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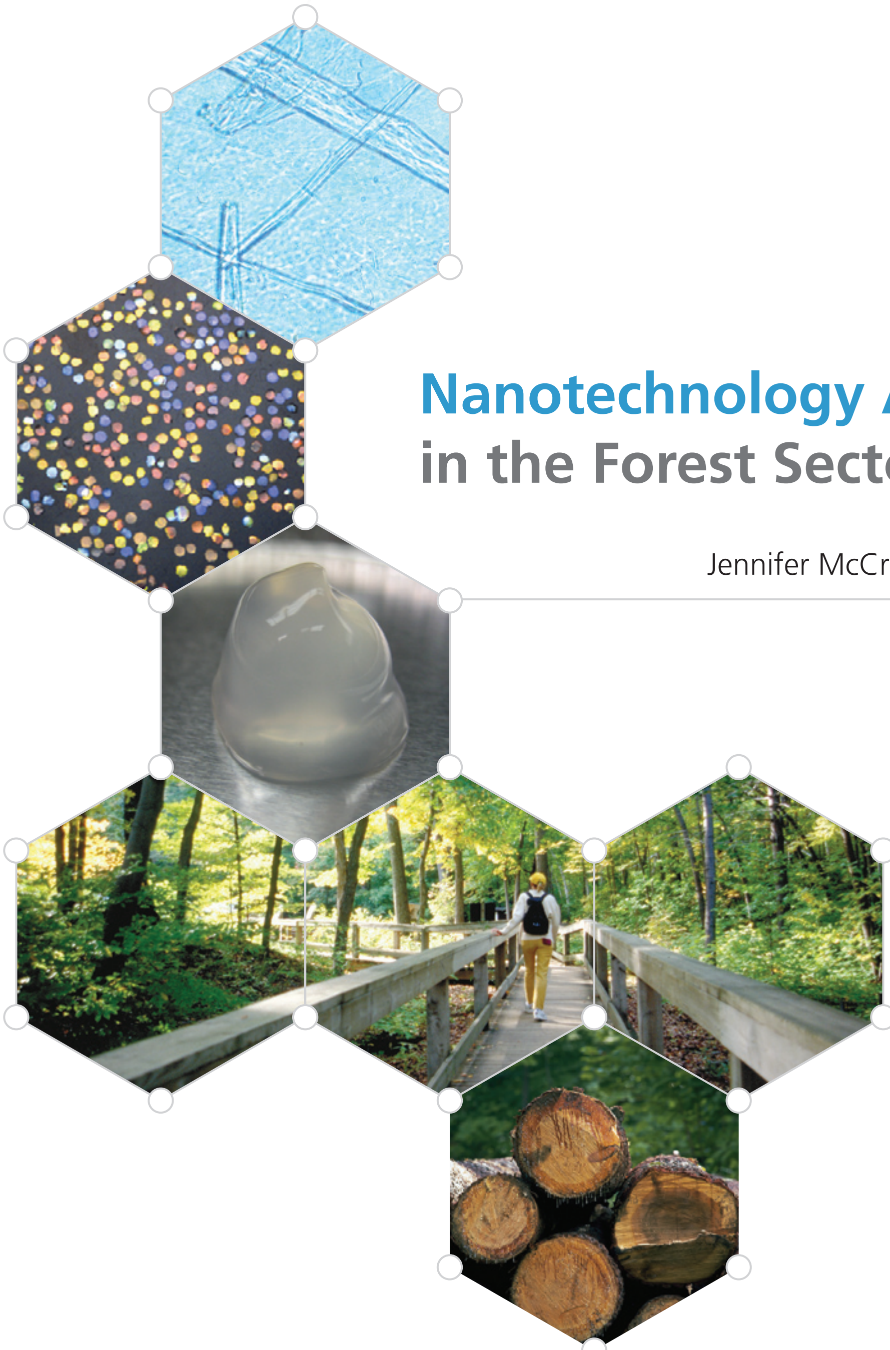

Nanotechnology Applications
in the Forest Sector

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Canada

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Contents

Introduction

Nanotechnology is a fairly new area of research and development. The range of application for nanotechnology is huge and it promises to improve our lives. Nanotechnology has been applied to many products that are currently on the market, for example, certain sunscreens, sports equipment, clothing, electronics, and packaging are nano-based. More than 600 consumer products using nanotechnology are known to exist as of April 2008 (http://www.cbc.ca/health/story/2008/07/10/nanomaterials-report.html). Nanotechnology has sparked much attention in a wide range of disciplines from electronics to material science. To benefit from nanotechnology applications, information sharing between the various associated disciplines will be useful. Moreover, lessons learned from biotechnology can help integrate nanotechnology into society and avoid public distrust.

