NANOTECHNOLOGY FOR FOREST PRODUCTS, PART 1

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Editor's Note: This article is a result of the Forest, Wood and Paper Industry's Agenda 2020 program focused on providing the industry with technology for a robust and sustainable future. Nanotechnology is one of the key "platforms" discussed at Technology Summit II, held in May 2004. This article discusses the development of the Nanotechnology platform. Part 2 will appear in a later issue of Solutions! magazine.

IN THIS ARTICLE YOU WILL LEARN:

- The wide opportunities offered by nanotechnology research.
- Two research strategies for capitalizing on these opportuities.

ADDITIONAL RESOURCES:

- To download "Nanotechnology for the forest Products Industry—Vision and Technology Roadmap", visit www.tappi.org or www.nanotechforest.org.
- Home page of the National Nanotechnolo0gy Initiative, the multi-agency framework for federally-funded nanotechnology R&D: www.nano.gov.

Nano-sized particles may be small, but for our industry they offer huge potential Nanotechnology represents a major opportunity for the forest products industry to develop new products, substantially reduce processing costs, and open new markets in the coming decades

Our ability to view materials at atomic dimensions—to determine and alter how materials are constructed at nano- and atomic scales—provides the opportunity to develop new materials and products in unprecedented ways In the past, materials scientists concentrated efforts on simple, single-crystals and homogeneous materials that were easier to understand and could be analyzed by the techniques of the time. We now have much improved tools to investigate and understand how wood, a composite cellular material, is synthesized in a tree; how the molecular and nanoscale components are assembled; and how this architecture and assembly controls material properties.

We define nanotechnology 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 differ from bulk properties At the one nanometer (nm) level, quantum mechanics rules, at dimensions above 100 nm, classical continuum mechanics, physics, and chemistry dictate properties of matter. Between one 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 other qualities.

The many thousands of wood-based products derived from our forests are ubiquitous and taken for granted in our everyday world—the hallmark of a great product and great material. Nanotechnology now offers the opportunity to re-invent the way we use wood and wood-based materials, and the industry that converts it to the myriad of products in use today. Nanotechnology can enable the development of a wide range of new or enhanced wood-based materials and products that offer cost-effective substitutes for non-renewable materials used in the manufacture of metallic, plastic, or ceramic products.

By employing nanotechnology to revitalize the forest products industry, we can strengthen one of America's core manufacturing competencies. The U.S. has a massive infrastructure in place for growing, harvesting and processing wood products, which provides a key employment base in almost every state. This infrastructure provides a fundamental strategic advantage to build on for preserving the global economic competitiveness of this industry. With this in mind, we can truly believe that forest-based material will be the material of the 21st Century.

ROADMAP FOR PROGRESS

In 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 convened on October 17-19, 2004, at the National Conference Center in Lansdowne, Virginia. More than 110 leading researchers with diverse expertise from industry, government laboratories, and academic institutions from North America and Europe attended. The workshop produced a document titled "Nanotechnology for the Forest Products Industry—Vision and Technology Roadmap". This forest products industry roadmap is available for downloading on the TAPPI website (www.tappi.org) as well as www.nanotechforest.org.

Figure 1 summarizes the roadmap.

Workshop participants identified some of the unique properties and characteristics that make wood lignocellulosic biopolymers an exciting avenue for nanotechnology research. These characteristics include:

- 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.
- New analytical techniques adapted to biomaterials are allowing us to see the structure of wood in new ways.
- Lignocelluloses as nanomaterials and their interaction with other nanomaterials are largely unexplored.

Potential uses identified at the workshop for nanotechnology include developing intelligent wood- and paper-based products with an array of built-in nanosensors to measure forces, loads, moisture levels, temperature, pressure, and chemical emissions, as well as to detect attack by wood decay fungi and termites. 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 and flexibility of nanofibrillar cellulose offer the opportunity to make lightweight strong materials with greater durability. By comparison, carbon nanotubes have very high strength but are brittle[1]. 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 less 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 many more new products.

