Nanotechnology and the Forest Products Industry
Exciting New Possibilities

Dr. Jim Bowyer

Dr. Jeff Howe
Kathryn Fernholz
Matthew Wenban-Smith

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Introduction

Nanotechnology – it's the hottest field of science these days, with roots dating back to the 1950s. Basically, nanotechnology involves manipulation of molecular building blocks to create or modify materials or devices.

The potential is great. Dr. Ralph Merkle, a pioneer in the nanotechnology field, explains it this way:

> *Manufactured products are made from atoms. The properties of those products depend on how those atoms are arranged. If we rearrange the atoms in coal we can make diamond. If we rearrange the atoms in sand (and add a few other trace elements) we can make computer chips. If we rearrange the atoms in dirt, water and air we can make potatoes.*
>
> *Today's manufacturing methods are very crude at the molecular level. Casting, grinding, milling and even lithography move atoms in great thundering statistical herds. It's like trying to make things out of LEGO blocks with boxing gloves on your hands. Yes, you can push the LEGO blocks into great heaps and pile them up, but you can't really snap them together the way you'd like.*
>
> *In the future, nanotechnology will let us take off the boxing gloves. We'll be able to snap together the fundamental building blocks of nature easily, inexpensively and in most of the ways permitted by the laws of physics. . .*

Properties of Nanomaterials

Materials reduced to the nanoscale can suddenly show very different properties compared to what they exhibit on a macroscale, enabling unique applications such as improved suntan lotion and stain resistant pants. For instance, opaque substances become transparent (copper); inert materials become catalysts (platinum); stable materials turn combustible (aluminum); solids turn into liquids at room temperature (gold); insulators become conductors (silicon). Much of the fascination with nanotechnology stems from these unique quantum and surface phenomena that matter exhibits at the nanoscale.

Wikipedia (http://en.wikipedia.org/wiki/Nanotechnology)

The relatively recent development of scientific tools, such as atomic force and scanning tunneling microscopes that allow measurement and imaging of extremely small structures, have laid the foundation for this new field of scientific inquiry and opportunity. Most early work in this area has focused on carbon and the use of carbon nanotubes (perfectly straight tubules with diameters of nanometer size, and properties close to that of an ideal graphite fiber) for applications ranging from microelectrodes in electrochemical reactions to mechanical reinforcement of a range of products. Now, efforts to apply nanotechnology to the forest products field are underway, with the possibilities limited only by the imagination.

For purposes of reference, a nanometer is one billionth of a meter. A sheet of paper is about 100,000 nanometers thick.

Working at the Nanoscale

A recent commentary by Forest Products Laboratory scientists about cellulose nanofibrils (cellulose molecules and bundles of cellulose molecules or microfibrils) as compared to carbon nanotubes included the observation that "cellulose nanofibrils exhibit a modulus [a measure of strength] roughly one-quarter to one-fifth that of carbon nanotubes, yet they are produced naturally without the need for energy consuming, high-temperature processing." This observation underscores the remarkable properties of wood and raises the possibility that naturally occurring cellulosic structures may have uses across the emerging nanotechnology field. Also a possibility is that technologies may be developed to allow molecule-by-molecule assembly of entirely new products, new components, new coatings and surface treatments that are stronger, lighter, and more durable than products and materials currently available; it may also become possible to use plant-derived materials in the manufacture of high-tech materials and products now made entirely from non-renewable raw materials.

Nanotechnology could transform the forest products industry in virtually all aspects – ranging from production of raw materials, to new applications for composite and paper products, to new generations of functional nanoscale ligno-cellulosics. Research and development in nanotechnology is critically important to the economical and sustainable production of these new generations of forest-based materials that will meet societal needs while improving forest health and contribute to the further expansion of the biomass-based economy.

Excerpt from *Nanotechnology for the Forest Products Industry – Vision and Technology Roadmap, 2005*.