So what really is nanotechnology? It is a multidisciplinary field of applied science and technology that deals with matter on the atomic and molecular scale in the size range of 1–100 nm. Particles and matter at these dimensions display unique and novel physical and biological properties that are unlike those displayed by particles at larger dimensions. This is significant for research and development because these novel particle properties can lead to many innovative applications in a multitude of disciplines. Nanotechnology draws from several disciplines including chemical engineering, physics, electrical engineering, material science, chemistry, biology, and colloid science. For most people, it is difficult to conceive how small a nanometre (10^{-9} m) really is. A red blood cell is approximately 8000 nm wide (http://www.cbc.ca/health/story/2008/07/10/nanomaterials-report.html). DNA is an example of a natural structure that is approximately

Petawawa Research Forest collection.

1–2 nm. There are also man-made nanoparticles such as carbon nanotubes[1] and buckyballs[2] that are 1–10 nm.

Over the last couple of years, the potential for nanotechnology development in the forest sector has become apparent and realizable. Nanotechnology provides a means for developing wood-based materials and improving forest-based materials that could prove to be important contributors to the forest-based economy. Also, new processes developed through nanotechnology are anticipated to revolutionize the forest industry in wood-based products, fiber-based products, pulp, paper, wood composites, production processes, and functional lignocellulosics (Atalla et al. 2006).

[1] Molecular carbon allotropes that are cylindrical.

[2] Molecular carbon allotropes that are spherical and are composed of 60 carbon atoms.

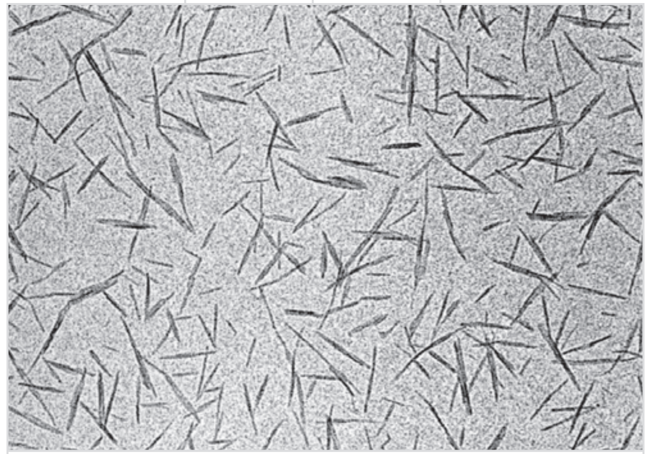
Applications

New Materials

Nanotechnology has the potential to develop a multitude of new materials that can be used in the forest sector. Many novel nanofibers, biocomposites, laminates, resins, and lignocellulose products are either in the research stage, in development, or on the market. New nanomaterials will invigorate the forest sector through technological advancement and research opportunities.

Nanofibers

Recently, there has been interest in the study of nanomaterials derived from renewable resources. Nanofibers and nanofibrils that originate from cellulose form an important class of nanomaterials. Cellulose remains one of earth's most abundant biological raw materials and it may become an alternative to nonrenewable materials such as ceramics or metals (Wegner and Jones 2006). Lignocellulose and cellulose have significant potential as nanomaterials because they are abundant, renewable, have a natural nanofibrillar structure, and can self-assemble into useful structures. These nanofibers and nanofibrils can be isolated from the kraft wood–pulp process and from many other sources of cellulose (Wang et al. 2007). They can be incorporated into various types of polymers to form composites. Cellulose nanofibers can be used as structural elements in applications such as plastic reinforcement and gel forming and thickening agents (Wang and Sain 2007). Organic fillers, used in composites, are an advantageous replacement to synthetic fillers because they are biodegradable, cost less, have good thermal properties, and are lightweight compared with their inorganic counterparts (Bhatnagar and Sain 2005). Cellulose nanofibers are natural structural elements of cellulose that can be woven into mats for use in reinforced composites, for example, polyvinyl alcohol film, significantly increasing tensile strength. The mechanical properties of composites depend on the properties of the individual components (Nakagaito and Yano 2004). Cellulose nanofibers have a stiffness of 145 GPa and a tensile strength of 7.5 GPa (Beecher 2007), similar to the strength properties of carbon nanotubes that are currently used for reinforcing materials. However, the cellulose nanofibers would be much less expensive to develop and are lightweight, which has important implications for applications in the automotive sector, aerospace engineering, medicine, industry, and numerous material sciences.



