Editorial

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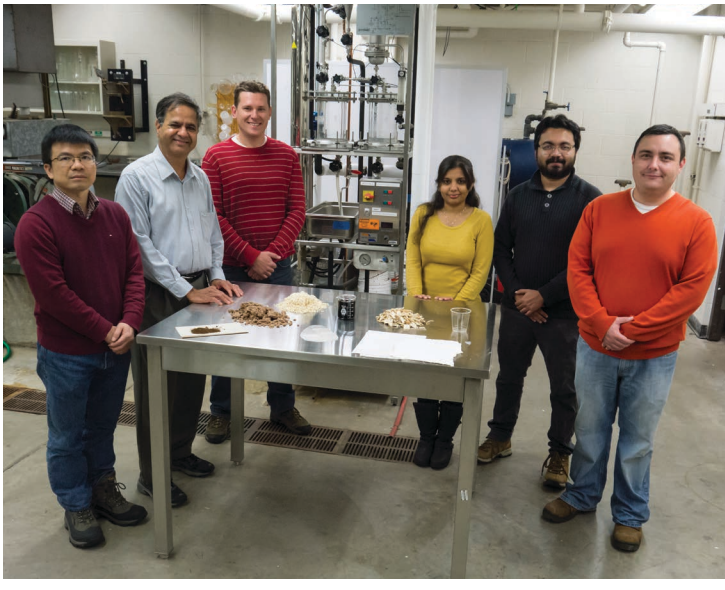
To paper and beyond at the University of Minnesota

Editor's Note: *This column is a continuation of* TAPPI Journal*'s column series featuring research and researchers from pulp, paper, biorefinery and related schools and institutions.*
– Monica Shaw, Editorial Director

In this column, *TAPPI Journal* spoke with Dr. Shri Ramaswamy of the University of Minnesota, where he is a professor in the Department of Bioproducts and Biosystems Engineering (BBE). He holds an M.S. and a Ph.D. in Paper Science and Engineering from the State University of New York (SUNY) in Syracuse, as well as an M.S. in Chemical Engineering from Syracuse University and a B.S. in Physics and Pulp and Paper Engineering from the University of Roorkee, India. Dr. Ramaswamy also has more than nine years of experience in the paper industry in various capacities, including process engineering, chemical applications technology development, and process research and development.

Since joining the University of Minnesota in 1995, Ramaswamy has seen significant growth in what was then the Department of Forest Products, with Paper Science and Engineering as one of the areas, and is now the Department of Bioproducts and Biosystems Engineering. Here, he discusses the evolution of this department and his personal research interests in the areas of bioproducts from lignocellulosic biomass, as well as structure-property relationships in porous media, especially bio-based materials.



Professor Shri Ramaswamy and his team of students and researchers at the University of Minnesota pursue innovative integrated forest biorefinery solutions and explore the feasibility of converting wood and other lignocellulose to pulp and paper, biofuels, plastics, and renewable energy. From left to right, Dr. Peter Huajiang Huang (research assistant professor), Dr. Shri Ramaswamy (professor), Lucas Stolp (scientist and graduate student), Sahana Ramanna (Ph.D. candidate), Sudhanya Banerjee (Ph.D. candidate), and Leonard Reynolds (scientist). Photo courtesy of Nkauj Vang.

How did paper-related studies evolve into the Department of Bioproducts and Biosystems Engineering at the University of Minnesota?

Around 14 years ago, we changed from a wood and paper science department to a broader bioproducts department. We were the first ones in the country to do so by envisioning how this field and research—and ultimately the industry—would evolve. Being a frontrunner can be difficult, because people always wonder and question your strategy, but we really wanted to position our department towards the future and continue to attract high quality students, as well as increase research opportunities and opportunities for students and graduates.

From a scientific and technical viewpoint, we realized that with wood, paper, and forest products, we were essentially dealing with lignocellulosic biomass and its conversion to various products, along with their end-use applications. At the time, however, the forest products department primarily focused on wood products and pulp and paper—the focus of our forest products community for 100-plus years. As discussions about the future of oil prices and alternative energy forms increased, the U.S. Government began recognizing and investing in bio-based

products as an emerging area, especially new products made from biological resources. So, we broadened our paper science and engineering program and curriculum to Bio-based Products Engineering and later to Bioproducts and Biosystems Engineering as we merged with the Biosystems and Agricultural Engineering Department and embraced broader renewable resources and their sustainable utilization. This opened up even greater opportunities for our students and graduates.

