

**NANOCELLULOSE
STATE OF THE INDUSTRY
DECEMBER, 2015**

At the time of the TAPPI Nanotechnology for Renewable Nanomaterials Conference (TAPPI Nano) in June, 2014, there was only one commercial entity producing nanocellulose for market development: CelluForce. Since then, the market has exploded.

A year later, TAPPI Nano Atlanta, June, 2015, featured a tour of the new American Process, Inc. demonstration plant in Thomaston GA. Today, we can report that there are four commercial entities producing nanocellulose at capacities beyond pilot plant scale: CelluForce, American Process, Paperlogic and Borregaard (see Table 1 and Table 2), and several more are producing near-nano materials such as microfibrillated cellulose (MFC) and cellulose filaments. In addition, numerous research facilities are producing nanocellulose, and several new lab and pilot plants have been announced (included in Table 1 and Table 2), and we believe there are numerous unreported lab scale facilities at universities, paper mills, and other sites.

**TABLE 1
CELLULOSE NANOFIBRILS (CNF) CAPACITY
CURRENT AND ANNOUNCED 2015
(kg per day)**

Paperlogic	2,000
University of Maine	1,000
Borregaard, Norway	500
American Process	500
Nippon Paper, Japan	150
Innventia, Sweden	100
CTP/FCBA, France	100
Oji Paper, Japan	100
Stora Enso, Finland	Pre-commercial
UPM, Finland	Pre-commercial
FPIinnovations, Canada	Pilot
Norske Skog	Pilot
SAPPI, Netherlands	Pilot
VTT	Pilot
Daicel, Japan	Lab
Luleå University of Technology, Sweden	Lab
US Forest Products Laboratory, USA	Lab

TABLE 2
CELLULOSE NANOCRYSTALS (CNC) CAPACITY
CURRENT AND ANNOUNCED 2015
(kg per day)

CelluForce, Canada	1,000
American Process, U.S.	500
Holmen (Melodea), Sweden *	100
Alberta Innovates, Canada	20
US Forest Products Lab	10
Blue Goose Biorefineries, Canada	10
India Council for Ag. Research	10
FPIinnovations, Canada	3
Melodea, Israel	Pilot

*2016

WHAT IS NANOCELLULOSE?

We note that many things are referred to as nanocellulose. Indeed, we have an alphabet soup of NCC, CNC, NFC, CNF, MFC, CMC, MCC, CF. We also have a confusing litany of terms to go with our alphabet soup: nanocrystalline cellulose (NCC), cellulose nanocrystals (CNC), cellulose whiskers, nanofibrillated cellulose (NFC), cellulose nanofibrils (CNF), microfibrillated cellulose (MFC), carboxymethylated cellulose (CMC), microcrystalline cellulose (MCC), and cellulose filaments (CF).

By definition, nanocellulose is nano-scale, i.e. having at least one dimension less than 100 nanometers in size. Two materials fit this definition: cellulose nanocrystals (CNC), sometimes called nanocrystalline cellulose (NCC) or cellulose whiskers, and cellulose nanofibrils (CNF), sometimes called nanofibrillated cellulose (NFC).

Some of the materials in our alphabet soup are referred to as nanocellulose, but are not nano-scale. A number of these micro-scale materials (e.g. microfibrillated cellulose and cellulose filaments) are often mentioned in conjunction with nanocellulose, and are being offered for some of the same applications as CNC and CNF. Therefore, they will be addressed here even though they are not nano.

Microcrystalline cellulose (MCC) has been known since the 1800s and its use in pharmaceutical excipients and as a food additive dates back at least as far as 1942. Carboxymethylated cellulose (CMC) has also been known for decades as a thickener and food additive and is classified by the FDA as GRAS (generally regarded as safe). MCC and CMC are not nano-scale, and not generally considered to be in the nanocellulose family, and therefore will not be discussed here.