Transmission electron micrograph of cellulose nanocrystals 10 nm wide x 150 nm long.

Nanocrystals

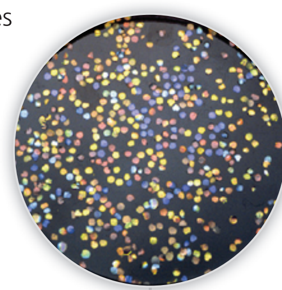
Cellulose nanocrystals or cellulose whiskers are useful when incorporated into a polysulfone polymer membrane. A study conducted by Noorani et al. (2007) indicates that adding cellulose nanocrystals increases the tensile modulus and permeability of a polysulfone composite. This is beneficial for fabrication of nanocomposite membranes used in bioseparation devices.

Laminates/Coatings

Nanocomposite laminates are a promising application that can be applied to forestry. Sealants, coatings, and laminates are currently being used to preserve and treat wood (Atalla et al. 2006). These preservative products can be modified at the molecular level to improve durability and moisture, decay, and fire resistance (Atalla et al. 2006). With nanotechnology, it is possible to create a wood-based product that has been altered at the molecular level.

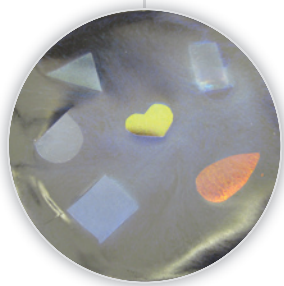
Lignocellulose

Lignocellulosic material, with a nanofibrillar structure, is produced from renewable forest resources and can function in a wide range of commercial products.



Confetti of different-colored nanocrystalline cellulose iridescent film.

Pieces of nanocrystalline cellulose iridescent films incorporated into a transparent nanocrystalline cellulose film.



For example, lignocelluose can be used to remove phosphorus in point and nonpoint source pollution in water (Kim et al. 2006). This is significant for the forest industry because it could be a large provider of lignocellulose for pollution removal. Current water phosphorus treatment systems are not very efficient. Therefore Kim et al. (2006) conducted research on the lignocellulose-based anion removal media (LAM). They studied how it could be applied to adsorb phosphorus at various concentrations from polluted water bodies. Results demonstrated that LAM is significantly more efficient at removing phosphorus than the current most efficient phosphorus-absorbing media. Additionally, economic studies suggest that LAM is a very inexpensive means of phosphorus removal from water.

Wood Resistance

Nanotechnology has created an opportunity to fabricate wood-based products that have ultraviolet resistance, fire retardancy, pest resistance, moisture control, and fungal resistance. For the forest sector, this has important implications for processing and developing wood-based products. For example, moisture causes decay, swelling, and shrinking in wood. Therefore improving moisture control will help develop a wood product that can be used for a variety of commercial applications.

Ultraviolet Protection

To achieve a higher level of ultraviolet resistance in wood products, nanotechnology can be applied by modifying the wood itself or by applying a coating to the wood.

Antaria Limited developed nanoZ™, a transparent industrial zinc oxide nanoparticle coating that protects wood, plastics, and textiles from ultraviolet and microbial degradation (http://www.antaria.com/pdfs/nanoz/nanoz_brochure_02.pdf). It consists of zinc oxide nanoparticles that do not agglomerate and have a narrow size distribution, resulting in significantly reduced light scatter. This product can be used for industrial wood applications.

Moisture Resistance

Nanotec Pty Ltd., located in Australia, created Nanoseal® Wood, which is used primarily as a water repellent but can also be used to resist ultraviolet degradation. Nanoseal® Wood is a water-based wood surface treatment that is used to prevent water damage. Despite its name, Nanoseal® Wood is not a sealant. There is a molecular bond between the administered nanoparticles and the substrate. The nanoparticles form an extremely thin mesh that repels water, is invisible, and still allows water vapor to escape from the wood. Nanoseal® Wood protects wood products from decay, fungi, rot, swelling, and shrinking and may be used for indoor and outdoor timber products. It is friction resistant; cannot be removed by water, cleaning products, or high-pressure washers; and does not contain any volatile organic compounds, oils, solvents, or pesticides (http://www.nanotechwire.com/news.asp?nid=1584&pg=2).

