Research Work Unit Description

USDA-Forest Service RESEARCH WORK UNIT DESCRIPTION Ref: FSM 4070	1. Number FS-SRS-4701	2. Station Southern Research Station
	3. Unit Location Pineville, LA 71360-2009	

4. Research Work Unit Title
UTILIZATION OF SOUTHERN FOREST RESOURCES

5. Project Leader (Name and address)
Timothy G. Rials, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360-2009

6. Area of Research Applicability	7. Estimated Duration
Southern U.S. and Tropical Areas	5 years

8. Mission
The mission of RWU-4701 is to define and describe the fundamental raw material characteristics influencing the sustainable and environmentally sound use of southern forest resources.

9. Justification and Problem Selection

A number of trends have converged in recent years that either directly or indirectly impact the pressure on the South's forests for commodity wood and fiber products. Sharply reduced harvests from federal lands in the West (and South), increased population in the South (the second fastest growing region in the Nation), and increasingly diverse expectations of forest benefits and products by our Society have strained the supply and availability of renewable forest resources. At the same time, demand for commodity products derived from forest resources has substantially increased. Currently, in the United States, the equivalent of a six foot long two-by-four piece of lumber is consumed by every person, everyday. This compares with just less than 2 feet of 2x4 lumber for the global consumption of wood per capita, highlighting the extent to which wood is woven into the fabric of our Society. This dilemma sets the stage for the current focus and discussions on sustainable development and sustainable forest management that are taking place in the natural resource arena.

It is impossible to overstate the importance of the South's forest resources in providing for the diverse product needs of the Nation. Home to about 40 percent of the Nation's productive timberlands, the South currently provides about 70 percent of its pulpwood, 40 percent of its hardwood lumber, and 33 percent of its softwood lumber. Of the Nation's production capacity of particleboard and medium-density fiberboard, the South accounts for 45 percent and 54 percent, respectively. Recent projections of nationwide timber demand suggest significant growth over the next 50 years (by 35 percent for softwoods and 80 percent for hardwoods). Much of the pressure to meet the Nation's continuing appetite for this versatile, renewable material will fall solidly on Southern forests.

(Continued on next page)

10. Approach to Problem Solution (Start at conclusion of item 9.)

Signature	Title	Date
Recommended	Assistant Director for Research	
	Assistant to Staff Director	
	Staff Director	
Approved	Station Director	
Concurred	Deputy Chief for Research	

9) JUSTIFICATION AND PROBLEM SELECTION, Continued

This challenge also presents a unique opportunity that the South is clearly able to accommodate because of two distinct characteristics: 1) unmatched productivity potential and 2) the structure of forest land ownership. Recent numbers compiled by the Forest & Wildlife Research Center at Mississippi State University for the State of Mississippi illustrate this. In terms of productivity, greater than 80 percent of commercial forest land is capable of producing over 85 cubic feet of wood volume per acre annually. Nationwide, only 23 percent of the commercial forestland offer this same level of productivity. Most of the South's forestland is privately owned.

However, to fully realize the productivity advantage, the small, non-industrial, private landowner must be actively engaged. Recent numbers, again for Mississippi, reveal that 65 percent of the State's 18.5 million acres are in the hands of small landowners and farmers. For the broader South, the latest surveys indicate that of the 124.1 billion cubic feet of live timber, nearly 67 percent belongs to small landowners while only 8.4 percent are on Forest Service land. Interestingly, the average annual removal of forest products in the South stands at 8.9 billion cubic feet with only about 4 percent of that coming from federal lands. It is clear that the South's forest resource is vitally important to the Nation, and the South is uniquely positioned to provide for the projected demand for forest products.

It is important to consider the significance of the South's forest resource to the culture and economy of the region, as well as the Nation. The Forest Industry ranks first in value of all agricultural crops in the Southern states from Louisiana to South Carolina. When compared to other industrial components of the South's economic base, the Forest Industry is again first in employment (560,000 jobs), and wages and salaries ($8.5 billion in 1985). In Mississippi, the total output of the Forest Industry was $11.4 billion with $4.9 billion in value added to the economy. Among the various sectors of the industry, solid wood products is substantially larger than pulp and paper or furniture (representing about 45 percent of the total output), and it is expected to remain the predominant sector despite growth in the pulp and paper industry. By providing assistance to this industry with new information and insights on the complex concerns surrounding resource utilization, the Southern Research Station assumes an important role in maintaining and advancing the quality of life in the South, the Nation, and the World.