CELLULOSE NANOCRYSTALS (CNC)

Cellulose nanocrystals are rice-like in shape, typically 3-5 nm in width and up to 500 nm in length. CNC can have surface charge and some forms exhibit chiral nematic properties. CNC is good for strength, reinforcement, rheology modification, and also for optical, electrical, and chemical properties. Several new developments with CNC were announced in 2014 and 2015, including many announcements at the TAPPI Nano conferences in Vancouver, June 2014 and Atlanta, June 2015.

Historically, CNC has been produced by acid hydrolysis, most often with sulfuric acid, but also with phosphoric acid or hydrochloric acid. However, in the past fifteen months two new processes have appeared from **American Process Inc.** and **Blue Goose Biorefineries Inc.**

At TAPPI Nano 2014, American Process (API) presented its AVAP process for low cost nanocellulose from biomass. In April, 2015, API started up a 100 ton per year plant at its biorefinery in Thomaston GA. API produces both CNF and CNC, in both the well-known hydrophilic varieties as well as unique, proprietary, lignin coated hydrophobic, oleophilic varieties that are compatible with hydrophobic polymers and can be readily redispersed if spray dried. The first shipments of BioPlus™ nanocellulose from the API plant were made in April, 2015.

American Process has numerous patents and patent applications for its biorefinery process as well as the production of nanocellulose, including patent application [US 20140154757 A1](#) *Processes and apparatus for producing nanocellulose, and compositions and products produced therefrom.*

Also at TAPPI Nano 2014, Blue Goose Biorefineries, a subsidiary of Nano-Green Biorefineries Inc., presented its patent pending catalytic biomass conversion process to convert a variety of biomass sources to MCC and CNC. Blue Goose operates a 30 kg per week pilot plant in Saskatoon, SK. The process uses hydrogen peroxide in an acidic environment (patent application [WO2013000074A1](#)).

Samples from both API and Blue Goose can be purchased on line with no intellectual property restrictions.

Alberta Innovates Technology Futures (AITF) reported on its pilot plant at TAPPI Nano 2015. AITF is working to optimize pilot plant operating parameters such as sulfuric acid concentration, temperature and reaction time

CelluForce started up its one tonne per day demonstration plant in January, 2012. At TAPPI Nano in Vancouver, June 2014, CelluForce announced 6 Joint Development Agreements, and cited applications in oil and gas, adhesives, water treatment, coatings, food, and cementitious materials. In March 2015, CelluForce announced that Schlumberger joined Domtar and FPIInnovations as investors. Schlumberger and CelluForce will collaborate in developing applications for CNC in oil and gas drilling fluids.

At TAPPI Nano 2014, **Melodea** reported on its operational lab scale pilot plant at Rehovot, Israel to produce CNC from paper mill sludge. In 2015, Melodea, along with investors Holmen AB, MoRe Research and SP Technical Research Institute of Sweden, announced a pilot facility in Örnsköldsvik, Sweden, adjacent to MoRe. The plant is also supported financially by Västernorrland County Administrative Board, the Kempe Foundations, SP Technical Research Institute of Sweden, and the Önneshö Foundation.

CELLULOSE NANOFIBRILS (CNF)

Cellulose nanofibrils are spaghetti-like in shape with typical dimensions of 20-300 nm in width and up to several microns in length. Technically, nanomaterials must be less than 100 nm in at least one dimension, and some material that is considered CNF may not meet this definition.

CNF is good for strength, reinforcement, and rheology modification. Because of their greater length and aspect ratio, CNF particles may become entangled and this may allow them to reinforce composites in a different manner than CNC particles which do not become entangled, but rather interact with the polymer matrix. In some applications, CNF may perform better than CNC.

CNF is essentially produced by a mechanical process, and this can be aided by enzymatic or chemical processes. One well known chemical process uses TEMPO-mediated oxidation, TEMPO is a tetramethylpiperidine compound that serves as a catalyst. The TEMPO process can produce excellent flexible transparent films, but the TEMPO material itself is toxic, expensive and difficult to work with.

