitigating CO₂ emissions and influencing global climate change.

PROGRESS: Four tree identification and measurement models are being compared for their accuracy in detection and measurement of trees within stem-mapped loblolly pine experimental spacing trials. The results of this work will be used to develop and validate individual-tree growth and yield models based on multi-year LiDAR data. GIS models are being developed to improve the ability to create statistically efficient sampling strata from GIS images. The preliminary results show that at a minimum, statistical efficiency can be increased by 25 percent. A 25 percent statistical efficiency gain translates into an inventory cost reduction of at least 25 percent. An operational geo-spatial database has been developed and satellite age and type and classifications from 1972 to 2006 have been generated. These will provide accurate growth and yield projections and sampling frame construction. Change detection methods have been employed to create growth and drain layers for the 2004, 2005, and 2006 inventories in support of the addition of a mill location decision support module in the Mississippi Institute for Forest Inventory (MIFI) user interface. The biomass knowledge-base developed for MIFI is being utilized to estimate the potential woody biomass supply for biofuel generation in Mississippi and is being adapted for use in small-scale inventories to estimate carbon credits. MIFI has completed the field inventory for three of five inventory regions in Mississippi. Reports have been generated for the 2004 (southwest region) and 2005 (southeast region) inventories. Calculations for the 2006 (central region) inventory report have been completed. The 2007 (northeast region) inventory measurements are being collected. New inventory procedures have been adopted and implemented to allow for storm and other damage assessments and for locating and quantifying invasive species. The inventory interface/decision
support software is currently available to the public for downloading on the MIFI Web site, www.mifi.ms.gov.

**IMPACTS:** Final results are not completed at this time to fully report on their impacts; however, intermediate products such as the biomass component estimators have been added to the MIFI decision support interface and are being operationally utilized. Inventory results demonstrate that for much of the State, approximately 75 percent more wood is being produced than consumed and this surplus can add significantly to the existing $14 billion total output of Mississippi’s forest and forest products industry. Good growth and drain estimates guarantee the stability and sustainability of the forest products industry that accounts for 6.6 percent of the State’s total industrial output. These tools will allow the state to entice forest product industry investors to build or expand existing facilities. In the 32 months since the on-line MIFI Decision Support System has been operational, there have been 95 requests for installation or analytical support. From these requests, 67 cursory analyses were conducted to assess the availability of various product species combinations within the currently inventoried MIFI regions. The 28 remaining requests were directed toward intensive and detailed analyses for very specific combinations of species product availability including diameter distributions, growth-to-drain ratios and spatial distribution. Currently, two bio-energy facilities are pursuing capital funding for locating mills within Mississippi and one traditional timber product company is poised to start construction of a facility pending a renewed vigor in their portion of the market.

**GRADUATE STUDENTS:** Thirteen graduate students and two post-doctoral associates have worked on this project.

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**Development of large-area inventory techniques for measuring forest landscape change (continued)**

E.B. Schultz, T.G. Matney, R.C. Parker, D.L. Evans, K.L. Belli

| 061130 | September 1, 2006–August 31, 2008 |

Development of large-area inventory techniques for measuring forest landscape change (continued)
Production of bio-energy feed stocks from forest understory vegetation

P.H. Steele, L.L. Ingram Jr.,
E. Hassan, D.L. Grebner

Proposed for 2008
July 1, 2008–June 30, 2010

Production of bio-energy from lignocellulosic biomass is a high priority research area for the nation. A 2005 USDA study has determined that 1.3 billion dry tons of lignocellulosic biomass were currently available to produce one-third of the liquid fuels required for U.S. transportation fuels. The forestry biomass component comprised nearly one-third of the 1.3-billion dry ton supply required. However, 145 million dry tons of the forest biomass identified as available in the forestry component is comprised of wood industry residuals that are being utilized as energy for process heat for the industry itself. Of the 223 million dry tons remaining in the forestry biomass category, one component is comprised of fuel wood, of which, only 17 million tons are not currently utilized. The only components of forestry biomass actually available from the total of 368 million tons initially identified are 47 million dry tons of urban waste, 64 million dry tons available from harvesting and land clearing residue and 60 million dry tons from fire hazard reduction operations. Therefore, of the 368 million dry tons of forestry biomass identified as available to produce liquid fuels, only about half is from actual new sources of forestry biomass. Therefore, a shortfall of approximately 15 percent in the total 1.3 billion dry tons estimated as available for production of future transportation fuel can be expected. Additional sources of biomass are required to produce a critical mass of transportation fuels now and in the future. One source of forestry biomass not adequately quantified to date is the large volume of understory biomass growing in pine plantations in the southeastern U.S. It has been demonstrated in slash bundler studies on post harvest pine plantations that bundled harvest residues are suitable for bio-oil production with only a slight increase in ash content.