Current research in the forest products arena is probing a number of possible near-term applications of nanotechnology including the use of nanoscale indentations in individual wood fibers for the purpose of enhancing adhesion and coatings durability, insertion of non-wood materials into woody cell lumens, cell walls, or fiber matrices to enhance product properties, and even inclusion of microchips in wood-base products to create "smart" materials that can flag changes in such things as loads, forces, moisture levels or the onset of decay or that might even be able to respond to changes in their surrounding environment. An interesting wrinkle on the paper recycling front has emerged from the laboratories of scientists studying nanotechnology applications to the paper industry. Currently, one of the technical limitations in paper recycling is that fiber is damaged each time it is processed, translating to fiber loss of 12 to 50 percent with each reuse. Recent findings suggest that it may be possible to repair recovered fibers through the addition of nanoparticles to damaged surfaces of wood fibers (Eadula et al. 2006). This raises the possibility that it may someday be possible to reuse fibers indefinitely.

In the longer term, increased understanding of plant biology and physiology, coupled with continued advances in nanotechnology may lead to development of a vast array of products that *self assemble* using little or no energy in the process. Bringing this to reality will require a better understanding of bio-chemical processes that take place within a developing woody cell.

Understanding Developing Cells May Lead to New Approaches in Manufacturing

The essential nature of wood at the micro-scale has been known for a very long time. Cell walls are intricate structures composed of cellulose, hemicellulose, and lignin, with rather precise ordering of these elements within distinct layers of the cell wall. The result is a remarkably strong natural material, produced using solar energy, which need only be cut into different shapes to create a myriad of useful products.

More interesting is the fact that the creation of cellulose and other compounds, and subsequent development of intricate layering, occurs just beneath the bark of trees within the cytoplasm of newly-formed and developing cells, using as a raw material basic sugars that are produced in the process of photosynthesis. The fact that the intricate structure of the woody cell wall defines many of the physical and mechanical properties of wood, combined with the fact that this intricacy develops within living cells raises interesting possibilities. If scientists were, for example, able to understand the intricate mechanisms that control formation of chemical compounds and subsequent ordering within the cytoplasm of developing cells under the guidance of genetic encoding, that might enable them to develop new and high strength materials that self-assemble from molecular building blocks.

Nanotechnology and Process Improvements

Potential gains from nanotechnology are not limited to the esoteric. Currently on the radar screens of wood scientists are nanotechnology applications that could address long-standing intractable problems in lumber manufacturing. Hardwoods that are difficult to dry without incurring degrade might, for example, be made easier to dry through insertion of nanoparticles into the wood structure to facilitate moisture movement (thereby reducing energy consumption in drying) while at the same time eliminating collapse, or preventing surface checking with moisture loss. Similar treatments might also be used to prevent re-adsorption of moisture by wood once it has been dried, or to avoid undesirable migration of extractives to wood surfaces, or fading with exposure to ultraviolet light.

Risks and Unknowns

As mentioned, one of the characteristics of operating at the nanoscale is that the materials can behave very differently. These changed and new behaviors can create incredible opportunities for innovation and creation. However, these changed behaviors may also have unintended consequences, and how these changed behaviors will interact with the environment, including the human body, is not entirely understood. Concerns about the potential risks and unknowns of nanotechnology have been raised primarily in connection with medical applications, but all industries exploring the use of this technology will likely need to research risk factors as well as the potential benefits.

The Bottom Line

As discussed in earlier Dovetail reports, increasing interest in bio-energy and bio-chemicals is likely to have a substantial impact on domestic forests and the forest products industry (Bowyer et al. 2005, 2006). Parallel advancements in science, including those in the developing nanotechnology field, will soon greatly expand the options available to society for beneficial use of wood and woody biomass. Such advancements are also likely to lead to enhancement of current manufacturing processes as well as properties of traditional products. Product applications will be broadened and the array of products made wholly or partially of wood will be significantly increased. Every aspect of the current wood products industry will ultimately be affected by these changes. The very real prospect of gaining an ability to produce better and longer-lasting products while employing natural processes has positive implications for not only the bottom line, but for sustainability of the forest industry as well as society at large. Given the likely impact of nanotechnology it is important that society support investment in biomaterials research, and that the forest products industry keep abreast of progress in this emerging area of science.

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DOVETAIL PARTNERS, INC.
528 Hennepin Ave, Suite 202
Minneapolis, MN 55403
Phone: 612-333-0430
Fax: 612-339-0432
www.dovetailinc.org