For this vital southern industry to survive and prosper in light of increased demand and pressure on its resource base, issues of sustainability must take center stage. In contrast to days past where the term was primarily used to convey that the amount of timber grown exceeded the amount of timber harvested, the definition of sustainability has expanded to consider much more than commodity products. The capacity to provide habitat for songbirds, to support a viable wildlife population, and to provide clean water are all recognized as vital indicators of ecosystem sustainability. The broadened concept of sustainability, the intense competition for the many uses and benefits of the South's forests, and new questions of environmental consequences have emphasized the need for continued progress in the conservation of wood. Advances in technology and in wood and fiber science are critical if we are to move toward long-term sustainability.

The interest in conservation is at the core of forest utilization research, which has traditionally addressed matters concerned with the efficient and effective use of wood. Dramatic advances in utilization efficiency of the South's diverse forest resource have been made over the years where fully 99 percent of harvested biomass is used in some way, virtually eliminating residues. Opportunities for further improvement remain, however, through the development of new, high-value uses for low-quality hardwoods, and recycled wood and paper fiber. Perhaps the greatest need for research lies in the complex questions surrounding effective and environmentally sound use of the raw material.

As noted earlier, the range of raw material properties has widened over the years and is likely to increase even more. At the same time, an array of composite wood products has been developed suggesting that new opportunities are available for more effective use of the raw material base. It is likely that improved criteria for the selection of raw material with appropriate characteristics for a particular process or composite system will: 1) reduce manufacturing residue, 2) reduce energy costs, 3) minimize unnecessary adverse environmental impacts, and 4) increase the value of the resource base. The key to progress in effective utilization, as well as continued advances in utilization efficiency, is the availability of fundamental information about forest resources as raw materials. In responding to this need, the Unit's primary function is to define and describe the fundamental raw material characteristics influencing the sustainable and environmentally sound use of southern forest resources.

The first major research area for the Unit addresses the structure and significance of a widely overlooked category of natural products. Variations in the amount and composition of secondary plant metabolites (compounds other than cellulose or lignin) account for most of the chemical differences between plants. Many of these compounds are notable for their biological activity. They influence processes in natural forest ecosystems, are important in terms of environmental impacts associated with the manufacture and use of forest resources, and have good commercial potential as a renewable source of high-value specialty chemicals. Plant polyphenols, such as tannins, constitute the second (after lignin) most abundant renewable source of phenolic compounds on Earth. The terpenes, such as turpentine and rosin, are especially important constituents of the Southern pines.

Many thousands of secondary plant metabolites have been described. Compounds of novel structure and properties continue to be found in plants at an exponentially increasing rate. Nevertheless, many natural products chemists are now turning their attention away from a narrow focus on structure elucidation toward more understanding of the properties of these compounds. Despite substantial efforts, <u>a gap in our understanding of the fundamental physical properties that are central to the biological/ecological significance of plant polyphenols or terpenes limits their usefulness</u> (Problem 1). If we are to understand the environmental impacts of plant polyphenols on soil or water quality, or to expand their use as renewable sources of high-value chemicals, we need to learn more about their properties as anti-oxidants and their complexes with proteins or metal ions. If we are to understand the role of plant terpenes in forest ecosystems, successfully mitigate the impact of volatile terpenes on air quality, or expand the use of this potentially valuable renewable resource; we need to learn more about the reactions of the terpenes and the properties of their products.

Sustainability is reliant on the complete utilization of the resource base, including low-quality species and recycled wood and paper fiber. Composite technology promises the greatest potential for these utilization challenges, while offering the best opportunity for effective utilization of the resource base. Breaking down wood into its constituent fiber elements is not exceedingly difficult. The challenge lies in reassembling the elements (regardless of geometry or configuration) to meet desired end-use specifications. The manner in which these elements are reassembled dictates the strength and stiffness, the dimensional stability, and the long-term durability of the end product. This is true because the performance characteristics of any composite depend on the properties of the isolated components and the nature of the interaction between them. Therefore, our Unit's second objective is to study fundamental principles of engineering mechanics, adhesion and adhesives, and the physical chemistry of interfaces needed to optimize properties of wood/polymer composites. This approach is important to: a) assist in the development of new, high-value materials from low-quality woods; b) optimize the properties of materials made from recycled paper and plastics; c) find new ways to use solid wood residue in composite materials.