Researchers at the United States Department of Energy's Oak Ridge National Laboratory (ORNL) developed a superhydrophobic glass powder that is said to outperform nature in water repellency (http://www.sciencedaily.com/releases/2007/11/071129142426.htm). The product is patent-pending and is predicted to have a significant impact on commercial products due to its ease of manufacturing, low cost, and wide range of application. The ORNL nanomaterial is an amorphous silica coating that causes liquid-based solutions to be repelled from almost any surface, accomplished by treating the glass with a hydrophobic solution. The properties of the powder amplify the effect of the water's surface tension and make the powder "unwettable." The powder creates a cushion of air between the surface it coats and the liquid on the surface. It is a thermal and an electrical insulator and can be applied to a wide range of products including wood-based materials.

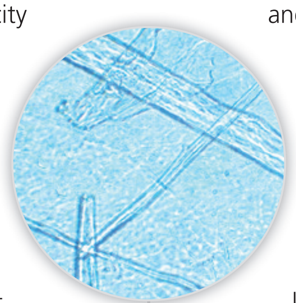
Currently, humidity sensors are used for numerous applications. Yang et al. (2006) developed a humidity nanosensor that can be used to detect humidity levels in a substance with great specificity. The device uses nanopores that are incorporated into a polymer membrane sensor that can detect a change in the resistance and capacitance. Water adsorption occurs in the nanopores and alters the resistance and/or capacitance. The actual nanosensor is created from a pair of metal electrodes that are positioned on the top of a porous nanopore layer. The authors propose that this device would be ideal for use on wood roofs because it is flexible, durable, and has high sensitivity to moisture damage.

Pest Resistance

A pest-resistant wood-based product would be of great benefit to the forest industry. Moreover, a product that can improve the current pest-resistance treatment would be advantageous. Pests can cause significant damage to wood products and the respective wood-based product economy. In the past, a major product in the forest industry was southern pine lumber that was treated with chromated copper arsenate (CCA) for preservation (Laks and Heiden 2004). Yet, there was concern about the environmental safety and health risks associated with its use. Contemporary organic biocides have a better environmental safety rating than CCA (Yang et al. 2006), although biocides that have a lower solubility can cause skin irritation in humans. Laks and Heiden (2004) proposed a product that provides a method for applying organic biocides to wood without causing irritation. The invention consists of incorporating biocides of varying solubilities into nanoparticles of a particular size that are then integrated into wood and wood products without causing adverse skin irritation. Nanoparticles of a certain size range can be made to penetrate wood through conventional pressure treatment techniques that are currently used for water-suspended biocides. Biocides may include insecticides, fungicides, and bactericides. Therefore the appropriate biocides can be used to target certain organisms. Nanoparticles impregnated with biocides can be used in the manufacture of wood composites and pressure-treated wood products such as particle board, plywood, and medium density fiberboard. The methods used in this invention can also be applied to the treatment of wood with fire-resistant chemicals such as boric acid. Moreover, additional additives can be incorporated into nanoparticles such as water repellents, colorants, and ultraviolet inhibitors (Laks and Heiden 2004).

Currently, wood preservation products are manufactured without chromium to minimize negative environmental effects. However, without chromium, biocides are more susceptible to leaching, which can also cause adverse environmental effects. Additionally, biocide leaching leads to degradation of the wood product itself (Heiden et al. 2005). The environmental concern associated with biocide leaching has stimulated research to discover methods to reduce or eliminate biocide leaching from wood and wood-based products. Heiden et al. (2005) undertook a research project that focused on using nanotechnology to sequester copper and organic biocides in wood to minimize biocide leaching. More specifically, they developed a method to incorporate wood preservatives into polymer nanoparticles that help to control the release rate of the biocide to eliminate loss through leaching. The nanoparticle acts as a storage unit for biocides as well as a controlled release apparatus that functions by diffusion. The actual nanoparticle's hydrophobicity can be controlled and this controls the diffusion rate. This method for biocide wood application can be applied to water-insoluble biocides.

A copper nanoproduct was recently developed and commercialized in North America as a wood preservative material. Matsunaga et al. (2007) compared the microdistribution of copper in conventional wood preservation treatment with that of the copper nanoparticle product. The efficacy of wood preservation products depends partially on the ability of the preservation product to penetrate the wood microstructure. Matsunaga et al. concluded from this project that the microdistribution of copper preservation nanoparticles covers a more extensive range in the wood compared with conventional copper preservation products. Therefore nano-sized copper particles would benefit the forest product industry because they are more effective than conventional products for wood preservation purposes.



