Nanocellulose

On the cusp of commercialization?

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Could you imagine that representatives of IBM and Bell Helicopter Textron would be keynote speakers at a pulp and paper industry conference, and they would be asking the industry for new, innovative bio-based materials to use in their mainline products?

Not a chance, just a few years ago. Now, this dialogue between seemingly dissimilar industries is happening, as shown at Tappi's 2012 International Conference on Nanotechnology for Renewable Materials held in Montréal, Canada, recently. This precedent may signal an irrevocable change in the industry, as new wood fiber based nano-products may eventually form a lucrative revenue stream aside from the traditional paper industry fiber consumption. Major businesses outside of pulp and paper are now hungry for sustainable bio-materials with enhanced functional properties which can displace or improve upon traditional petroleum-based or other non-renewable materials.

Knocking at the door

Just recently, the whole "nano" field has created a lot of awareness, exemplified by some headlines which say that nanocellulose is stronger than steel. Indeed, a nanocellulose additive does vastly enhance the strength of composite materials, but strength is not the only attribute. There are many potential applications for nanocellulose-containing products including barrier films, coatings, papermaking additives, paint rheology modifiers, automotive components, cosmetics, concrete strengthening additives, colored films without pigments, and paper-like flexible electronic displays. Even medical applications such as scaffolding for building nerve cell networks and rebuilding human cartilage and tendons are being investigated.

Bell Helicopter, IBM and many other companies in diverse fields, are knocking at the door to see what the fledgling nanocellulose industry can provide for them. Interest and research activity in nanocellulose – a broad term to describe many different versions of extremely small-scale fibrillated or crystalline cellulose – has blossomed over the past few years. Literally hundreds if not thousands of researchers are working on the development for a multitude of applications. Figure 1 illustrates how research and technical publications in this area have skyrocketed over the past several years. The list of top national contributors to the field of knowledge indicates that this is a worldwide effort.

While the research activities will no doubt continue for many years, production of products containing nanocellulose on a commercial scale may be just around the corner. New pre-commercial pilot plants have recently started-up to move the product from the laboratory to the point where it can be produced in sufficient quantities for production trials in a variety of process applica-

Nanocellulose crystals shown here can produce composite materials stronger than steel

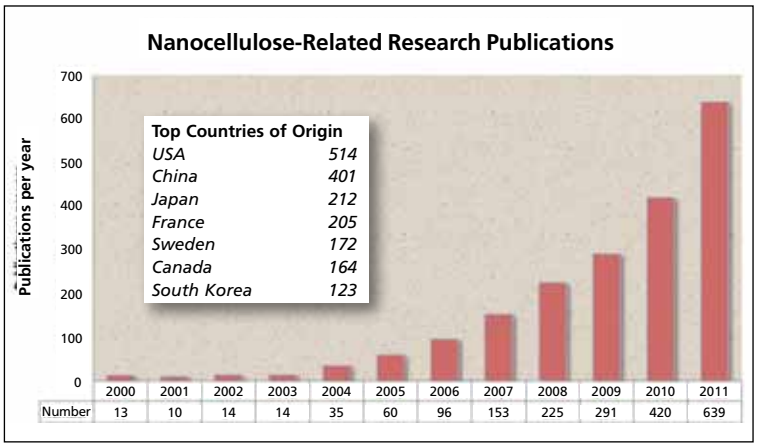

Fig. 1: Research and technical publications regarding nanocellulose have skyrocketed over the past several years

The data analysis is courtesy of Kristiina Oksman, Professor at Luleå University of Technology

tions. Grams of production in the lab are now measured in hundreds of kilograms and tonnes. Domtar, Stora Enso and UPM are the first pulp and paper companies to invest in pilot-scale demonstration plants.

The recent Tappi Nanotechnology Conference was an interesting and innovative blend of what research is going on, what the challenges are, and what the near and far future may hold. The business of innovation and market focus in research and development, and R&D risk management by collaboration and partnerships were other recurrent themes. The topics of the technical presentations included fundamental research of nanomaterials and applications in polymer composites, films, light-responsive composites, wood coatings, paper strength-enhancing additives, paperboard coating additives, wood adhesive reinforcement, and food packaging. There were also nine poster presentations by students from Canada, USA, China and France.

Rolled pulp from the adjacent Domtar Windsor mill is the feedstock for the CelluForce NCC pilot plant, part of which is shown on the bottom

Other sessions discussed the development of standards in the new, just developing industry and health and safety issues. So far, the safety issues do not seem to be a concern, but they must be diligently addressed and approved by authorities.

A game changer

Vincent D'Arienzo of Bell Helicopter Textron gave a keynote address outlining the potential for nanomaterials, including nanocellulose, in the manufacture of its aircraft. Vincent is a technical fellow who is part of a team set up to develop a 20-year technology roadmap that will introduce new products and improve existing platforms. He said that nanotechnology is a game changer since it gives the hope that the next generation of aircraft will be lighter and perform better. "We would like to tap into the potential of bio-based nanotech," he said.