Knowledge of the physical and mechanical properties of the constituent elements is a prerequisite to determining composite product performance. There exists a large database of properties for common wood species. However, the current wood supply is vastly different from this database due to changing forest management practices. In addition, there is little fundamental information available on physical and mechanical properties of individual wood fibers, and the effect of recycling on the size, shape and mechanical property distributions of fibers. Substantial progress has been made in our laboratory in establishing experimental methods to characterize engineering properties of wood fiber and to study surface structure. This opens new avenues to study the formation of various fiber composites, where <u>there is a need to improve composite properties by evaluating the physical and mechanical properties of primary wood constituents</u> (Problem 2).

Information on the mechanisms of property development is important to the advancement of existing composite technologies like medium-density fiberboard. The development of new material systems to accommodate emerging resources is also an important concern. One composite material of interest results from the combination of wood with thermoplastic polymers. Although this work was originally motivated by the potential reinforcement of plastics with renewable wood fiber (still of great interest), the versatility of thermoplastic polymer/wood combinations has since been demonstrated using a number of processing methods and particle configurations. In fact, considerable progress has been made toward commercialization of several wood/thermoplastic composite materials.

This first generation wood/thermoplastic polymer composite comes mainly as a result of the improved understanding of relationships between processing variables and composite structure. Still, restrictions to non-load bearing applications remain because of continued problems associated with adhesive interactions between the dissimilar materials. In contrast to the thermosetting polymers that have traditionally been used for bonding wood, thermoplastics are large molecules with limited chemical reactivity. This means that conventional adhesion mechanisms like mechanical attachment and covalent bonding are not readily available, and alternative approaches to adhesion must be considered. As such, new composite material development is limited by an inadequate understanding of interfacial structure and properties (Problem 3).

As the concern about ecosystem sustainability and the demand for conservation of natural forest resources increases, the raw material base for the forest products industry shifts to short rotation, intensively managed, plantation forests. The renewable faster-grown plantation forest materials are viewed by many as being key to sustainable and environmentally acceptable production of many manufactured items. Pine plantations comprise one-third of the South's timber resources (Cubbage, 1989) and are projected to yield 50 percent of the total harvest volume by the year 2000 (USDA Forest Service). Additionally, greater attention is being given to the production of hardwood fiber under a short-rotation woody crop regime — an intensive “agricultural” approach designed to harvest in less than ten years. The primary focus of intensive management practices has been toward supplying the specialty fiber needs of the pulp and paper industry; however, in light of the tightening fiber supply and progress in composite engineering, this resource may also prove valuable for solid wood and fiber composites.

The interest in short-rotation production technologies has arisen in part as a response to the Public's concerns over environmental quality. Similar concerns have emphasized the need to consider product life-cycle and to recycle wood and paper waste to minimize their impact on landfills. To the forest products industry's credit, dramatic progress has been made toward reducing and re-using waste materials; however, certain portions of the wood product stream present unique challenges that require innovative approaches to extend their life-cycle. A surprising amount of southern pine is treated with preserving chemicals including creosote and CCA. The hazardous nature of these chemicals and the lack of biodegradability of the wood products has limited disposal alternatives, and has created a vast inventory of material with no perceivable value or use. In light of these issues, effective utilization of wood from difficult-to-recycle and intensively managed sources into high performance composite products needs to be improved (Problem 4).

Considerable progress has been made (and further advances are undoubtedly forthcoming) in relating raw material properties to the performance characteristics of their final composite material. This type of information offers tremendous possibilities to more effectively utilize the forest resource of the South; however, implementation has been problematic because the analytical tools required to provide pertinent information on the raw material in a timely manner were not available. Currently, forest inventories provide information on species composition, volume, and a subjective indication of tree quality. No information on chemical composition is recorded. Tree improvement efforts over the years have relied on increased volume growth. No consideration has been given to specific gravity or microfibril angle of the wood. Forest health monitoring focuses on crown dieback and species diversity. The type and amount of primary and secondary metabolites are not measured. Access to more detailed information is important for forest managers, plant managers, and process engineers to make informed decisions related to effective use of the wood resource. Also, many useful and quantitative criteria of ecosystem sustainability, silvicultural treatment effects, and forest health may be reflected in the composition and properties of the forests' primary output — wood. As such, optimal utilization of the forest resource is not possible because the relationships between tree growth variables, fundamental wood properties, and end-product performance are not sufficiently understood (Problem 5).