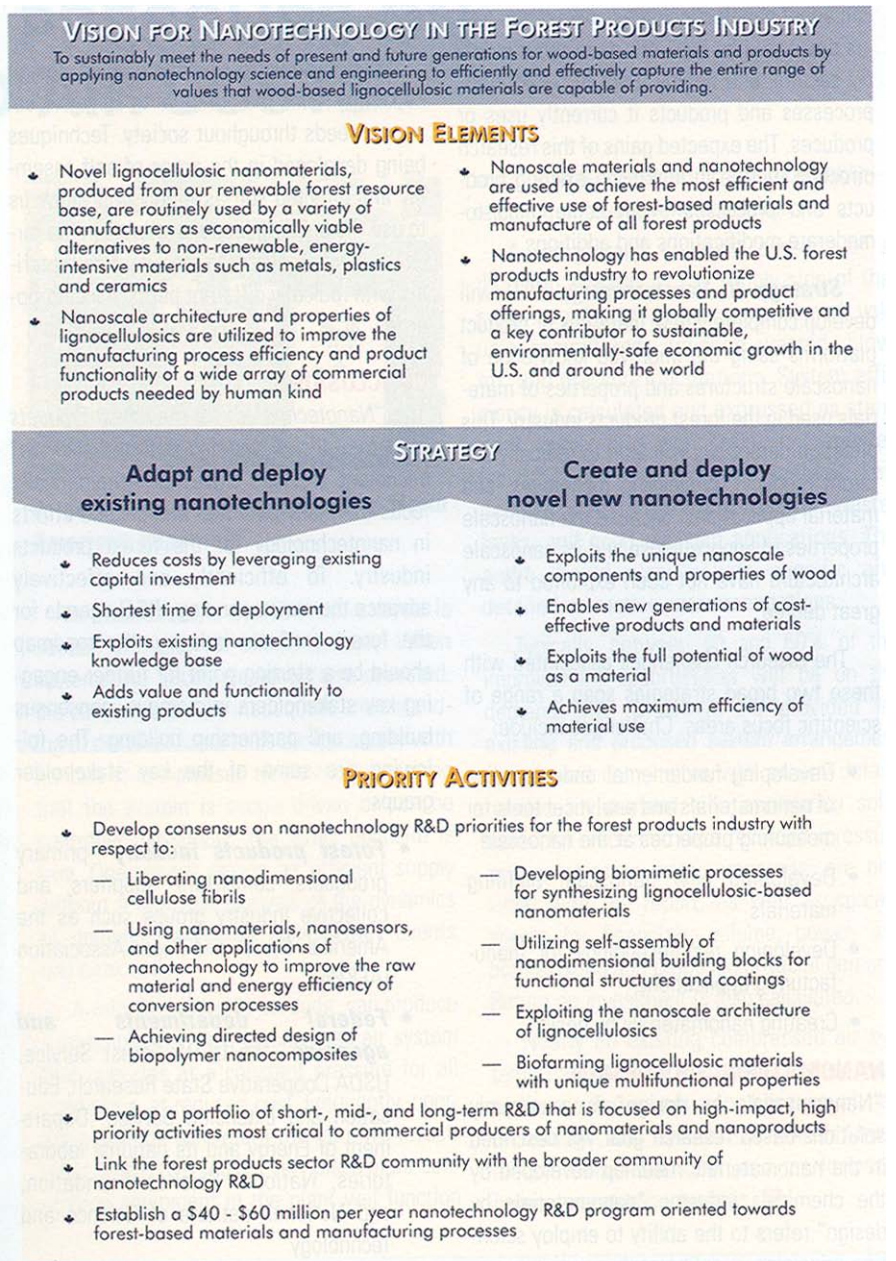

Figure 1: Overview of the Forest Products Nanotechnology Roadmap.

Nanotechnology can be used to improve processing of wood-based materials into paper and wood products by improving water removal; eliminating rewetting; reducing energy usage in drying; and tagging fibers, flakes, and particles to allow customized property enhancement in processing.

AN R&D STRATEGY TWO APPROACHES

Nanotechnology research and development (R&D) strategies for the forest products industry encompass two broad approaches:

Strategy I: The forest products industry

can adopt nanotechnologies and nanomaterials developed by R&D efforts in other industry sectors, and deploy them into materials, processes and products it currently uses or produces. The expected gains of this research direction will be in improving existing products and processes—with some minor-to-moderate modifications and additions.

Strategy ***II:*** Nanotechnology R&D will develop completely new materials or product platforms using the improved knowledge of nanoscale structures and properties of materials used in the forest products industry. This direction potentially will lead to radically different products, processing techniques, and material applications, because the nanoscale properties of lignocellulose and its nanoscale architecture have not been exploited to any great degree.

The research challenges associated with these two broad strategies span a range of scientific focus areas. Challenges include:

- Developing fundamental understanding of nanomaterials and analytical tools for measuring properties at the nanoscale
- Developing new nanoscale building materials
- Developing nanotechnology for manufacturing applications
- Creating nanomaterials by design.

NANOMATERIALS BY DESIGN

"Nanomaterials by design" is a uniquely solutions-based research goal. As described in the nanomaterials roadmap developed by the chemicals industry, "nanomaterials by design" refers to the ability to employ scientific principles in deliberately creating structures (e.g., size, architecture) that deliver unique functionality and utility for target applications."[2] This research area will focus 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 nearly limitless flexibility for precisely building material functions around end-use applications.

Such a powerful, function-based design capability holds the potential to solve critical unmet needs throughout society. 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.

CONCLUSIONS

The *"Nanotechnology for the Forest Products Industry—Vision and Technology Roadmap"* document provides a way to systematically focus the many potential and diverse efforts in nanotechnology for the forest products industry. To efficiently and effectively advance the nanotechnology R&D agenda for the forest products industry, the roadmap should be a starting point for further engaging key stakeholders in dialogue, consensus building, and partnership building. The following are some of the key stakeholder groups:

- ***Forest products industry***—primary producers, converters, suppliers, and collective industry groups such as the American Forest and Paper Association (AF&PA).
- ***Federal departments and agencies***—the USDA Forest Service, USDA Cooperative State Research, Education and Extension Service, Department of Energy and its national laboratories, National Science Foundation, and National Institute of Science and Technology.
- ***University and research institute/laboratory communities*** (both national and international)—These include universities with forest products and pulp and paper departments and programs, umbrella university groups such as the Pulp and Paper Education and Research Alliance and the Society of Wood Science and Technology, and research institutes and laboratories focused on the forest products industry; as well as the established research communities already involved in nanotechnology research and development.

A critical step in moving nanotechnology for the forest products sector forward is to gain consensus among stakeholders on what the specific focus should be for the short term, mid term, and long term. It is important to focus these efforts on high-impact, high-priority activities that will be the most critical to commercial producers of nanomaterials and nanoproducts.

Lastly, the industry must view the nanotechnology roadmap as dynamic, living document. Every three to five years, the industry should convene experts to reexamine the roadmap—experts who will review the industry's progress, redefine goals, and assess accomplishments in light of resources available and resources expended. S!

FOOTNOTES:

1. www.bimac.kth.se/News/Nyhetsbrev_14-04.pdf
2. www.chemicalvision2020.org/nanotechnology.html

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