As noted, the American Process Inc. demonstration plant produces CNF as well as CNC, including proprietary lignin coated hydrophobic varieties.

Paperlogic started up a 2,000 kg per day demonstration plant in May, 2015 at its Turners Falls MA paper mill, and at TAPPI Nano 2015, Paperlogic reported that it was in the process of optimizing and debugging the system. Paperlogic uses technology from GL&V to produce CNF with low energy cost, using technology first developed in conjunction with the University of Maine.

Borregaard announced in October 2014 that it would build a facility for the production of Exilva microfibrillar cellulose (MFC) at the Borregaard site in Sarpsborg, Norway. The project is based on new innovations related to the product itself as well as to the production process and the applications. The commercial scale facility will have an initial design capacity of 1,000 tonnes per year with a potential for expansion. Production is expected to start in the 3rd quarter of 2016.

Additional developments have been reported in Europe, including:

- **Innventia** in June 2014 announced plans to develop mobile facilities for nanocellulose production with Billerud Korsnäs, for papermaking.
- **CelluTech AB**, Sweden, a spin-off of Wallenberg Wood Science Center, is working with cellulose foams, spheres and magnetic cellulose
- **Stora Enso** announced that new board grades containing MFC are reaching the stage of packaging market entry.
- **SAPPI** announced new process for dry redispersible CNF with Edinburg Napier University. A pilot plant is expected late 2015.

In August 2014, the Japan News reported a consortium of 100 companies to explore nanocellulose applications: "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."

In September, 2015, **Oji Holdings Corporation** (Oji) announced that “they have signed an agreement with Nikko Chemicals to launch the joint development of Cellulose Nanofibers (CNF) for cosmetic applications.” (<http://www.pulpapernews.com/2015/09/oji-to-develop-nanocellulose-for-cosmetic-applications>)

A number of other companies have been cited as producers of CNF but some are not confirmed, and others are more likely to be producing some form of MFC or are developing applications with CNF. These include:

- Akzo Nobel, Netherlands.
- Asahi Kasei, Japan: Ceolus MCC.
- BASF (with Zelfo Technology), Germany.
- CelluComp, UK: Curran® “cellulose nanofibres” from food waste materials.
- Cellutech AB, Sweden: cellulose foams, cellulose spheres.
- Chuetsu Pulp and Paper, Japan.
- Daio Paper, Japan.
- Daiichi Kogyo, Japan: Carboxymethyl cellulose.
- Engineered Fibers Technology, U.S.: “Precision cut short fibers” from Lyocell.
- Essential Dynamics: Nanovae
- Ineos Bio, U.S.
- J Rettenmaier & Söhne (Arbocel), Germany: Arbocel MFC.
- Munksjo, France.
- Novozymes, Denmark
- Suzano, Brazil.

CELLULOSE FILAMENTS AND MICROFIBRILLATED CELLULOSE

It bears repeating here that much of what is called “nano” is indeed micro. Calling material “nano” makes it sound more advanced. At the same time, some of what is called “micro” is indeed nano. In some sectors, there are concerns about nanomaterials, and so the term “nano” is avoided.

Some new near-nano materials are often referred to as nanocellulose and discussed in conjunction with nanocellulose. We include these materials here in part because they are derived from the paper industry as is most CNF and CNC, and also because these materials can be used in the same applications as CNF and CNC and compete with CNF and CNC. Two of these materials are cellulose filaments (CF) and FiberLean™.

Cellulose filaments were developed by FPIInnovations, and in 2013 Kruger announced “a joint project to implement the world’s first five ton/day cellulose filament demonstration plant at Kruger’s Trois Rivières mill.” The plant started up with its first production of quality CF in June, 2014 and the first shipment of FiloCell™ cellulose filaments on July 10, 2014.