For years, the influence of microscopic features, like pits, on the properties of wood fibers have been recognized. However, the physical, mechanical, and chemical characteristics of wood are ultimately determined (in large part) by its most basic building blocks: cellulose, hemicellulose, and lignin. Spectral data, which provides information on chemical structure, can be related to physical and mechanical properties of wood. Recent results from laboratories around the world have clearly demonstrated the capability of spectral information (from near- and mid-infrared, and nuclear magnetic resonance), when combined with statistical methods like multivariate analysis, to provide accurate information on chemical composition and pulping behavior. In conjunction with our partners, we have demonstrated a similar capability for the prediction of wood's mechanical properties. This is particularly exciting given that this information can be generated in real time. It also raises a number of research questions, warranting the establishment of a new problem area.

The efficient and effective utilization of the South's forests is a vital component in fulfilling the concept of sustainability. In the South where the small, non-industrial, private landowner plays such a critical role, resource valuation is an extremely important consideration. Consequently, value-added utilization alternatives and the availability of information on relevant resource characteristics are important objectives for research. Our Research Unit will contribute to this goal by providing fundamental information on the characteristics of the resource, the properties of the raw materials, and their contribution to the performance of various composite materials.

10. APPROACH TO PROBLEM SOLUTION

Problem 1 — A gap in our understanding of the fundamental physical properties that are central to the biological/ecological significance of plant polyphenols or terpenes limits their usefulness.

The theme of this research effort is to define fundamental physical properties that are important in determining the biological or ecological significance of secondary plant metabolites. By taking a fundamental approach, the same experiment can provide information important to understanding the significance of these properties in the forest ecosystems, the environmental impacts of these compounds associated with processing of forest resources, and the potential for use of these compounds as high value specialty chemicals. Work will continue to concentrate on plant polyflavanoids. The work we will do in the area of plant terpenes and VOCs will depend on the level of outside funding we can obtain.

Component 1: Polyflavanoids

The polyflavanoids make up over 30 percent of the weight of most tree barks, are found in even higher proportions in some nutshells and are important components of tree leaves. RWU-4701 has been studying these compounds since 1972 and has built a knowledge base on the structure, reactions, and properties of polyflavanoids that has been important to a number of different approaches to use these compounds. Current work centers on the nature of their complexes with proteins. The interaction of plant polyphenols with other biopolymers such as proteins accounts for much of their ability to inhibit enzymes and anti–microbial activity in addition to representing their dominant commercial use in leather manufacture. We have exploited NMR and molecular modeling experiments which we will continue to build on in this planning period. Plant polyphenols are noted for their ability to complex with heavy metal ions. Recent advances in both Nuclear Magnetic Resonance (NMR) and Mass Spectrometry (MS) offer new experimental approaches to study polyflavanoid/metal complexes. We propose to expand our work into this area to better understand the significance of tannins to soil and water quality as well as to exploit these properties in specialty chemical applications. Another important property of polyflavanoids centers on anti-oxidant properties credited for their demonstrated effects in reducing cancer and heart disease in animals including humans. If we can learn to manipulate properties such as thermal stability, these compounds could have potential as industrial anti-oxidants as well. Therefore, through this planning period, our research on the polyflavanoids will be directed to their anti-oxidant properties as well as their complexes with proteins and metal ions.

Expected Accomplishments:

1. Expand on studies of selectivity in the association of flavonoid compounds with oligopeptides theoretically by various computational chemistry approaches and experimentally by NMR.

2. Begin new studies on the formation, structure, and properties of flavonoid-metal ion complexes.

3. Begin new studies on the anti-oxidant properties of flavonoid compounds with special emphasis on potential industrial applications.

Anticipated Outcomes:

Through these accomplishments, we expect to see that renewable plant polyphenols will increasingly serve as a basis for development of pharmaceutical and industrial specialty chemical products.

Component 2: Terpenes

Although the chemistry of terpenes in Southern pines has been studied for many years, there is still a lot to learn about these compounds. They are the primary Volatile Organic Compounds (VOC's) associated with wood products manufactured in the South. Increasingly stringent EPA restrictions on air emissions impact most aspects of the manufacture and use of wood products. Over the past planning period we have begun studies of the oxidation in monoterpenes under wood drying conditions, and examined the contributions of terpenes in knots to the VOC's associated with lumber drying. Through that research, we have made a start on building an MS and NMR spectral database that is becoming useful in establishing the structure of these compounds. The work we plan to do in this terpene component will depend on what external support we can obtain. We will attempt to obtain support for work that will expand on our understanding of the thermal/oxidation reactions of the terpenes in southern pines and attempt to define material balances of the amount and composition of volatile terpenes that enter and exit important elements of wood processing steps. Our research in this planning period, will continue to focus on the fundamental chemistry of terpenes related to VOC's associated with processing of Southern pines. We will continue to study their volatilization and oxidation under conditions comparable to a wide range of wood processing conditions. The forest products industry has struggled to develop accurate material balance data so as to really know how much of what compounds are emitted to air streams to comply with EPA regulations. Therefore, we will also examine what compounds enter and exit important elements of wood processing steps so as to provide more understanding of VOC emissions associated with lumber and composite wood products manufacture. An important element of this work is to define the structures of important oxidation products so that their biological and commercial significance might be assessed.