Among other objectives, Bell is looking at better protection against lightning and magnetic interference, fire resistance and impact resistance. Lowering costs is also an objective. He stresses that collaboration between different companies and research organizations was a key to their approach. "We need to find a way to work together since we make aircraft, not nanoparticles," he said. This need for collaborative development was stressed by other presenters and discussed during question periods.

Another keynote address was delivered by IBM's Dr Dylan Boday who is the Advisory Team Lead Engineer for the company's Materials Engineering Laboratory. IBM is pushing for bio-based engineering blends for its large mainframe computers. Boday describes some of the objectives of the company's sustainable materials initiative. "We are looking at alternatives to polymer-based materials and achieving equivalent functional specs at a neutral cost. The supply chain for alternate materials is very important to us." He cited some applications which could be appropriate for nanocellulose, including power supply enclosures, fan housings and connectors. But he stressed that the IT industry just at the beginning of exploiting these possibilities. "Baby steps are needed before sustainable materials are off and running," he concludes.

A presentation by Jean Hamel, vice president of Pulp, Paper and BioProducts at FP Innovations, described how

Mikael Ankerfors

Jean Moreau

Canada's primary pulp and paper non-profit research organization changed its orientation and ways of thinking over the past few years. The former Paprican is now focused on innovative, focused and nimble research and product development to address potential customer needs. Nanocellulose – specifically nanocrystalline cellulose – is one successful example. He said, "We are seeing the industry in a different way now. Basically, we are disassembling wood into its most minute components and then re-assembling it into some other form to add value." The key to their efforts is to develop an efficient process, develop the product to add value and bring it to existing or new customers.

Green chemicals from Mother Nature

Hamel's speech led directly to a presentation by Jean Moreau, President and CEO of CelluForce, a new company formed less than two years ago as a joint venture between FP Innovations and Domtar Inc. With significant investments by Canadian federal and Québec provincial government agencies, the world's first NCC (nanocrystalline cellulose) demonstration plant was inaugurated in early 2012 in Windsor, Quebec, adjacent to a large Domtar integrated kraft pulp and fine paper mill. The plant has a designed capacity of one t/d of NCC which will be shipped to various undisclosed collaborators who will investigate the application of NCC in their products. The NCC process uses acidic hydrolysis followed by several separation stages to arrive at the final dried product. The plant is still in its ramp up mode right now.

NCC, with its extremely minute crystalline structure, is not aimed at papermaking applications, explains Moreau. "It is specialty chemical not a commodity, so it

is aimed at high value-added products. It has opened up a whole new world of applications of green chemistry which Mother Nature offers," he says.

CelluForce has signed up 30 collaborators who will evaluate production trials. By 2016, Moreau foresees industrial scale production plants which may have a production capacity of perhaps 50 t/d. The volumes of NCC will not be large at the beginning since the desired functional properties can be achieved with low addition rates, perhaps 1 to 2 % of the product's weight. "In rheological applications in the oil and gas industry even one half percent makes a difference," says Moreau.

Production plants in the future may be attached to pulp mills like Domtar's or may be built on-site by the end users. Moreau leaves the door open for collaborators to build the plants themselves under license.

Crystals vs. fibrils

While the Canadian industry is focusing mainly on NCC, European and other researchers and industrial partners are looking at the potential of nanofibrillated cellulose (NFC) and the larger dimensioned microfibrillated cellulose (MFC) which are produced by a mechanical disintegration process. The difference between the crystalline products and the fibrillated product is much like comparing rice to spaghetti. Unlike the crystalline product, the nanofibrils are appropriate for papermaking furnish applications.

The Innventia pilot plant in Stockholm produces 100 kg/d of nanofibrillated cellulose

The world's first pilot plant to produce NFC was inaugurated in Stockholm by research company Innventia in February 2011. The pilot plant is designed for a production at 100 kg/d. "With larger volumes, we can study the use of nanocellulose in applications that require more material," says Mikael Ankerfors, a research manager at Innventia. Previously, the production process was much too energy-intensive, for the commercialization of nanocellulose to be conceivable. Due to the process developments carried out by Innventia, the energy consumption has been reduced by 98 %.

Ankerfors says Innventia is currently working with up to 30 collaborators interested in NFC applications. He emphasizes that, as an independent research organization, Innventia's goal is not to sell NFC but to help others work with it. He foresees commercial products using NFC to come out within one to two years. Commercial plants to produce NFC for use as a wet-end additive in papermaking will be initially be in the scale of perhaps 5,000 t per year or less, as dosage levels will be limited. In fact, one presentation at the recent Tappi conference by UPM researchers documented pilot machine results where 1 % to 2 % dosage levels were used. By reinforcing the strength of a paperboard sheet, a significant reduction in grammage was possible while maintaining strength specifications.

In pursuit of commercialization

In addition to Domtar, through its CelluForce joint venture, forest industry companies UPM and Stora Enso are also getting in on the pursuit of nanocellulose commercialization. In November 2011 UPM said that it has started pre-commercial production of fibril cellulose at a pilot plant in Espoo Finland and is currently developing new fibril cellulose applications with industrial partners. The production capacity was not disclosed although a spokesperson said that it would be "a significant amount for trials at UPM mills."