Nanocrystalline cellulose crushed in a ball mill to be used to reinforce paint.

Nanoemulsions are effective in pesticide formulations especially when used with water-insoluble pesticide products (Wang et al. 2007). A nanoemulsion is a mixture of two unblendable substances that contain particles that are between 20 and 200 nm. They have consistent and very small droplet sizes which allows for uniform deposition on target plant leaves. The effectiveness of a given product for agrochemical pesticide delivery depends on whether it is likely to be diluted when used and whether the capacity for solubilization is retained on dilution. Wang et al. (2007) demonstrated that a nanoemulsion, with a water-insoluble pesticide (beta-cypermethrin), retains its solubilization capacity when diluted. Results demonstrate that nanoemulsions exhibit excellent properties for use as a delivery system for beta-cypermethrin. Nanoemulsions can deliver more particles per spray and therefore less pesticide spray can be applied to the target organism without the loss of effect.

A silver-nanoparticle antimicrobial paint was recently developed and can be used to coat wood, glass, steel, and polymeric surfaces (Kumar et al. 2008). Silver is an effective biocide against several bacteria, fungi, and viruses due to its low toxicity to human cells, high thermal stability, low volatility, and durability. Nano-sized silver particles have a large surface-to-volume ratio that provides an increased antibacterial efficacy. Kumar et al. (2008) developed this silver nano-paint to provide an environmentally friendly product that can be manufactured in a single step.

New Processes and Techniques

Nanotechnology could revolutionize many of the current forest product industry manufacturing processes, from pulp and paper manufacturing to wood conversion (Atalla et al. 2006). Novel concepts and modifications of current processes could lead to breakthrough bottom-up manufacturing in an industry that functions predominantly in a top-down manner. The forest industry could benefit immensely from this shift, but for it to occur, it will be important for the forest product industry to share analytical nanoscale tools and nanotechnology knowledge with other industrial sectors.

Nanoindentation

For nanotechnology applications, it is important to understand the properties and structure of the product in question at the nanoscale. To date, the complexity of wood has hindered researchers in their attempts to modify and control its behavior as an industrial product. A technique that can facilitate this task is nanoindentation, a method used to test the mechanical properties of a surface at the micron or submicron level (Moon et al. 2006). It tests primarily the hardness of the materials under analysis (http://www.nanoindentation.cornell.edu/Introduction/Nanoindentation-Introduction.htm).

The mechanism works by a hard tip being pressed into a sample with a known load. When the tip is removed, the area of the residual indentation is measured and the hardness can be calculated. The nanoindentation mechanism can be applied to the study of the mechanical properties of wood. For example, wear resistance and impact resistance are important when dealing with wood flooring. Wood densification, wood chemical modification, and wood impregnation with resin can improve the hardness of wood (Moon et al. 2006). By understanding the mechanical characteristics of how these processes modify cell walls in the wood, it would be possible to make a specific hardening process more effective. Gindl et al. (2004) used nanoindentation to determine that phenol-formaldehyde (PF) diffused into wood cell walls, whereas polymeric methylene diphenyl diisocyanate (pMDI) did not. Nanoindentation led to the discovery that the PF cells have a greater degree of hardness than the pMDI cells (Gindl et al. 2004). In addition to measuring hardness, nanoindentation provides the means to measure mechanical changes during wood decay (Kumar et al. 2008). Studying the mechanical processes of wood decay and degradation could lead to prevention methods. There are several studies that have been conducted with nanoindentation to evaluate cell wall lignification (Gindl et al. 2002), modification of melamine (Gindl and Gupta 2002), and mechanical properties of native wood fibers (Tze et al. 2007).

Layer-by-Layer Nanocoating Technique

The layer-by-layer (LbL) nanocoating technique produces an extremely thin film of polyelectrolytes, proteins, or nanoparticles. Lu et al. (2007) used the LbL technique to position several layers of TiO_2, SiO_2, and halloysite clay nanotubes on kraft softwood products. They compared the LbL nanoparticle paper products with a control paper and found that the paper brightness and porosity were significantly higher in the nanocoated fiber paper than the control. The elevated porosity of the LbL paper creates the opportunity for applications in pharmaceutical and biomedical applications. Therefore the LbL nanocoating process could have significant promise for the pulp and paper industry.