Expected Accomplishments:

1. Continue to define thermal/oxidation reactions of volatile terpenes in Southern pines under conditions similar to wood processing operations.

2. Continue to build on GC-MS and NMR databases for volatile organic compounds of significance to the forest products industry.

3. Explore the chiral selectivity of monoterpenes in Southern pines.

Anticipated Outcomes:

Through these accomplishments, we expect to see further reductions in the environmental impacts of wood industry processes on air quality.

Problem 2 — There is a need to improve composite properties by evaluating the physical and mechanical properties of primary wood constituents.

Research will focus on property assessment and material characterization as they relate to the structural performance of wood-based composites and can be subdivided into the following components:

Component 1: Constituent property assessment

The primary factors governing the stiffness and strength of wood-based composites are the properties of their corresponding components. This holds true for all composites regardless of component size. Material properties for large components (e.g. lumber and veneer) are well documented and there currently exist large databases for these components. There is, however, limited information for smaller components (e.g. microfibrils, fibers, and fiber bundles), which precludes the ability to model the performance of certain types of composites. We have made significant contributions to the knowledge of fiber properties and failure mechanisms since the previous RWUD, but there is much more to be done. Constant advances in technology allow us to design testing equipment that can sample more rapidly, with greater accuracy, and more precision.

Expected Accomplishments:

1. Develop a next-generation tensile testing machine for determination of individual fiber mechanical properties.

2. Develop techniques and collect data regarding secondary fiber mechanical properties such as collapse and transverse stiffness/strength.

Anticipated Outcomes:

Through these accomplishments, fundamental information on wood fiber properties will be made available that is required to understand and model wood composite properties.

Component 2: Surface morphology

The manner in which stresses are transferred from component to component in any discontinuous system is one of the primary factors governing the mechanical properties of a composite. Previous attempts to characterize fiber/fiber stress transfer have been tenuous at best. We will approach stress transfer not by looking at minute fiber/fiber specimens but by characterizing and quantifying the surface of individual fibers and the influence of these variables, in conjunction with fiber mechanical properties and orientation, on the structural performance of fiber-based composites. Characterization of surface morphology and various surface variables will be accomplished with the aid of an on-site atomic force microscope (AFM). In addition to characterizing the surface roughness of individual fibers, the AFM will also be used to study the effect of fiber generation methods and for the fundamental characterization of wood fibers at extremely high magnifications.

Expected Accomplishments:

1. Quantify the surface roughness and morphology of individual wood fibers and the influence these variables have on the properties of wood fiber-based composites.

2. Conduct fundamental studies as to the morphology of individual wood fibers with the AFM, with emphasis on individual microfibril and cellulose crystallite morphology.

Anticipated Outcomes:

Through these accomplishments, wood fiber generation methods will be identified that optimize fiber-fiber bonding capacity to maximize fiber efficiency in composite materials.

Component 3: Composite mechanics

The ability to engineer a structural composite from wood is a function of our knowledge of the component properties and their distribution and orientation within the composite. The engineer can, with some degree of certainty, predict the performance of glue-laminated beams and laminated veneer lumber because a great deal of information exists as to the respective mechanical response of lumber and veneer to stresses and strains. The orientation and three-dimensional distribution in space of these large components can also be controlled with relatively little effort. The ability to engineer wood composites is inversely related to component size, with fiberboard being the most difficult structural composite to engineer. Not only do we not know much about the mechanical properties of individual wood fibers, but also we do not fully understand the relationship between component and composite properties. In addition, we do not know the effect the fiber-generation process on fiber properties and the effect of pressing conditions and variables on the 3-dimensional microstructure of fiber-based composites. This discovery will allow us to understand the mechanics of fiber-based composites and the genesis of composite stiffness and strength.

Expected Accomplishments:

1. Establish analytical and empirical models relating the physical and mechanical properties of wood fibers and the structural performance of fiberboard.

2. Establish relationships between juvenility of fibers and their effect on the mechanical properties of fibers and composites.

