The Growing Promise of Nanocellulose

Nanocellulose is finally making the leap from the lab to the market, and pulp and paper companies need to pay attention to the opportunity it offers.

GLENN OSTLE

The drooping demand for communication papers has caused many pulp and paper companies to look at converting to different grades or find additional revenue streams. Spurred on by the industry's growing interest in sustainability and its heavy investment in wood-based products, two technologies appear to hold promise in this regard: bioproducts and emerging nanocellulose technology.

It has taken a while, but bioproducts are now starting to make their way in the industry. Regular announcements appear about new facilities or joint ventures relating to biorefining or new uses for lignin, sugars and cellulose. In 2014, North America's advanced biofuel industry reached a production capacity of more than 800 million gallons, up from the previous year and almost double the capacity in 2011.

Commercialization of nanocellulose, however, seems to be on a longer path. This is not surprising in one way as so much development work still needs to be done, but is surprising in that it doesn't seem to be on the radar of many pulp and paper companies, despite the fact that it offers so many future opportunities.

The evolution of bioproducts is exciting for our industry and presents the opportunity for new revenue streams. But essentially it is just driven by the need to find a new fuel source. By comparison, the application of nanocellulose will result in brand new products with applications that are still to be identified and that will provide unique competitive advantages. And it originates from cellulose, so why aren't more pulp and paper companies pursuing it?

CelluForce's Richard Berry asks a question during the final panel discussion.

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ATTENDING THE CONFERENCE

More than 265 technical experts from 24 countries gathered at Atlanta in June to attend TAPPI's International Conference on Nanotechnology for Renewable Materials to learn about research being performed to create nanocellulose-based materials or products. Mirroring the growing international interest in nanotechnology, more than 40 percent of attendees were first timers, and more than half were from outside the U.S.

The conference, now in its 10th year and cycling annually between the U.S., Canada, and Europe, featured 116 presentations covering lab and pilot research being conducted on nanocellulose—including how it is currently being commercialized—in a wide range of fields, including composites, electronics, biomedical and specialty applications.

Keynote speaker, Dr. Marie D'Iorio, executive director of the National Institute for Nanotechnology and professor of physics and assistant VP of nanotechnology research at the University of Alberta, pointed out that the field is still in its early stages. She described some of the challenges of nanotechnology commercialization, including scalability, manufacturing, integration, lifecycle assessment, and health and safety. To demonstrate how new technology often is slow to take hold, she cited the carbon tube, which 20 years after being discovered is still being developed in the areas of manufacturing, simulation and modeling, standard materials and protocols for commercial applications.

WHY ALL THE FUSS?

Nanocelluose is an abundant, sustainable and renewable resource with a host of advantages ranging from high strength and light weight to low cost. The U.S. Forest Service estimates that by 2020 it could add $600 billion to the

U.S. economy, and in February the forest products industry's Agenda 2020 announced that it was one of six research areas it intended to pursue under its Advanced Manufacturing Technology cooperative agreement with the National Institute of Science and Technology. Not bad for a technology that is still more in the test tube than in the field.

According to Jack Miller, principal consultant, Market-Intell Inc., although nanocelluse has been known since the 1950s, only in the last few years has it moved from the lab to the market as technical and cost challenges have prevented it from achieving extensive commercialization. Miller also said that nanocellulose technology today faces an "investment gap" as funding from government and research institutions is limited. "Each effort must be a sound value proposition and business case," he said. "Ultimately, customers will have to fund the investment to bring nanocellulose to commercial scale."

Pia Qvintus, head of research area for Finland-based VTT, said that she believes "CNF is on the verge of a breakthrough" as there are already several CNF producers in the market and new applications are emerging. She feels they have a great potential as strength additives in multilayer films and membranes, and as rheology modifiers. Qvintus pointed out that the key potential markets for nanocellulose include paper and board, packaging composites and films, paints and coatings, oil and gas, manufactured textiles and cement.

The number of patents for nanocellulose has also been increasing in recent years, according to Jesse Kautto of Pöyry, who says that research is clearly focusing more on applications where nanocellulose can be applied, without immediate drying or surface modification. The greatest amount of patent activity has been taking place in China, followed by the World Intellectual Property Organization (WIPO), Japan and then the U.S. Says Kautto, "Understanding the competitive advantages of nanocellulose is necessary in order to identify the 'killer apps,'" she says.

MATERIALS OR PRODUCTS

The majority of the conference papers in Atlanta were presented by either university research groups or independent research organizations that are creating nanocellulose in lab or pilot scale that could, when finalized, be a material used to improve an existing product. A smaller portion of the research covered nanocellulose material designed to become products themselves.

American Process opened their doors for tours of their 4,100 sq. ft. nanocellulose pilot plant in Thomaston, Georgia, where, using their AVAP pretreatment process, they produce 3-10 tpd of CNC, CNF and blends; lignin coated nanocellulose; cellulosic sugars; and cellulosic ethanol.