A second CF plant was announced by **Performance BioFilaments Inc. (PBI)** in June, 2014. PBI is a joint venture between Mercer International and Resolute Forest Products, and uses the FPIInnovations technology. Site evaluations for manufacturing facilities at the scale of 50,000 to 100,000 tonnes per year are underway. PBI is targeting the commercial production of CF to commence in 2018,

but samples for evaluation and applications development are available now from PBI, produced at Kruger Trois Rivières.

At TAPPI Nano Vancouver, June, 2014, **Imerys** announced the installation of a FiberLean™ facility at the Verso mill in Bucksport, Maine. Imerys is a diversified mineral supplier, and as such its core competency is grinding. With FiberLean, a form of MFC, the pulp and the minerals are ground together promoting adhesion of the fibrils and minerals, and better retention of the minerals. The Bucksport mill closed in late 2014, but Imerys reports a FiberLean facility at Trebal (Cornwall UK) with capacity of 1,500 tpy. Imerys also reports an additional 6,000 tpy in progress at other sites globally, with projected capacity of more than 12,000 tpy by early 2017.

FORECASTS

Numerous forecasts have been issued for nanocellulose, some with timetables, some without. Some of these forecasts defined what forms of nanocellulose were included, some did not. In preparation for the 2015 TAPPI Nano conference, Jack Miler for Market-Intell and TAPPI interviewed the two keynote speakers, Marie D'lorio, Executive Director of Canada's National Institute for Nanotechnology (NINT), and Theodora Retsina, CEO at American Process. Both wisely declined to give a forecast. However, Retsina noted that the market for nanocellulose could be larger than any of us imagine. It has often been repeated that new developments take longer than expected and the slow pace of development should not discourage anyone. As Bill Gates famously said, ***"We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten."***

We also note that definitions of what is and what is not nanocellulose are not universally accepted. Thus, any forecast must clearly define what is and what is not included. One report suggested that the nano cellulose market in 2014 was around \$250 million, with projected growth (CAGR) of 19% to 2019. Leading players cited include Innventia AB (Sweden), Novozymes (Denmark), and Ineos Bio (Switzerland), but of these, only Innventia is producing nanocellulose, and that in a 100kg/day pilot plant.

Forecasts are difficult enough when there are established trends to base a forecast on, but for an emerging industry forecasts should be regarded with extreme caution. A summary of recently published forecasts follows in Table 3:

Table 3
Nanocellulose Market Forecasts

	<u>Tonnes (000)</u>	<u>Year</u>
Vireo Advisors, high	56,481	potential
USDA	34,000	~2045
RISI, potential	23,551	potential
Vireo Advisors, low	18,283	potential
RISI, forecast	450	2025
Arbora Nano	145	NA
CelluForce	15	2017
Future Markets	0.8	2017

There is little doubt that the potential is great, but much work remains to be done before that potential is realized. And, that work must be done not only by producers of nanocellulose but also by those who use it to develop new composite materials and new applications.

PROFILES OF LEADING COMPANIES

American Process Inc.

750 Piedmont Ave. NE

Atlanta, GA 30308

www.americanprocess.com/bioplus

American Process Inc. (API) is a privately held company that specializes in the development of technologies for the commercial production of sugars and ethanol from biomass. API was founded by Theodora Retsina in 1995 as an engineering consulting company in the forest products industry. Since then, API has completed over 500 energy integration studies and projects within the industry and identified annual energy savings opportunities of billions of dollars.

In 2005 API began to self-fund R&D on biomass-derived sugar technology. The company has successfully developed two technologies for biomass-derived cellulosic sugar and ethanol: GreenPower+[®] and AVAP[®]. The construction of a demonstration plant for GreenPower+ technology started in 2011 in Alpena Michigan, and the plant in started up the second quarter of 2012.

In April 2013, GranBio, a 100% Brazilian pioneer in biorefinery technologies, completed the acquisition of a 25% equity investment in API.