3. Study three-dimensional fiber movement and fiber collapse in structural fiberboard using microtomography.

Anticipated Outcomes:

Through these accomplishments, numerical models will be generated to evaluate fiber composites with increased structural performance and improved raw material efficiency.

Problem 3 — New composite material development is limited by an inadequate understanding of interfacial structure and properties.

Wood composites, in their many forms, will play an increasingly important role in providing for the sustainable production of affordable building materials from Southern forest resources. As noted earlier, composite performance is determined primarily by the properties of the wood particles, the polymer binder, and the interfacial region that is established between the two distinct phases. The interphase can actually dominate strength properties since it determines stress transfer efficiency between the individual components. Very little information is actually available on the structure-property relationships of this important component of wood composites. This problem area will study the relationship between wood surface properties and interfacial characteristics, and is structured into two components addressing thermosetting and thermoplastic polymer systems.

Component 1: Thermoplastic composites

Recent progress in wood fiber/thermoplastic composite materials has been enabled primarily through advances in process technologies, including compounding equipment and chemical aids, to improve compatibility and dispersion of the wood particles in polyolefins. Limitations in adhesive bond strength between these dissimilar components continue to result in undesirable creep behavior that restricts the composite to non-structural applications. This should come as no surprise since virtually every adhesion mechanism exploited in conventional thermosetting composites is effectively excluded by the current processes under investigation for wood/thermoplastic polymer material manufacturing. The high molecular weight and limited reactivity of thermoplastics restrict the ability to develop mechanical attachments and covalent bonds with the fiber wall polymers. Also, the absence of moisture to plasticize the fiber polymers further reduces the likelihood of interfacial interaction through mechanical means. This element of the problem will focus on studying the contribution of block copolymers to the development of interphase structure and properties, with particular emphasis given to defining the critical chain length needed for effective entanglement.

Expected Accomplishments:

1. Determine the relationship between chain architecture and interfacial structure and properties for styrene-acrylic acid compatibilizers.

2. Investigate the influence of wood fiber on the phase morphology of polymer blends and the development of interphase structure.

3. Continue to develop experimental methods to evaluate interphase structure and properties, including atomic force microscopy techniques.

Anticipated Outcomes:

Through these accomplishments, we expect improved performance from wood-polymer composites that will expand their application while utilizing the lower quality fiber resource.

Component 2: Thermosetting composites

Traditional panel composites will continue to rely on thermosetting resins like phenol-formaldehyde, urea-formaldehyde, and polyisocyanates as binders. High moisture bonding and diverse wood characteristics will continue to challenge the performance requirements of thermosetting adhesives, and will require greater versatility be engineered into these materials. To successfully accomplish this, new insight into panel consolidation and the resin cure process is important. Research over this last reporting period has demonstrated the power of microdielectric analysis as a tool to monitor adhesive cure under actual production conditions. This technique will be combined with spectroscopic methods to develop a comprehensive view of the panel formation process. The information will help to increase process efficiency, improve composite properties, and reduce the variability in end product performance.

Expected Accomplishments:

1. Investigate the cure behavior, morphology, and properties of polymer modified phenol- and urea-formaldehyde.

2. Study the rheological processes involved in bonding high moisture substrates using microdielectric analysis and spectral techniques.

Anticipated Outcomes:

Through these accomplishments, we expect improvements in adhesive bonding efficiency and reductions in energy requirements for composite panel manufacturing.

Problem 4 –– Effective utilization of wood from difficult-to-recycle and intensively managed sources into high performance composite products needs to be improved.

Recently available raw materials present nearly as many technological and technical challenges as opportunities. For example, the increased volume of juvenile wood resulting from intensively managed production schemes is a concern. Also, increased recovery of preservative treated wood has created a huge challenge since this material cannot be landfilled, and cannot be readily incorporated into existing processes. The problem area is structured into two elements based on the origin of the raw material.

Component 1: Intensively managed raw material

In order to plan new investment and to assess stand management practice, industry urgently needs information ranging from the effects of silvicultural regimes on volume production and wood quality through to the properties of end products produced. Knowledge on the effects of raw material and process variables on product properties will enhance complete tree utilization from plantations, and provide data needed for the successful conversion of this resource into valuable products. The development and application of material science principals can lead to the invention of high-performance composite wood products in which properties can be engineered using well-defined design principles. This research will support the development of intensively-cultured production approaches for wood by investigating this material's performance in existing process technologies and composite systems.

Expected Accomplishments:

1. Determine the raw material properties and end product performance of improved growing stock produced under intensive management regimes.