The primary objective of this project is to quantify volumes of understory biomass available on plantation pine sites of various ages just prior to first and second thinnings and final harvest. Regrowth of the vegetative understory will be measured at one year intervals for two years to determine the potential for sustained yields of understory biomass as related to stand age at time of understory biomass harvest. For sustainable harvest of understory biomass, the removal for bioenergy must not decrease the long-term fertility of the timber land. To determine potential fertility decrease from understory biomass harvest, soil tests will be performed at harvest and at one-year intervals on harvest sites.
A web-based decision support system to assess optimal locations for forest products and bio-energy manufacturing facilities and the availability and sustainability of forest feedstocks

E.B. Schultz, T.G. Matney, D.L. Evans, D.L. Grebner, R.C. Parker, J. Fan

Proposed for 2008

July 1, 2008–June 30, 2010

A Web-based decision support system (DSS) to assess optimal locations for forest products and bio-energy manufacturing facilities and the availability and sustainability of forest feedstocks specifically address a national priority in energy and carbon management. Computer-based decision support systems are needed that efficiently coalesce geospatial information, forest inventory, transportation costs, and socio-economic factors allowing capital investors to rapidly assess the economic risk and sustainability of proposed manufacturing locations and capacities.

This research addresses the quantification and utilization of forest resources as it pertains to the development of the forest products manufacturing and woody biomass liquid fuel markets. The objective is to provide information and decision support tools to optimize the allocation of forest resources under various utilization scenarios by assessing the availability and sustainability of woody biomass production and the optimal location of forest products and bioenergy manufacturing facilities.

The specific objectives are to:

1. Enhance an existing Web-based forest inventory decision support system by integrating:
   a. forest products manufacturing and bio-energy production facility specifications and raw material requirements (garnered from the user)
   b. a geospatially-based forest inventory and feedstock projection system, and
   c. a transportation network and cost database into a mathematical programming optimization model. Models will provide the minimum raw material procurement cost and sustainability of feedstocks and will be presented in a Windows interface format for use by industry, policy makers, forester managers, and private landowners.

2. Characterize the impact of a woody biomass liquid fuel market on greenhouse gas emissions, carbon sequestration management, and fossil fuels displacement.
An economic analysis of the potential establishment of bio-refinery plants in Mississippi

D.L. Grebner, I.A. Munn, C. Sun

Proposed for 2008

July 1, 2008–June 30, 2010

The motivation for developing bio-ethanol as a transportation fuel is based on concerns about energy supply, national security, environmental quality, and economic development. Numerous ethanol plants are currently under construction and already operating in the nation. Although all of these plants use corn as the primary raw material, it is expected that more industries will turn their inventories into other sources of feedstock. Cellulosic ethanol has some advantages over starch-based sources and is being considered as an important feedstock to produce bio-ethanol. Woody biomass can be generated in almost every state of the country and its low value for food application opens the possibility to develop larger production scales.

In Mississippi, forests cover almost 20 million acres and annually represent over $1 billion worth of timber and related forest products. Earlier research estimated the total industry output related to the forestry and forest products industries exceeded $14.8 billion. Despite the forest richness and its economic value, no ethanol plants are commercially working in the state. Further, none of the 76 ethanol plants under construction selected Mississippi as their establishment site. These facts lead to the following questions: what would happen if, in the next years, this situation turns different and investors decide to construct or move their plants into the state? What would be the impacts of these plants on key areas such as expenditures, taxes, transportation, insurance, and employment in the state? Recognizing the lack of manufacturing plants is not new; the ability to understand impacts associated with the potential establishment of these plants is a matter of fair concern.

The main objective of this study is to investigate the potential impacts generated by recent market and policy programs oriented to increase ethanol production from woody biomass.

Specific objectives are:
1. determine the economic impacts of the potential establishment of a cellulosic ethanol manufacturing plant on other industrial sectors of the state;
2. determine the contribution of ethanol industries to the public revenues of the state, county, and local governments; and
3. determine the contributions of ethanol plants to total employment, income, value added, and value of shipments. These multipliers will be used to evaluate the incremental contribution to the state’s economy from per unit changes in the number of ethanol plants.
Publications


Cooper, J.E., P.H. Steele, B.K. Mitchell. 2006. Identifying knot wood in kiln-dried red oak and southern pine lumber with dielectric scanning. Pages 1-5 in ASNT Fall Conference and Quality Testing Show, Space for Infinite NDT Possibilities. Houston, TX.


Publications


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