Pulp and Paper

In the pulp and paper industry, nanotechnology has enormous potential. Research is being conducted on smart paper, methods for reducing emissions in the paper industry, printability improvements, and opacity improvements (Agarwal et al. 2006).

Smart Paper

Agarwal et al. (2006) describes smart paper as electrically conductive and explores a method to realize a controlled conductive coating for lignocellulose microfibers that can be incorporated into paper through layer-by-layer nanocoating. Currently, the conductive paper can be functional and stable for more than six months. This type of research will be especially beneficial for producing electronic devices, capacitors, inductors, and transistors. Conductive nanocoating on wood fibers can be useful for the development of sensors, communication devices, and electronic paper displays. Continued research in this area promises to revolutionize the pulp and paper industry.

Researchers are using nanotechnology to develop transparent transistor circuits that can be applied to "e-paper" (http://www.sciencedaily.com/releases/2007/06/070626140339.htm). Fully transparent nanowires, developed by Ju et al. (2007), have excellent transparency, flexibility, and remarkable device performance. Moreover, the nanowires can be incorporated into paper to create conductive, usable, flexible, and transparent paper products.

Filtration Systems

Nanofiltration is a pressure-driven membrane separation process that provides an excellent segregation of ions. Nanofiltration can be used to manage or treat water and it can separate water ions with great selectivity. This type of water filtration provides a competitive means to manage pulp and paper wastewaters (Puurunen and Vasara 2007). The water that is used in the pulp and papermaking process can be recycled to reduce freshwater consumption, which is better for the environment and also reduces industrial costs.

Paper Coating

Nanotechnology can be used to improve certain aspects of paper quality. TopChim, a company that specializes in paper and cardboard technology, has developed a nanotechnology-based paper surface treatment called NanoTope. This coating product, when applied to paper, creates a glossy finish, high whiteness, and stiffness (http://www.topchim.com/zeta.pdf). NanoTope creates paper that fixes ink well, which leads to a higher resolution and a denser printed image. Moreover, this product has good printability performance.

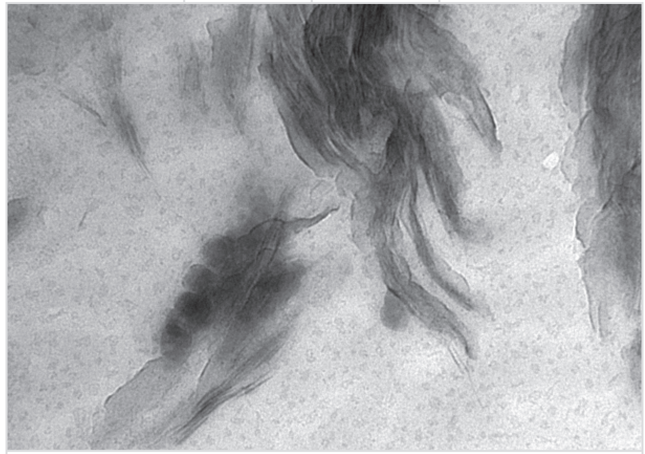
A spray-on water-repellent nanocoating for paper has been developed that consists of hydrophobic polymers and waxes. After application, the spray dries and a nanostructure is created through self-assembly of the nanoparticles. This nanostructure is a barrier to water that can be useful for many applications.

Environmental and Human Health Risks

As nanotechnology gains popularity in the industrial and commercial world, it is essential to analyze its environmental and human health risks. By learning more about the risks associated with nanotechnology, we will be better equipped to understand the exposure routes and potential safety issues associated with its use.

There is a discrepancy between the number of published papers that deal with the development of nanoparticulate material and the number of toxicity studies being done. This discrepancy is being addressed as scientists become more concerned about the implications of nanotechnology. Dr. Dietram Scheufele states that scientists are saying that they do not know whether there are problems because the research has not been done (Scheufele et al. 2007). There is some evidence, however, that nanoparticles may have adverse effects on the environment, humans, and animals. For example, Oberdörster et al. (2005) have shown that due to a high surface area-to-volume ratio, nanoparticles are more biologically active than other larger molecules and can enter the human body. Dr. Scheufele also conducted a survey of the number of nanotechnology articles published in major newspapers in 2004, 2005, and 2006 (http://www.nanolawreport.com/2007/12/articles/new-nano-public-opinion-poll-published-in-nature-nanotechnology). He compared the number of articles that mentioned the environmental, health, and safety (EHS) risks or nanotechnology regulation with the overall number published. Over 1200 nanotechnology articles were published in 2004, in 2005, and again in 2006. Only about 20% of these articles mentioned potential nanotechnology EHS risks or regulation.