Every application of nanocellulose is, or should be, of interest to the pulp and paper industry because each could conceivably grow into a potential market for pulp. Wood-based nanocellulose also shows great promise when combined with paper and board products. So it would seem logical that pulp and paper companies, with more than 100 years of pulping experience and large, installed bases, would be taking the lead in this research. Yet, only a handful of pulp and paper companies and suppliers made presentations at the conference. This could possibly be attributed to the high cost of being a pioneer in new technology, or simply, as Richard Berry of CelluForce suggests, that a lot of research is being done "under the radar."

Pulp and paper companies and suppliers that made presentations at the conference included:

Alberta Innovates Technology Futures: In 2010, was funded through a collaboration of governments and financial contributions from Alberta-Pacific Forest Industries, to design and construct a new CNC pilot plant. It can produce 20 kg of CNC per day.

American Process: One of the conference sponsors, API opened its doors for tours of their 4100 sq ft nanocellulose pilot plant in Thomaston, Georgia, where, using their AVAP pretreatment process, they produce 3-10 tpd of CNC, CNF and blends; lignin coated nanocellulose; cellulosic sugars; and cellulosic ethanol. April 2015 marked their first shipment of nanocellulose under the trade name: BioPlus. They are anticipating achieving commercial scale in two or three years. During her luncheon presentation, an energized Theodora Retsina, API president and CEO, challenged the group to "rethink trees" by asking "what *can't* nano do?"

Imerys: Described their FiberLean™ microfibrillated cellulose/mineral composite product

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family of materials that have been developed from bench to production scale. They presented a new cost effective grinding based method for production of MFC from minerals and cellulose pulp. They estimate producing more than 12,000 tpy by early 2017. In 2014, Imerys installed a microfibrillated cellulose plant at the Verso paper mill in Bucksport, Maine.

Kruger, Trois Rivieres/FPInnovations: Together in a three-year, $43 million project to build the first pre-commercial Cellulose Filament (brand name FiloCell) plant at Kruger's Trois Rivieres mill in Quebec, with a nominal capacity of 5 tpd. Their process can peel a kraft fiber into 1000 cellulose filaments. They expect to open up new markets for Canadian pulp and paper manufacturers in the areas of reinforcement, tissue and towel, lightweighting of paper, creating high bulk/high opacity for LWC, high opacity in publication grades and re-dispersible pure 15-30 gsm CF Film. They also anticipate serving markets including composites, adhesives and rheology modifiers. In November 2014, they won the "Open Innovation" Award.

Melodea/Holmen: Announced a pilot plant to produce CNC from paper mill sludge, waste and wood pulp in 2016 that will be the first CNC pilot plant in Europe. Melodea produces CNC films for coating that can be applied as a transparent oxygen barrier for packaging, to reduce friction on load-bearing o-rings, and as a coating for sports equipment. They also produce CNC foams that can be used for composites and insulation, and rigid foams for sandwich composites that are fire resistant.

Nippon Paper. Described efforts to prevent aggregation of CNFs during the drying process and to re-disperse them in water. They are creating nano composites for Functional Sheets (packaging materials, transparent films, filters) and Functional Additives (rheology modifiers, etc.) 30 tpy TEMPO, CMC, carboxhlated CNF. Estimated that they can produce 150 kg of CNF per day.

Oji Paper. CNF is a nano-size cellulose fiber with a high aspect ratio which is produced by pulp fibrillation. Last year Oji, the largest pulp and paper company in Japan, with 31,000 employees, successfully manufactured a continuous roll of transparent CNF film that can be used as a material for flexible organic light emitting displays (OLED), foldable solar cells and TFT substrates.

Southworth Company/Paperlogic: A collaboration with the University of Maine, GL&V, the USDA Forest Products Laboratory and funding from P3Nano resulted in the startup of the commercial cellulose nanofibril production facility. Kenneth Shelling, mill manager/technical director of the small, privately owned company in Turners Falls, MA, described their 30 tpd paper machine that started up May 15, 2015, and how the company has sold off papermaking operations and is now evaluating new and innovative technologies such as nanocellulose and nanomaterials. Their goal is to demonstrate that refiner-based CNF is scalable to commercially relevant production rates, and to ultimately maintain a competitive advantage in the specialty paper marketplace. It is estimated that they can produce 2,000 kg of CNF per day.

Other pulp and paper related organizations involved in commercial development of nanocellulose that did not present at the conference include:

NORTH AMERICA

- **Blue Goose Refineries:** Can produce 10 kg of CNC per day.
- **CelluComp:** Curran® cellulose nanofibers from food waste materials.
- **CelluForce:** Joint venture betweeen FPInnovations and Domtar. In 2014, announced the first commercial application for cellulose nanocrystals and can produce 1000 kg per day. In February, it received a contribution of $4 million from Sustainable Development Technology Canada to optimize the extraction process of cellulose nanocrystals for use in the oil and gas sector. Recently, oil and gas giant Schlumberger became a shareholder.
- **Engineered Fibers Technology:** Producing nanofibrillated fibers from Lyocell.
- **Performance BioFilaments** (Mercer/Resolute JV): Cellulose filaments. Future plans for 50,000 to 100,000 tpy.
- **U.S. Forest Products Lab:** Can produce 10 kg of CNC per day.
- **University of Maine**, Orono, ME. Can produce 100kg of CNF per day.