"Fibril cellulose is part of UPM's renewal and our Biofore strategy. We are currently focusing on commercializing fibril cellulose. The first stage mainly consists of developing products used in paper and packaging materials and the concrete and paint industries. We are also looking for new partners to develop new applications," says Esa Laurinsilta, director, UPM Fibril Cellulose. UPM's fibril cellulose has proved to be functional in several application tests over the past few years. "In October 2011, we produced the first industrial-scale batch of specialty paper reinforced with fibril cellulose at the UPM Tervasaari mill," Laurinsilta says.

Stora Enso also announced a similar step toward commercialization by starting up a MFC pilot plant at its

Imatra mill site in Eastern Finland that was started up at the end of last year.

Stora Enso CEO Jouko Karvinen says, "With MFC we will be able to develop lighter, stronger renewable packaging materials, a lot more with a lot less. The pre-commercial plant will put us into a unique position to accelerate customer-driven innovation and product concepts from this technology. In the longer term, as we continue to renew and challenge ourselves, the applications of this renewable material may well extend to replacing today's fossil-based materials such as plastics and some specialty chemicals, and aluminum – revolution instead of evolution."

Other suppliers of micro or nano scale cellulose include Borregaard in Norway which produces MFC on a pilot scale, Rettenmaier in Germany which produces nanocrystalline cellulose as an inert filler for pharmaceuticals, and Daicel of Japan which markets its trademarked Nano Celish product.

New research-focused pilot plants

The need for materials for research purposes has also spawned new small scale pilot plants which have just been announced. This summer, the U.S. Forest Service Forest Products Laboratory opened a USD 1.7 million NCC pilot plant in Madison, Wisconsin, USA. The attributes of products using NCC have caught the attention of companies in the automotive, aerospace, electronics and medical-device industries as well as the military for use in lightweight armor and ballistic glass. The first commercialized product to come from the program will likely be a paper coating, says a spokesperson. The University of Maine's Forest Bioproducts Research Institute is building a pilot-scale plant for manufacturing cellulose nanofibrils (CNF) in Orono, Maine, USA. Six other universities and the US Forest Products Laboratory are involved in the project.

A pilot facility in Edmonton, Canada will produce nanocrystalline cellulose. The USD 5.5-million pilot plant, created through a collaboration of the Alberta and Canadian federal governments in partnership with industry, will use wood and straw pulp. Canadian company Bio-Vision Technologies based in Nova Scotia, Canada will build a pilot plant producing carboxylated nanocrystalline cellulose.

New products just becoming apparent

While the research and application development will continue for many years, new products using micro or nano scale cellulose are just becoming apparent. Just announced in early 2012, the VTT Technical Research Centre and Aalto University in Finland have developed a method which enables manufacturing of nanofibrillated cellulose film, which is suitable for food packaging to protect products from spoilage. The films can be manufactured using devices that already exist in the industry, without the need for any major additional investment.

Daicel in Japan is developing applications for its Nano Celish, a nanocellulose product. The company says that mixing nano-scale fibers into a resin produces an exceptionally strong composite product which helps to produce increasingly lighter automobiles. The addition of Nano Celish to resin does not affect its transparency. For this reason, the company says it is now planning to mix it into plastics to manufacture a composite material substitute for glass.

"Killer apps" to come?

Today's nanocellulose is a catch all term which combines together quite different types of very small-scale cellulose derivatives. Those different types of products have distinct properties and applications. As the industry matures, standards and terminology will be refined and well-defined grades of nanocellulose may become apparent, perhaps like familiar grades of paper and pulp. Some day MFC, NFC and NCC and variations of them may become as distinct as TMP and NBSK.

The future looks promising as there is an incentive to make these products work from the supplier's side and the end-user's side. Both the push and pull of the market exist together. There is much work to be done and challenges to be overcome to economically scale up pilot plant processes to production facilities and to easily and cost-effectively make the products work in industrial processes. Patience and perseverance will be required as there may be some failures as well as successes. In the future, the "killer apps" of the industry may become apparent.

The future is for the students

Perhaps the most promising part of the nanocellulose revolution is the number of students working on the science and applications all over the world. It seems that wood cellulose is becoming high-tech and maybe a cool field to work in. Recently, Janelle Tam, a 16-year-old high school student from Waterloo, Ontario won the Canadian Biogenius award competition sponsored by the pharmaceutical company Sanofi for her work on a science project in which she demonstrated that nanocrystalline cellulose could be effective is a powerful anti-aging antioxidant. It may be superior to Vitamin C or E because it is more stable and its effectiveness won't diminish as quickly. Janelle chemically paired NCC with a well-known nanoparticle called a buckminster fullerene. These bucky balls are already used in cosmetic and anti-aging products. The new NCC-buckyball combination acted like a nano-vacuum, sucking up free radicals and neutralizing them.

If this level of interest and dedication among young people can be maintained then the future is indeed bright. ■