2. Develop new technology to accommodate plantation-grown wood and short rotation woody crops in solid wood composites.

Anticipated Outcomes:

Through these accomplishments, we expect to expand the utilization potential of high juvenile content woods into high performance composites.

Component 2: Value-added wood products from recycled materials

Recycling of wood and plastic from the solid waste stream into composite products is one attractive option for extending the wood resource and improving the environment. Early experiments investigating the effect of resin variables and plastic components on the properties and performances of wood particle/plastic panel products have generated encouraging results and provided a clear direction for study. In addition to emphasizing adhesion limitations, the project also suggested that dimensional stability and thermal expansion of the fiber may significantly impact composite formation and properties. We will investigate ways to circumvent these limitations while evaluating alternative processing schemes, like a multi-layer sheet assembly technique.

Expected Accomplishments:

1. Improve dimensional stability of wood and recycled paper fiber by ester crosslinking with multifunctional, polycarboxylic acids and anhydrides.

2. Evaluate the influence of polymer melt flow behavior on composite formation and uniformity.

While preservative-treatment (CCA and creosote) of wood products significantly prolongs their service life and extends the forest resource, waste disposal is a major concern. Recovery and recycling is an important alternative, and is considered to be a highly desirable phase in the life-cycle management of treated wood. The most viable recycling option for treated wood is composite manufacturing. The long-range goal for this research component is to develop an environmentally friendly recycling process involving the manufacture of composite products from this waste stream that incorporates a closed loop recycling system to achieve zero discharge of hazardous waste.

Expected Accomplishments:

3. Determine the effects of the raw material properties on adhesive compatibility and long term performance of composite products.

4. Investigate conditions required for liquefaction of treated wood residue, and the properties of the resulting polymeric resin.

Anticipated Outcomes:

Through these accomplishments, we expect to identify and develop new product alternatives for waste wood and fiber that currently represent a disposal challenge.

Problem 5 — Optimal utilization of the forest resource is not possible because the relationships between tree growth variables, fundamental wood properties, and end-product performance are not sufficiently understood.

Advances in silviculture and biotechnology have provided the necessary foundation to drive the idea of a resource tailored to specific end-use requirements from concept to reality. Exploiting this unique opportunity requires that two distinct information gaps be addressed. First, the characteristics of wood that define performance in a particular product – be it paper, lumber, oriented strandboard, or a yet-to-be-developed composite – need to be better quantified. Second, to control these important characteristics during wood formation, the influence of growth conditions and genetic factors on the fundamental chemical and physical properties of the wood must be established. Progress in filling these two knowledge gaps depends upon the availability, and accessibility, of wood property information. This research area will focus on the development and use of rapid assessment methods to study wood characteristic/product property relationships at the molecular level. The approach will provide basic information on wood characteristics that is broadly applicable to issues surrounding forest inventory and monitoring, ecosystem sustainability, and the efficient use of wood and wood fiber.

Little research has attempted to establish linkages between tree growth history and utilization opportunities. Chemometrics has emerged as a powerful scientific discipline for analyzing such complex systems. Multivariate statistical methods are used to uncover relationships that may be hidden in the large databases created by spectroscopic and chromatographic analysis of materials. The power and flexibility of chemometrics has been demonstrated on research problems from drug discovery to polymer synthesis to wine quality. In importing this analytical methodology to address questions surrounding forest resources, a dual experimental approach will be used to simultaneously facilitate implementation and to foster discovery. We will emphasize near-infrared (NIR) spectroscopy for the rapid assessment of wood in terms of fundamental physical and chemical properties that are currently recognized as relevant to process performance and product properties. The acquisition speed, ruggedness, and portability of NIR makes it an attractive candidate as a remote sensor for field inventories and process monitoring. The Southern Research Station houses a wealth of information on silviculture, genetic, and climate impacts on tree growth from existing long-term studies, offering a powerful database for this work to draw upon. In concert with this effort, experiments will study specific questions surrounding tree growth and wood structure/property relationships that are important in defining product performance. This project element will extend the chemometric methods to data generated from other analytical instruments that measure chemical and morphological features (*mid-IR, Raman, NMR, etc.*) in an effort to define the origins of the observed relationships.

Expected Accomplishments:

1. Establish sampling procedures to provide reproducible spectra from an automated analysis of increment core samples using a reflectance microbeam infrared technique.

2. Generate a spectral (near and mid-infrared) database of southern pine wood/fiber produced from different genetic sources and through various silvicultural regimes.

3. Identify relationships between spectral data and the chemical/physical properties of solid wood, wood strands, and wood fibers, and develop predictive models.