EUROPE

- **Billerund Korsnas/Innventia:** Mobile facilities for nanocellulose production.
- **Borregaard, Norway:** Exilva cellulose microfibrils 150 tpy. Commercial scale to 1000 tpy by 3Q16.
- **CelluTech AB** (Sweden): Cellulose foams, spheres and magnetic cellulose.
- **Innventia**, (Sweden): Estimated that they can produce 100 kg of CNF per day.
- **NamiCell** (France): Estimated that they can produce 100 kg of CNF per day.
- **Södra**, together with Innventia and seven other organizations, has been awarded an EU research project to increase investments in development for manufacturing carbon fibre-reinforced plastic composites from kraft lignin.
- **Stora Enso:** New board grades containing MFC are about to enter the packaging market.
- **SAPPI/Edinburg Napier University:** New process for dry redispersible CNF.
- **UPM,** Finland: Pre-commercial.

JAPAN

- **Daicel:** CMC, Celish MFC
- **Consortium of 100 companies** (2014).

Miller reinforced the importance of nanocellulose development in Japan by using a quote from *The Japan News* of August 8, 2014, which read: "The Japanese Economy, Trade and Industry Ministry contacted manufacturers that may use nanocellulose in the future, and established a study group for the public and private sectors. It will comprise major paper manufacturers such as Nippon Paper Industries and Oji Holdings Corp.; Toyota Auto Body Co.; Mitsubishi Motors Corp.; Mitsui Chemicals Inc.; Denso Corp.; Kao Corp.; and other interested companies."

OTHER EXCITING POSSIBILITIES

With 116 presentations at the conference, it was impossible to attend them all, despite the fact that some of the topics and proposed applications were exciting and conjured up visions of space-age products, including:

Jack Miller, Principal Consultant, Market-Intell Inc.

Sean Ireland, Verso.

Shaul Lapidot, Melodea.

Hiroaki Namba, Nippon Paper.

- Nanocellulose as a substrate for electronic products
- Interactive packaging
- Paper memory for Smart products
- Organic printed electronics on CNC substrates
- Wearable electronics and batteries
- Paper-based alternatives to bar codes and RFID
- "Tuneable" paper
- Recyclable solar cells
- Organic Field Effect Transistors
- Capacitors
- Transparent electrodes
- Photovoltaics
- Flexible displays
- Fragrance on clothing

Ken Schelling, Southworth.


Theodora Retsina, American Process.


Balazs Tolnai, Kruger, Inc.

- Bioplastics used in vehicles; expected to grow 100,000 to 600,000 tpy over the next 5 years.

THE RISKS

Before nanotechnology can go mainstream, there are a number of challenges to be overcome, beginning with the confusion over terminology. "The term nanocellulose is today used to refer to many things, many of them NOT nanocellulose," says Miller, who then categorized nanocellulose as either CNC, which are also called nanocrystalline cellulose (NCC) or cellulose whiskers, and CNF, cellulose nanofibrils, also called nanofibrillated cellulose.

Several presenters made the case that even for conventional and microforms of cellulose there are a number of knowledge gaps. For instance, it is unknown whether nanocellulose presents a similar or higher explosion hazard than cellulose. There is also a need for toxicity and ecological data to ensure health and safety. And the public's perception of and uncertainty about new products will also be a challenge.

Jo Anne Shatkin, from Vireo Advisors, agreed that there is still a lot of testing to be done and gave an overview of progress on a new Safety Data Sheet that would determine "a globally harmonized system of classification and labeling of chemicals." She stressed the unknown danger of breathing nanocellulose and noted that cellulose is currently considered only a "nuisance particulate."

CONCLUSION

The conference closed with a spirited panel discussion about how to commercialize some of the nanocellulose materials and products currently being developed at lab scale. There was general agreement that R&D labs should collaborate more to find ways to lower the cost of production.

The panelists agreed that as nanocellulose can be applied in so many fields, it is a little early to know which industries will be best suited for commercialization. Yet, they believe that successful commercialization would require focusing on those greatest opportunities. As one panelist put it, "[nanocellulose's] biggest strength is its greatest challenge – it is everywhere." Panelists felt that the other key to success (and challenge) would be finding partners and capital investors.

"It is best for a partner to be hungry and patient and have R&D capabilities," concluded Shaul Lapidot of Melodea, a company that is successfully commercializing nanocellulose. "At the end of the day it takes millions of dollars to create a new product."

On the surface the event was a roomful of technology. But in actuality it was a roomful of opportunity, especially for pulp and paper companies.

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Nano Awards

Two awards were presented during the conference. Orlando Rojas, professor of bio-based colloids and materials at Aalto University in Finland, was the recipient of the 2015 Nanotechnology Division Technical Award and Imerys FiberLean™ prize. He was honored for his research with lignocellulose for development of new materials and nanostructures.

J. Philip E. Jones received the International Nanotechnology Division's Leadership and Service Award, one of the founders, along with Ted Wegner, of a nanotechnology workshop that subsequently became the TAPPI Nanotechnology Division.


Robert Moon (right) presents Philip E. Jones the International Nanotechnology Division's Leadership and Service Award.


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