Wood products research in the USA

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Forest biomass conversion to biofuels and other value-added co-products; hyper-performance advanced composites custom tailored to end use requirements; advanced high performance wood-based structures; and nanomaterials and nano-enable high performance products from wood represent important research and development investment areas for the successful transformation of the forest products industry into a reinvented and reinvigorated growth industry in the 21st Century. Research and development investments in the preceding areas will help make wood the sustainable, renewable, and recyclable material of choice in the 21st Century.

Introduction

The United States (US) has been the world's largest producer of wood-based products and ranks third of all countries in volume of standing forest biomass. As a result, forest products are an important part of the US economy accounting for about 6.2% of the total US manufacturing Gross Domestic Product (GDP). Forest products contribute over $240 billion to GDP and account for approximately 1.1 million American jobs. The US Department of Agriculture Forest Service (USDA- FS) Forest Products Laboratory (FPL) – cooperating with industry, universities, and others – has been instrumental in advancing the U.S. forest products industry over the past 100 years. Current FPL research areas include the following:

- Developing new technologies for converting forest biomass for energy
- Sustainable chemical feedstock from wood
- Life-cycle analysis assessments of wood products

- Integrated building components for structures
- Engineering and construction standards
- Improving the performance of wood in use
- Environmentally acceptable wood preservatives
- High-performance composites and related adhesives technology
- Environmentally preferable pulping processes
- Economic utilization options for small-diameter timber
- Reduced environmental impacts at conversion facilities
- Improved efficiencies in hardwood processing
- Evaluation of the economic feasibility of new technologies and markets
- Nanoscience and technology of wood-based materials.

While the US forest products industry has had success in the past, its success in the 21st century is not assured as there are significant drivers of change affecting the Wood Products Industry sector world-wide. Drivers of change include:

- Integration of the World economy and subsequent escalation of industrial quality and cost competitiveness
- Growing population, affluence and changing demographics
- Accelerating pace of science and technology
- Mitigating the impacts of climate change through reduced use of fossil fuels
- Quests for individual nations to achieve energy security using biofuels
- Reducing the environmental footprint of human activities
- Reducing the carbon footprint of products and manufacturing processes
- Increasing efficiency of energy and materials use
- Emergence of the concepts of Sustainability, Green Buildings, Green chemistry, and Green Engineering and making life cycle comparisons among competing products and materials via use of life cycle assessment.

While the US forest products industry has become somewhat less fragmented through consolidation of companies through mergers, acquisitions, and shutdowns and closures of older and less efficient production lines, forest products companies generally have limited resources for research and development (R&D) and are increasingly dependent on government and government-sponsored entities for research. Because companies – whether large, medium or small – are facing increasing competitive market pressures, research is even more important to maintaining the positive economic, social and ecological contributions of businesses and production facilities. Universities and government laboratories such as FPL play a critically important role in conducting innovative research. FPL research priorities are advanced structures, advanced composites, nanotechnology, and forest biomass to biofuels and value-added co-products.

Advanced structures

As we move further into the 21st century, the demands and complexity of structures are ever increasing. In the past, structures were designed based solely on life safety issues. That is no longer the case. Today, structures are designed considering life safety along with functionality, environmental impact (e.g. Green building, energy efficiency, etc.) and economics. As a result, structural wood design is moving toward a performance-based design methodology that encompasses the entire life cycle of a structural system. Performance-based design procedures rely upon data that must have a strong scientific foundation. Technical data on the interactions between various exposure scenarios (e.g. mechanical loads, biological agents of deterioration, moisture exposure, fire performance, etc.) form the basis for performance-based wood design. Performance-based design will initially have its greatest impact on nonresidential wood structures where owner-users can realize its long-term benefits. Innovations and knowledge from development of a performance-based design approach also provides the framework for evaluating and minimizing the environmental footprint of wood-based structures.

Adoption of performance-based engineering concepts represents a major change in the thinking, practice, and education of designers. Perhaps most important is a shift away from dependence on empirical and experience-based conventions towards a design and assessment process more firmly rooted in realistic prediction of structural behavior under a spectrum of loading environments that the structure will experience. This requires a shift towards a more scientifically oriented approach with an emphasis on accurate characterization and prediction of structural performance. A second but equally important change in this approach is an emphasis on health monitoring of the structural system, which evaluates performance characteristics and identifies the need for renovation or new construction. These also form the foundation of strategies for revitalizing decaying infrastructure. A performance-based approach provides the appropriate framework for integration of sensing, monitoring, and control systems to monitor and maintain the health of structures. As a result of this, FPL structural research programs are in the general areas of: 1) structural systems, structural analysis and modeling; 2) durability and resistance to natural disasters (e.g. floods, hurricanes, tornadoes, earthquakes, etc.) to include performance and modeling; and 3) health monitoring (e.g. remote monitoring systems that utilize sensors to indicate degradation of wood structure).