Public concern about nanotechnology's harmful effects is somewhat less than that of scientists (Scheufele et al. 2007). This information disconnect could be detrimental to the future of nanotechnology. There seems to be minimal knowledge about nanotechnology among the general public. There are numerous types of nanomaterials and to date, there is not much regulation in their production or use. Moreover, because the types of nanomaterials are so diverse, it is almost impossible to have a set type of regulation and to classify them as one substance. In the United States, the material safety data sheets for the majority of nanomaterials are identical to that of the macro or bulk material (Colvin 2003).



Paint reinforced with nanometric clay.

When studying the environmental and toxicological effects of nanotechnology, it is important to investigate direct and indirect exposure routes. As the demand for nanomaterials increases, production will increase as well as possible exposure. Therefore analysis of how humans, animals, and the environment may come into contact with engineered nanomaterials is a necessity as nanotechnology becomes more prevalent in industry (Colvin 2003). Occupational exposure may be a significant risk as the safety precautions associated with the use of nanoparticles are often the same as the bulk materials of the same composition. This is important because nano-sized particles do not behave like their larger-sized counterparts. They have unique physical characteristics and are subject to different physical forces. Therefore specific restrictions should be developed in the occupational setting to account for nanoparticle size and corresponding properties.

Because there are so many envisioned applications for nanoparticles, it is important to be concerned about how they will behave when they enter the environment. A predicted widespread use of engineered nanoparticles in consumer products will lead to an inevitable increase in exposure rates in occupational, public, and environmental settings. It is crucial that the possible risks to human health and the environment be identified and mediated. It is important to undertake relevant research on the toxicity and effect of nanoparticles in general.

Overview of Nanotechnology Research Initiatives

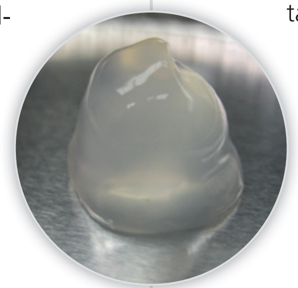
National Research Initiatives

In Canada, nanotechnology is becoming more of a research priority (Office of the National Science Advisor 2007). Nanotechnology is a growing field and incentives in both Alberta and Quebec are pioneering nanotechnology research in Canada. Funding for research is provided primarily by the Government of Canada through university research grants, research chair grants, and direct funding to create the physical infrastructure needed for research (that is, new facilities and equipment). Over the past decade, the federal and provincial governments have invested approximately $641 million in nanotechnology research.

Nanotechnology is one of the fastest emerging areas for research in the federal government's research and development portfolio in the last couple of years. Federal agencies and organizations such as the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR), the Canada Foundation for Innovation (CFI), and the National Research Council (NRC) provide significant investment dollars for nanotechnology research. In 2005–2006, NSERC funded approximately $20.9 million in nanotechnology research. In the past decade, NSERC has funded about 1200 projects with a focus on materials engineering, nanoelectronics, and photonics. The CIHR is more focused on nanomedical research including molecular imaging, clinical imaging, biomaterials, and drug delivery and has invested $35.4 million since 2000. The CFI was initiated by the Government of Canada to fund Canadian universities and research institutions. Since 1997, the Government of Canada has allotted $3.65 billion to the CFI and by the year 2010, it is estimated that number will reach $11 billion. Approximately $107 million of the government funding to the CFI has been directed to 173 nanotechnology research projects with a focus on nanoelectronics. The NRC is Canada's leader in research and development in the federal government. It invested about $20 million in 2005–2006 in nanotechnology research and has spent about $25 million in nanotechnology research programs including $2.7 million that was expended for the Pathogen Detection Program of the NRC's Genomics and Health Initiative that is based on biotechnology. At Natural Resources Canada, the nanotechnology research and development strategies are focused on three projects that are approved through the regular science and technology approval system and are therefore not specifically funded as nanotechnology projects: Nanotechnology for Climate Change; Nanotechnology for High-Performance Sensors, Actuators, Coatings, and Composites; and Nanoscience Application to Energy Technologies.