4. Investigate the contribution of specific chemical functionality and cell wall morphology to the mechanical properties of solid wood and wood-based composites.

Anticipated Outcomes:

Through these accomplishments, we expect to build the foundation of an expert system for the rapid, quantitative characterization of wood and its constituents.

Environmental Consideration: The work planned is categorically excluded from documentation of environmental analysis (FSM-1950).

Table I. Cooperation of RWU 4701 with other institutions.

PROBLEM NO.	*COOPERATION WITH*	*DESCRIPTION*
1.-C.1	Pacific Lutheran University (Tobiason)	Molecular modeling
	Louisiana College (McGraw)	Anti-oxidants, metal ion complexes
	Miami University Ohio (Hagerman)	Protein Complexation
	Mississippi State University (Nicolas)	Anti-oxidants, metal ion complexes
	Pacific Forestry Center (Preston)	Solid state NMR
1.-C.2	Louisiana College (McGraw)	Terpene structure
2.-C.1	BioComposites Centre (Mott)	Fiber property analysis
	University of Maine (Shaler)	Fiber property analysis
	SRS-4106 James Baker	Silvicultural effects
	SRS-4802 Jim Granskog	Economics of wood quality
	SRS-4101 Clark Baldwin	Wood quality
	National Renewable Energy Lab (Meglen, Kelley)	Rapid property assessment
2.-C.2	University of Southwestern Louisiana (Pesacreta)	Fiber surface morphology
	University of Maine (Goodell)	Wood fiber decay
2.-C.3	Biocomposites Centre (Mott)	Composite organization
	University of Maine (Shaler)	
3.-C.1	Michigan Tech University (Caneba)	Copolymer synthesis
	University of Maine (Gardner)	Surface energetics
	Washington State University (Wolcott)	Interfacial strength properties
	Oregon State University (Simonsen)	Interfacial interactions
	Louisiana State University (Collier)	Process rheology
	FPL RWU-4706 (Youngquist)	Process technology
	FPL RWU-4707 (Tchabalala)	Surface structure
3.-C.2	Washington State University (Wolcott)	Dielectric analysis
	Virginia Tech University (Frazier)	Interphase structure by NMR
	FPL RWU-4703 (Conner)	Adhesive cure
	Nat'l Renewable Energy Lab (Kelley)	Interface structure/property
4.-C.1	Louisiana State University (Choong)	Intersively managed raw material
	Auburn University (Tang)	Creep of wood composite
	Chinese Academy of Forestry (Fu)	LVL from short rotation woody crop
	Northeast Forestry University, China (Fang)	Recycled fiber
4.-C.2	Kyoto University, Japan (Shiraishi)	Liquefaction of wood
	Kyushu University, Japan (Higuchi)	Co-reacted soy/phenolic
5	Nat'l Renewable Energy Lab (Meglen, Kelley)	Chemometric methods
	Forestry Research Institute (Sorrenson)	Wood property relationships
	SRS RWU-4111 (Barnett)	Growth/property interactions
	BioComposites Centre (Mott)	Process monitoring

Table 2. RWU scientist years in each problem area over the five year planning period.

PROBLEM NO.	RWUD YEAR				
	1	2	3	4	5
1.-C.1	0.7	0.7	0.8	0.8	1.0
1.-C.2	0.3	0.3	0.2	0.2	
2.-C.1	0.4	0.4	0.4	0.3	0.3
2.-C.2	0.3	0.3	0.3	0.3	0.3
2.-C.3	0.3	0.3	0.3	0.4	0.4
3.-C.1	0.7	0.7	0.8	0.8	0.8
3.-C.2	0.3	0.3	0.2	0.2	0.2
4.-C.1	0.5	0.5	0.5	0.7	0.7
4.-C.2	0.5	0.5	0.5	0.3	0.3
5		0.2	1.0	1.0	1.0
TOTAL	4.0	4.2	5.0	5.0	5.0

Table 3. RWU budget allocation in each problem area of the five year planning period.

PROBLEM NO.	RWUD YEAR				
	1	2	3	4	5
1.-C.1	$175K	175	175	200	250
1.-C.2	100	100	75	50	0
2.-C.1	100	100	75	75	75
2.-C.2	100	100	100	75	75
2.-C.3	100	100	100	100	100
3.-C.1	175	175	150	150	150
3.-C.2	100	100	100	100	100
4.-C.1	125	125	125	125	125
4.-C.2	125	125	100	125	125
5		50	250	250	250
TOTAL	1,100	1,150	1,250	1,250	1,250