Advanced composites

The next generation of advanced wood and biocomposites must both meet the diverse needs of users for high-performance construction and specialty products while simultaneously promoting sustainability of forest and other natural resources. Advanced engineered wood and biocomposites must also provide advanced performance, durability, value, service-life, and utility. Next generation advanced composites must provide construction materials and building products that far exceed current expectations (e.g., lower cost, more adaptable, more reliable, lower maintenance, smarter, etc.) while opening new markets (e.g., commercial construction, automotive, aerospace, etc.) and reducing effects on the environment (e.g., energy, air, water, and waste). FPL research program activities are focused on hyper performance advanced engineered wood and biocomposites that:

- Combine wood, and natural biofibers, and non-biomaterials to create synergistic hybrid materials that far exceed the performance capabilities of current biocomposites
- Are renewable, recyclable, and totally sustainable
- Provide hyper-performance and superior serviceability that again far exceeds the performance capabilities of current biocomposites
- Are more durable, dimensionally stable, moisture-proof, and fire-resistant

- Possess integrated hyper-performance capabilities such as warning users when problems are imminent and/or possess multifunctional capabilities
- Have both materials and processes engineered to customize and optimize performance
- Are sustainably produced, be environmentally beneficial and be less expensive to produce and use (over the life cycle of use) than materials they replace.

Nanotechnology

Nanotechnology has enormous promise to bring about fundamental changes and significant benefit to the forest products industry. By becoming a user of nanotechnology materials and components in its products and processes, industry can upgrade its processes and produce new high performance consumer products from lignocellulosic-based materials in a safe and sustainable manner. The industry also can become a producer and developer of novel, sustainable nanomaterials to replace non-sustainable materials such as those from fossil-fuels. Use of nano-dimensional cellulose in nanocomposites will allow the production of much lighter weight materials to replace metals and plastics with widespread application to the forest products and other industries. Investments in nanotechnology for the forest products industry sector will have substantive, measurable, and pervasive beneficial effects for society such as increased Gross Domestic Product (GDP), increased employment, and creation of high paying, skilled jobs. It will also usher in cost effective and affordable production of sustainable materials and products close to markets where they are used thus greatly reducing transportation costs and energy consumption producing and transporting materials great distances as is the practice now. It will also greatly reduce the waste of materials and energy due to unnecessary over-construction of products and structures arising from our current lack of knowledge of nanoscale structures and interfaces. In the US, a nanotechnology-revitalized forest products industry will also enhance forest health and condition; retard the current accelerating trends of forest fragmentation, parcelization, clearing, and conversion of forest lands to non-forest uses; increase recharge of water to aquifers as 90 per cent of the precipitation that falls on a forest is retained; and provide the full array of other forest ecosystem services to include animal habitat, clean water, clean air, carbon sequestration, recreation, etc.

Nanotechnology is the scientific study and applications of materials that have at least one dimension smaller than 100 nm. The wood cell wall is composed of 3 to 10 nanometer elementary nanofibrils and how they assemble into the cell wall and how they associate with the hemicellulose and lignin in the cell wall are all nanoscale architectural concerns. The crystalline cellulose in wood can be isolated as a particle of up to 300 nm length and 3 nm width. These cellulose nanocrystals have useful properties for reinforcing polymers and should be available at a fraction of the cost of other nano-fibers such as carbon nanotubes. The forest products industry has a role to play in supplying the cost-effective nano-dimensional materials to make a commercial reality of nano-reinforced composites.

