Editorial

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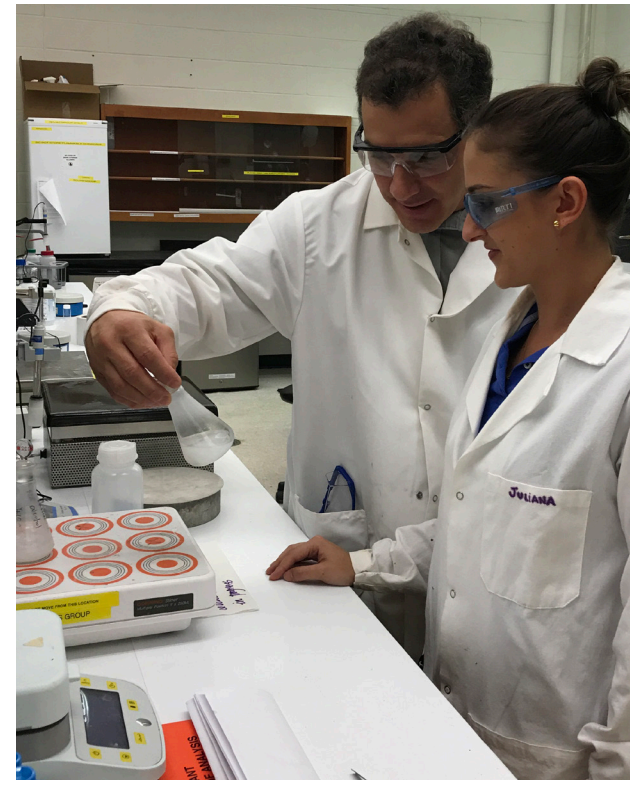
The Laboratory of Soft Materials & Green Chemistry at North Carolina State University

This is the first in a series of columns featuring research and researchers from pulp, paper, biorefinery and related schools and institutions. In this column, TAPPI Journal spoke with Dr. Lucian A. Lucia about his laboratory, *The Laboratory of Soft Materials & Green Chemistry*, at North Carolina State University (NCSU) in Raleigh, NC. This lab's efforts are in materials science topics focused on the green chemistry of renewable polymers such as cellulose and lignin.

Lucia currently serves as an associate professor in the Departments of Forest Biomaterials (Wood & Paper Science) and Chemistry and as a faculty in the programs of Fiber & Polymer Science and Environmental Sciences. He received his Ph.D. in organic chemistry from the University of Florida for modeling photoinduced charge separation states of novel Rhenium (I)-based organometallic ensembles as a first order approximation of photosynthesis. Lucia began his professional career as an Assistant Professor at the Institute of Paper Science and Technology (IPST) at the Georgia Institute of Technology examining the mechanism of singlet oxygen's chemistry with lignin and cellulose. Here, *TAPPI Journal* speaks with Lucia about his recent work in bacterial cellulose, as well as his thoughts on traditional pulp and paper studies, and the industry at large.



Dr. Lucia working in The Laboratory of Soft Materials & Green Chemistry at North Carolina State University with Juliana Jardim, a M.Sc. student from Brazil who intends to become a Ph.D. student there next spring.

How did your previous training and studies influence your current work at The Laboratory of Soft Materials and Green Chemistry?

Cellulose is the common thread for me, from my past into my more recent work attempting to re-engineer it as a smart material, which goes back to when I studied energy storage in plants. I was trained as a photochemist to examine how matter uses sunlight to store energy in such things like lignocellulose. I later learned how various chemistries could break down lignocelluloses, which led me to understand how materials from plants could provide us with significant material chemical advantages. I have always been interested in the work of researchers like Vincenzo Balzani of the University of Bologna, who has long advocated the idea of developing supramolecular systems that can take on the characteristics of energy storage devices, transistors, diodes, machines, and logic circuits. This idea of supramolecular systems intrigues me because they work in a cleverly designed way to do the same things their macro counterparts do, but at a much smaller scale.

While we typically think of cellulose as plant based, some strains of bacteria also make cellulose, and they make it much faster than plants do. We can also tweak them much more easily than plants to generate cellulose with targeted functionality. By changing conditions, food sources, and other variables, we can constrain the living bacteria systems to

change the chemical and physical properties of the cellulose.

In my laboratory, we have examined electrical capacitance using bacterial cellulose. Some of the recent work is to engineer bio-based batteries by combining bacterial cellulose with graphene oxide to provide an overall structural asymmetry to potentially store charge. We found that bacteria can absorb or ingest many chemicals, graphene being one of them, whose precursor, graphene oxide, is reduced to graphene in their environment. Graphene is a functionally rich material in physics, material science and engineering, and chemistry because of its mechanical, electrical, optical, and associated properties.