In 2013 API celebrated the startup of the second demonstration plant for AVAP technology with a 1 ton/day cellulosic sugars production facility in Thomaston GA and in the third quarter of 2014, API announced the lab scale production of cellulose nanofibrils and nanocrystals. In first quarter of 2015 API trademarked the name BioPlus[™] and BioPlus-L[™], and in April 2015, pre-commercial production of cellulose nanocrystals and nanofibrils started at the Thomaston biorefinery ½ ton per day demonstration plant.

Borregaard

PO Box 162

1701 Sarpsborg, Norway

www.borregaard.com

Borregard's 2013 revenues were NOK 3,997 million (\$660 million), 42% of which derives from Borregard's Specialty Cellulose Business. Borregaard has one of the world's most advanced and sustainable biorefineries. Borregaard produces advanced and environmentally friendly biochemicals, biomaterials and bioethanol that can replace oil-based products. Borregard's business areas include:

- Performance Chemicals
- Specialty Cellulose, including Borregaard ChemCell

- Other (fine chemicals and ingredients)

Borregaard announced in October 2014 that it would build a facility for the production of Exilva microfibrillar cellulose (MFC) at the Borregaard site in Sarpsborg, Norway. The project is based on new innovations related to the product itself as well as to the production process and the applications. The commercial scale facility will have an initial design capacity of 1,000 tonnes per year with a potential for expansion. Production is expected to start in the 3rd quarter of 2016.

CelluForce, Inc.

625, Président-Kennedy avenue
Office 1501
Montreal (Quebec)
CANADA H3A 1K2
www.celluforce.com

CelluForce was formed in 2010 as a joint venture between FPInnovations, the Canadian forest products research and innovation center, and Domtar, a \$6 billion paper manufacturer, with an investment of \$43 million. Each partner owned 50%. CelluForce was the first commercial producer of nanocellulose, and its mission was to introduce nanocrystalline cellulose (NCC), now more commonly known as cellulose nanocrystals (CNC). In January, 2012, CelluForce started up a one tonne per day demonstration plant at the site of the Domtar pulp and paper mill in Windsor QC.

In March 2015, CelluForce announced that Schlumberger joined Domtar and FPInnovations as a third investor. Schlumberger and CelluForce will collaborate in developing applications for CNC in oil and gas drilling fluids.

Holmen AB

P.O. Box 5407, SE-114 84
Stockholm, Sweden
www.holmen.com

Holmen is a forest industry group that manufactures printing paper, paperboard and sawn timber and runs forestry and energy production operations. Its Iggesund Paperboard unit produces 0.5 million tonnes of solid bleached board and folding boxboard, and Holmen Paper produces 1.3 million tonnes of printing and writing paper. 2014 sales were 15,994 million SEK.

In 2013, Holmen became a major shareholder in Melodea, and sub-licensee of technology licensed to Melodea for production of CNC from paper mill sludge.

In 2015, MoRe Research, with Holmen and SP Technical Research Institute of Sweden, invested in nanocrystalline cellulose by building a pilot facility in Örnsköldsvik. The facility will be the first of its kind in Europe and represents an important step, allowing interested companies to develop nanocrystalline cellulose from cellulose-based material on a large scale.

Imerys Minerals, Ltd.

154, rue de l'Université

F-75007

Paris, France

www.imerys.com

With 14,900 employees in almost 50 countries and 234 industrial sites around the globe, Imerys is the world leader in industrial minerals. Revenue in 2014 totaled €3,688.2 million. Imerys products include kaolins, clays, calcium carbonates, feldspars and mica for markets such as paint, inks and coatings, paper and paperboard, building and construction products, plastics, sealants and adhesives, lawn care and landscaping, health, beauty and nutrition products.