The Canadian Forest Service, through the Transformative Technologies Program, is investing over $3 million a year for three fiscal years (2007–2010) to conduct research on nanocrystalline cellulose. The research and development projects will be realized by FPInnovations and its partners. The research will concentrate on 1. producing nanocrystalline cellulose; 2. developing nanocrystalline cellulose applications; 3. applying nanocrystalline cellulose to forest products processes; 4. addressing EHS concerns of nanocrystalline cellulose applications; and 5. chemistry applications for next-generation building solutions, including improving fire resistance of structural wood adhesives with chemical modifications and nanotechnology, and surface densification and impregnation using nanotechnology.

Provincial nanotechnology activities are occurring primarily in Alberta, Quebec, British Columbia, and Ontario, accounting for 95% of Canada's nanotechnology research initiatives. Alberta has classified nanotechnology as a primary research endeavor and has committed $130 million to research over the next three years—$30 million will be used for an undergraduate nanotechnology program to stimulate interest in this developing sector. In Quebec, nanotechnology



Top: One percent of nanocrystalline cellulose in water forms a stable colloidal suspension.

Middle: A 7% nanocrystalline cellulose suspension in water forms a gel.

Bottom: Pure freeze-dried nanocrystalline cellulose.

has been identified as a definite research priority in the Research and Innovation Strategy of the Government of Quebec. In 2001, NanoQuébec was created as a governing body to connect academia, government, and industry in Quebec (http://www.nanoquebec.ca/nanoquebec_w/site/fiche/12726). NanoQuébec is currently developing a research and development program for nanotechnology in the forestry sector in partnership with FPInnovations. The main themes of the program are the wood transformation sector and pulp and paper sector. The program budget is over $1 million of which $400 000 is being contributed by NanoQuébec and $300 000 by FPInnovations. Other sources, including NSERC, provide over $300 000 in funding (NanoQuébec 2008a). NSERC project selection is anticipated to be complete by January 2009 (NanoQuébec 2008a).

The Business-Led Networks of Centres of Excellence is a fairly new program that will provide funding of $46 million over four years to five select nanotechnology research groups (NanoQuébec 2008a). It is a joint initiative of Industry Canada, NSERC, the Social Sciences and Humanities Research Council of Canada, and CIHR. Currently, the Canadian Forest NanoProducts Network (ArboraNano) is one of the 10 programs in consideration for the funding. The network's objective seeks to "Create a new Canadian bio-economy using our vast sustainable forest resource and advanced nanotechnology concepts to create innovative high-value products in many different manufacturing sectors" (NanoQuébec 2008b).

In British Columbia, Simon Fraser University has opened a new facility that will specialize in nanotechnology as it relates to nanoscale processes and phenomena, a research focus that accounts for approximately 20% of Canada's overall nanotechnology research incentives. Ontario does not have a research strategy yet, but the provincial government is taking steps to move forward with nanotechnology research.

Nanotechnology is an important emerging field for research and development and Canada is working to develop strategies that are in line with this fact. The future of nanotechnology remains to be discovered and Canada is beginning to take a proactive role in its discovery.

International Research Initiatives

Internationally, the leaders in nanotechnology investment are the United States, Japan, and the European Union (Shand and Wetter 2006). In 2005 alone, the United States Government invested approximately $1081 million in nanotechnology research and development. The European Union and Japan invested $1050 and $950 million in 2005, respectively, in nanotechnology research and development. With the launch of the US National Nanotechnology Initiative (NNI) in 2001, nanotechnology has become a growing and promising field for investment. Since the NNI was initiated, the United States has spent over $5 billion on nanotechnology research and development. Next to the Apollo moon landing, this is the largest publicly funded science initiative (Shand and Wetter 2006).

Conclusion

Nanotechnology has significant promise in many different fields including forestry. Collaboration among industry, academia, and society must occur to overcome the challenges associated with the future of nanotechnology in the various sectors of application. Moreover, because nanotechnology draws from several fields, different sectors must contribute information and techniques to further the development of nanotechnology. To date, opportunities in nanotechnology are numerous and continue to expand in many sectors. In forestry, there is promise of the creation of new materials and more efficient wood-processing methods, as well as improvements to wood through increased pest resistance, decreased ultraviolet degradation, and moisture resistance. It is an exciting time for research in forestry as nanotechnology is relatively new and has so much potential. Yet, as with all young disciplines, it is important to evaluate the risks that nanotechnology may pose to the environment, humans, and animals. Currently, developing a framework for regulation is important and necessary. A greater understanding of the implications of using nanotechnology and the hazards associated with its use will ensure that nanotechnology is a valuable tool for our future.

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