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NANOTECHNOLOGY FOR THE FOREST PRODUCTS INDUSTRY

Nanotechnology is defined as the manipulation of materials measuring 100 nanometers or less in at least one dimension. In addition, nanomaterials must display unique properties and characteristics that are different than their bulk properties. At the 1-nanometer (nm) level, quantum mechanics rules, and at dimensions above 100 nm, classical continuum mechanics, physics, and chemistry dictate properties of matter. Between 1 and 100 nm, a hybrid exists, and interesting things can happen. Mechanical, optical, electrical, magnetic, and a variety of other properties can behave quite differently, providing the opportunity to develop materials with higher strength, greater opacity, and enhanced electrical and magnetic performances among many others.

Nanotechnology represents a major opportunity for the forest products industry to develop new products, substantially reduce processing costs, and open new markets. In the past, materials scientists concentrated efforts on simple, single-crystals and homogeneous materials. We now have much improved tools to investigate and understand how wood, a composite cellular material, is synthesized; how its molecular and nanoscale components are assembled; and how this nanoscale architecture and assembly control material properties. Nanotechnology can enable the development of a wide range of new or enhanced wood-based materials and products that offer cost-effective substitutes for nonrenewable materials used in the manufacture of metallic, plastic, or ceramic products. Also, by employing nanotechnology, we can strengthen wood as one of America's core manufacturing competencies. With this in mind, we can truly believe that forest-based materials will be the materials of the 21st century.

As a first step toward reaching the goals of applying nanotechnology in the forest products industry, a workshop to develop a vision, explore opportunities, and determine research needs was held October 17–19,2004, at the National Conference Center in Lansdowne, Virginia. Over 110 leading researchers with diverse expertise from industry, government laboratories, and academic institutions from North America and Europe were in attendance. Coming out of this workshop was a document titled "Nanotechnology for the Forest Products Industry-Vision and Technology Roadmap." This forest products industry roadmap is available for downloading at www.nanotechforest.org. Unique properties and characteristics of wood lignocellulosic biopolymers were identified that make them an exciting avenue for nanotechnology—lignocellulosic biopolymers are some of the most abundant biological raw materials; have a nanofibrillar structure; have the potential to be made multifunctional; and can be controlled in self-assembly; and lignocelluloses as nanomaterials and their interaction with other nanomaterials are largely unexplored.

Potential uses identified for nanotechnology include developing intelligent wood- and wood-based products with an array of nanosensors built in to measure forces, loads, moisture levels, temperature, pressure, and chemical emissions, as well as detect attack by wood-decaying fungi and termites. In addition, building functionality onto lignocellulosic surfaces at the nanoscale could open new opportunities for such things as pharmaceutical products, self-sterilizing surfaces, and electronic lignocellulosic devices.

The high strength of nanofibrillar cellulose together with its flexibility offers the opportunity to make strong and' lightweight materials

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with greater durability. Use of nanodimensional-material building blocks will enable the assembly of functional materials and substrates with substantially higher strength properties, which will allow the production of lighter-weight products from less material and with fewer energy requirements. Significant improvements in a diverse range of properties and functionality will be possible, making existing products much more effective and enabling the development of new products. Nanotechnology can also be used to improve processing of wood-based materials by improving water removal; reducing energy usage in drying; and tagging fibers, flakes, and particles to allow customized property enhancement in processing.

Two Approaches for a Nanotechnology R&D Strategy

Nanotechnology research and development (R&D) strategies for the forest products industry encompass two broad approaches: 1) Nanotechnologies and nanomaterials developed through nanotechnology R&D efforts in other industry sectors can be adopted and deployed in current wood and wood-based materials, processes, and products; and 2) Nanotechnology R&D will develop completely new materials and product platforms using the improved knowledge of nanoscale structures and properties of wood and its components. The R&D challenges associated with these two broad strategies span a range of scientific focus areas including: developing fundamental understanding of nanomaterials and analytical tools for measuring properties at the nanoscale; developing new nanoscale building materials; developing nanotechnology for manufacturing applications; and creating nanomaterials by design.

Nanomaterials by Design

"Nanomaterials by Design" is a uniquely solutions-based research goal that refers to the ability to employ scientific principles in deliberately creating structures (e.g., size, architecture) that deliver unique functionality and utility for end-use applications. This research area focuses on the assembly of building blocks to produce nanomaterials in technically useful forms, such as bulk nanostructured materials, dispersions, composites, and spatially resolved, ordered nanostructures. It will yield a new set of tools that can provide flexibility for precisely building material functions. Techniques being developed in the areas of self-assembly and directed self-assembly will allow us to use the building blocks available in the forest products industry to manufacture materials with radically different performance properties.

R&D Focus Areas

The workshop focused on the following five R&D areas on the basis that they provide the best path forward for a nanotechnology roadmap by identifying the underlying science and technology needed and foster essential interactions among visionary, interdisciplinary research and technology leaders from industry, academia, research institutions, and government. These areas are:

1. Polymer Composites and Nano-reinforced Materials—combining wood-based materials with nanoscale materials to develop new or improved composite materials with unique multifunctional properties.
2. Self-Assembly and Biomimetics—using the natural systems of woody plants as either the source of inspiration or template for developing or manipulating unique nano-, micro-, and macro-scale polymer composites via biomimicry and/or direct assembly of molecules.
3. Cell-Wall Nanostructures—manipulating the cell-wall nanostructure of woody plants in order to modify or enhance their physical properties and create wood and wood fibers with superior manufacturability or end-use performance.
4. Nanotechnology in Sensors, Processing, and Process Control—Using nonobtrusive, nanoscale sensors for monitoring and control during wood and wood-based materials pro-

cessing, to provide data on product performance and environmental conditions during end-use service, and to impart multifunctional capabilities to products.

5. Analytical Methods for Nanostructure Characterization—Adapting existing analytical tools or creating new tools (chemical, mechanical, electrical, optical, and magnetic) that accurately and reproducibly measure and characterize the complex nanoscale architecture and composition of wood and wood-based lignocellulosic materials.

In moving nanotechnology forward in the forest products industry, it is important to have collaboration and cooperation among researchers from various disciplines and organizations, including universities, research institutes, national laboratories, and government agencies and departments. In addition, linkages need to be made between research communities of the forest products sector and the broader community of nanotechnology researchers in order to capture synergies, enhance accomplishments, and avoid needless duplication of facilities and efforts.

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