The FPL Nanotechnology research program includes the following:

- Characterize the novel nanoscale and nano-structured properties and architectures occurring in wood cell walls
- Develop cost effective technologies for isolating nanocrystalline cellulose from wood
- Characterize cellulose nanocrystal morphology, physical, mechanical, piezoelectric and chemical properties
- Relate the mechanical and chemical properties of nanocrystalline cellulose to its nanoscale surface chemistry and morphology
- Understand the science and technology of water cellulose interactions at the nanoscale
- Understand and learn how to manipulate the photonic, piezoelectric, and electronic properties of lignocellulosic nanomaterials and nanostructures
- Develop the science and technology needed to modify the functionality of nanoscale lignocellulosic architectures present in wood cell walls
- Develop the science and technology needed for using the novel nanoscale and nano-structured properties and architectures occurring in wood cell walls to produce new hyper-performance, nano-enabled products
- Develop the nanomanufacturing science and technology needed to incorporate nanomaterials into macroscopic organic and inorganic composites of interest to the forest products industry

- Develop the science and technology needed to incorporate nanomaterials with a variety of functionalities to enhance the end use performance of wood-based materials to increase durability, strength, adhesion, increase strength to weight, etc.
- Work cooperatively with the forest products industry to help create the precompetitive science and technology needed to achieve its six priorities for nanotechnology – (1) creating higher strength and lighter weight materials and their products, (2) developing forest nanomaterials (e.g. cellulose nanocrystals), (3) controlling the interactions between water and lignocellulosic material, (4) producing hyper-performance nano-composites, (5) capturing and enhancing the photonic and electronic properties, and (6) reducing energy usage and capital costs in processing
- Develop and incorporate unique nanoscale sensors into wood-based products for processing and end use applications.

The forest biorefinery – forest biomass to biofuels and co-products

Forests can sustainably provide substantial renewable sources for biobased products and bioenergy critical to maintaining and enhancing US environmental quality and economic and energy security. The production, handling, and use of woody biomass for energy production and lignocellulosic products – as would be required for a forest biorefinery – are not new for the forestry sector. About 50% of the U.S. current renewable energy comes from wood-fed hog boilers and spent pulping liquor recovery boilers at forest product industry's manufacturing facilities. The breakdown of forest biomass feedstock into basic wood components – as would be required in the forest biorefinery – is also not new to the forest products industry. For example, on the order of 115 million (oven dry) tons of wood are processed annually in the US to extract cellulose for pulp and paper. The forest industry already has significant infrastructure for the production, harvest, and transport of wood – but not primarily for energy, liquid fuels, and chemical feedstock production as would likely be the focus of a forest biorefinery.

A number of important factors influence and contribute to the commercialization and expanded use of wood in forest biorefineries to make biofuels and other value-added co-products. These factors include 1) feedstock sources, feedstock production technologies, and other costs to supply wood feedstock; 2) harvesting and forest operations technologies, transportation, in forest pre-processing technologies; 3) types of conversion technologies including their feedstock needs, conversion efficiencies and costs; 4) connections to forest restoration treatments; and 5) development and deployment of biomass to energy facilities. The economics for producing advanced biofuels from forest biomass are tenuous as witnessed by the need for public funding to reduce risks for commercial efforts. A number of factors must come together with the aid of a focused research and development program to improve conversion technologies and reduce feedstock costs to enable advanced biofuels to be commercially viable without public subsidies.

FPL is developing technologies that permit forest biorefineries to produce bio-based products, bioenergy, and other value-added co-products. For example, FPL is working with a variety of partners to develop the integrated forest products biorefinery where wood-derived hemicellulose sugars are efficiently and effectively removed and fermented to ethanol prior to either being pulped for papermaking or processed into panel products. FPL is also developing new and improved separation technologies to produce chemical constitutive materials from wood at high yield. These constitutive materials will then provide biochemical substitutes for a variety of non-renewable feedstock. Other work includes developing technologies to simultaneously co-ferment C-5 and C-6 sugars to ethanol; developing wood pretreatment processes to allow recalcitrant cellulose to be more easily converted to monomeric sugars; nanocatalysis to produce polyols; developing new and novel high temperature liquid metals based pyrolysis and gasification conversion technologies; and conducting life cycle assessment and carbon foot print evaluations of biorefineries and their products.

Conclusion

The areas of forest biomass to biofuels and value-added co-products; hyper-performance advanced composites; advanced high performance wood-based structures; and nanotechnology and nanomaterials from wood represent important areas for the successful transformation of the forest products industry from the low profit, commodity-based industry of the late 20th Century to a reinvented and reinvigorated growth industry in the 21st Century. New technologies in these areas will help make wood the sustainable, renewable, and recyclable material of choice in the 21st Century replacing fossil fuel derived materials and other less desirable materials. FPL research is focused on developing the underlying enabling science and technology to achieve a renewed use of wood that serves to improve the health and condition of forestlands as well as help prevent privately held forestlands from being converted to non-forest uses by providing sufficient economic returns to cover sustainable forest management costs and provided adequate rates of return to forestland managers and owners.

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