Cellulose itself has many opportunities to take the place of today's plastics and electronics in their existing forms, as say, polyethylenes, PMMAs, or even some solid-state electronics. We can take a soft material like cellulose and engineer it to display the functional properties of hard solid-state electronics or tough nanocomposites.

Does bacterial cellulose compete with the potential of the lignocellulose in the paper industry?

Even though it has the same chemical composition as lignocellulose, bacterial cellulose is of much higher quality. However, it doesn't compete in the same markets as lignocellulose as it's more of a specialty product because it can't be produced in comparatively huge volumes. However, it can be engineered faster than normal engineering pathways in trees because you control the bacteria's living conditions.

To grow bacterial cellulose, biofermentation is done in a reactor through the control of temperature, pressure, reagents, nutrients, etc. It's processed differently than normal pulp from a tree, but once you are done, it has tremendous advantages that normal wood doesn't have. These are found in its physical properties, like strength, hydrophilicity, overall purity, and degree of crystallinity. It is a unique cellulose with enormous commercialization potential. In the overall published literature, there may be more patents than publications on it.

What is an example of a specialty end-product made with bacterial cellulose?

Bacterial cellulose can make a film of any dimension in the z direction (thickness) that provides an excellent cover for burn victims because it is transparent, allowing medical personnel to monitor healing. In today's health care market, opaque gauze or similar materials must be removed to check progress, which can interrupt healing and cause pain, but bacterial cellulose can stay in place because it is see-through and provides a uniform sealed and moist barrier to speed up healing and prevent infection. Its hydrophilicity, porosity, and favorable gas permeation for carbon dioxide transpiration and oxygen delivery also make it an excellent cover for burns. In addition, it has witnessed tremendous success as a cosmetic moisturizer.

How many students work in The Laboratory of Soft Materials and Green Chemistry?

We have 10 students. Of those 10, four are Ph.D. students and one is a Master's, and the remainder are visiting scientists, technicians, or undergraduates. At NCSU, we are very focused on recruiting and graduating Ph.D.'s.

Do you see students gravitating more toward biomaterials or toward traditional paper science?

We have been dealing with this issue for about 10 years now. There isn't enough funding for traditional pulp and paper science, or we might have a much more robust traditional graduate program because the post-graduate curriculum is really driven by funding. At IPST at its peak in 2000, we had unrestricted funding and we had 80 students, most of which were studying for a Ph.D. Even today, we could have the same number if the market would support it, but some calculations say the market could only support 30 Ph.D. graduates globally. There is much more of a demand for Bachelor's and Master's degrees in this current economic climate.

The funding today is in non-traditional biomaterial, bioenergy, and biorefinery areas. These are great areas, but they aren't as abundant in terms of careers as the existing pulp and paper and allied industries. In the last five years, I am not aware of an NCSU Ph.D. student who has done a traditional pulping project; they have done pulping, but more for pretreatment to explore pulp deconstruction into glucose for bioethanol or other fuel.

How do you feel about the potential for nanotechnology in our industry?

As with any research area, we must evaluate its merits. If nanotechnology passes the muster as a usable, and needed technology, it will stay and we'll figure out how it complements paper. Today, we are marrying the two in incredible ways, like using lignocellulosic scaffolds to introduce nanomaterials in industries like biomedical (tissue engineering),

pharmaceutical (drug delivery), electronic (sensors), food (antimicrobial), cosmetics (nutrients), etc. So, there's a way nanotechnology can evolve with the help of paper, but I don't think it will replace what we do with paper now. Even with nanocellulose, there are wonderful things to be done, but it's tough to envision it as a massive industry. I think it can be a niche industry and address some needs, but I don't see it addressing the needs of society the way paper does.

How do you feel about the future of the traditional pulp and paper industry in context of new developments like biomaterials?

I feel it would be a disservice to the world if we didn't continue to focus on existing traditional industries like pulp and paper. This industry needs institutions like NCSU to continue producing top-quality graduates. We realize that someday we will have a much more entrenched biomaterials industry -- bioenergy, bacterial cellulose, nanocomposites, and whatever that ends up meaning, but we can't stop serving this glorious industry. People will always need some form of lignocellulosics.

The threat to our industry may actually be its core character – sustainability. Can we continue to grow enough trees in a sustainable way? Can we treat mill effluent sustainably? Can we economically replace equipment in a mill after depreciation? Will we have enough people that understand mill processes to serve the industry?

Our industry should aggressively work together to better communicate the value of paper and this industry to the public, because people take for granted the many things they need that come from lignocellulose. Wood is a quintessential part of art, culture, civilization, and everyday life. **TJ**