At the TAPPI Conference in Vancouver, June 2014, Imerys announced the installation of a FiberLean™ facility at the Verso mill in Bucksport, Maine. The Bucksport mill closed in late 2014, but Imerys also has a FiberLean facility at Trebal (Cornwall UK) with capacity of 1,500 tpy. Imerys also reports an additional 6,000 tpy in progress at other sites globally, with projected capacity of more than 12,000 tpy by early 2017. FiberLean MFC “is an innovative composite of Micro-Fibrillated Cellulose (MFC) and mineral. Application of FiberLean™ MFC typically allows replacing 10-15% fiber.” Imerys adds that “paper containing FiberLean™ maintains bulk and stiffness, despite the higher density of MFC and higher filler-to-fiber ratio. This is achieved as the paper is smoother and has up to 30% better bond strength. Paper with improved smoothness can be Calendered at lower pressure and/or in fewer nips.”

Kruger Inc.

3285, chemin Bedford

Montréal, Québec H3S 1G5

<http://www.kruger.com/en/>

Founded in 1904, Kruger Inc. is a major producer of publication papers, tissue, lumber and other wood products, corrugated cartons from recycled fibres, green and renewable energy and wines and spirits. The Company is also a leader in paper and paperboard recycling in North America. Kruger operates facilities in Quebec, Ontario, British Columbia, Newfoundland and Labrador and the United States.

On December 18, 2013, FPInnovations and Kruger Inc. announced “a joint project to implement the world’s first five ton/day cellulose filament demonstration plant at Kruger’s Trois-Rivières Paper Mill.” The press release adds that “the research and innovation project represents investments totaling \$43.1 M, including funding from Natural Resources Canada, through the Investments in Forest Industry Transformation (IFIT) Program, as well as a grant from the Québec Ministry of Natural Resources, a loan from Investissement Québec, a contribution from Kruger Inc. and funds from FPInnovations’ pulp, paper and bioproducts industrial members.”

Paperlogic

A Southworth Company

36 Canal Street

Turners, Falls, MA

<http://www.paperlogic.com>

Paperlogic is the specialty and technical papers division of Southworth Company, a small privately owned company that has been manufacturing high specialty, technical, and business papers for industrial and commercial applications since 1839.

In May, 2015, Paperlogic started up a 2,000 kg per day CNF demonstration plant at the Paperlogic mill in Turners Falls MA. Paperlogic uses technology from GL&V to produce CNF with low energy cost, using technology first developed in conjunction with the University of Maine.

The objective is to demonstrate that refiner-based CNF production technology is scalable to commercially relevant production rates and operating efficiencies. The plant is expected to verify full scale CNF production costs estimated from pilot scale operations and confirm that a reliable supply of commercial CNF can support additional application development. At TAPPI Nano 2015, Paperlogic reported that it was in the process of optimizing and debugging the system.

Performance BioFilaments

Suite 1120, 700 West Pender Street
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<http://www.performancebiofilaments.com/>

Performance BioFilaments Inc. (PBI), was created in March 2014 as a joint venture between Mercer International and Resolute Forest Products, and is focused on the commercialization of cellulose filaments (CF). Cellulose filaments are recently-developed materials derived from wood pulp, consisting of very long, thin cellulosic strands. Performance BioFilaments is growing its team of technical specialists that will focus on application development of cellulose filaments in high value composite materials and chemical rheology modifiers. Site evaluations for manufacturing facilities in Canada capable of commercial production of cellulose filaments at the scale of 50,000 to 100,000 tonnes per year are also underway. PBI is targeting the commercial production of CF to commence in 2018.

About the author

Jack Miller is Principal Consultant, Market-Intell LLC, which he founded in 2005. He has also been Consulting Manager, Global Nanocellulose Sales, American Process Inc., since December, 2014. His experience with nanocellulose dates back to 2009 with market research in applications for CNF and CNC, and later as Business Development Consultant with CelluForce Inc.

Jack is also an Associate Consultant with RISI, and is the author of the 2014 RISI study *Nanocellulose: Technology, Applications, and Markets*. He has presented on nanocellulose at TAPPI and RISI conferences in the U.S., Canada, and Brazil, as well as conferences on composites, nonwovens, adhesives, textiles and other nanocellulose applications.