Pulp, paper, and wood products and composites are still a big component of what we do, but our motivation for the change is to be more forward thinking and discovering innovative approaches and sustainable solutions for new value-added products. Paper consumption is decreasing in the U.S. in markets like printing and writing papers, while tissue and packaging are growing.

Since the University of Minnesota transitioned its paper-oriented program to one focused on bioproducts and biosystems engineering, there has been proliferation of such changes among traditional pulp and paper schools. What would you say is unique about the University of Minnesota's approach?

For one, it was unique to be a front runner, but secondly, Minnesota has strong agricultural and forest-based industries, and we combined the two areas to address both agriculture-based and natural resource-based systems, processes, products, and solutions to create the Department of Bioproducts and Biosystems Engineering. Our department is affiliated with the College of Food, Agricultural and Natural Resource Sciences as well as the College of Science and Engineering. Our engineering students matriculate from the College of Science and Engineering.

How did becoming Department of Bioproducts and Biosystems Engineering eventually impact your student population?

Working with a range of renewable resources—wood, agricultural residues, algae, etc.—gave us more breadth in areas of study. Within the Bioproducts and Biosystems Engineering major, we have three areas of focus: bioproducts engineering (formerly paper science and engineering), food engineering (food can also be considered a bio-based product) and environmental and ecological engineering (addressing environmental and ecological aspects of biological resources, systems, and processes). As a result of the broadened scope, our undergraduate enrollment has grown within the engineering major from just 18 undergraduate students in the Paper Science and Engineering program in 1995 to 190 students in the BBE undergraduate major today.

Along the same lines, there has been more funding available to study biomass utilization and conversion, biological resources and systems, as well as to address environmental sustainability. This has helped us attract more graduate students. Within our department, our faculty advises around 100 graduate students in a variety of graduate programs. There are also about 50 post docs and researchers, and a total of about 250 people, including faculty, staff, and researchers.

One of your own primary research areas is the study of lignocellulosic biomass for second-generation biofuels, bioenergy, and bioproducts. What it your main focus in these studies?

In our research group, one of the primary focus areas is process modeling, simulation, design, and their applications in an integrated biorefinery. Here, we study the feasibility of producing multiple products from biomass, including fiber, cellulosic ethanol, chemicals, polymers, and energy. The first step was to model the entire pulp and paper process, including the chemical and energy recovery systems. With these efforts, we showed that it is possible to effectively separate the low molecular weight sugars and convert them into biofuels or bioplastics, integrated with the overall pulp and paper process.

We've shown that we can extract some of the hemicellulose present in wood prior to the pulping process and use it to make biofuels or value-added bioproducts. Currently, some of the removed sugars are being burned along with black liquor. When the extracted low molecular weight sugars are combined with waste cellulose fines from the mill and converted to bioethanol or bioplastics, the process becomes more economically feasible. We have shown that for a large mill (2000 tons/day) in the U.S., it is possible to produce about 30 million gallons of ethanol per year from these two sources—without adversely affecting pulp and paper quality.

Do you feel there is a good chance for success with the biorefinery concept, given there are certain political and market forces that could impact it, especially when it comes to fuel prices, as well as concerns from the pulp and paper industry about pulp yield and end-product quality?

It is very possible, but, yes, there are many factors to consider. From a big picture point of view, there has been a policy in place in the U.S. for using second-generation biofuels made from lignocellulose (i.e., forest and agricultural residue), and it's already in the marketplace. For example, DuPont is implementing a major plant in Iowa that uses corn cobs or stover to make ethanol. Such plants are either standalone or in conjunction with a corn-based ethanol facility. Along the same lines, the wood products and pulp and paper industries are well suited to pursue such an approach, which could provide an additional revenue stream.

While a biorefinery is still a very viable option, the pulp and paper industry continues to face significant challenges, including increased global competition, facing the effects of digital technologies, and other factors, and the investments in this new technology have been very limited. Other industry sectors continue to invest in R&D in biofuels and bioplastics. And yes, fuel is a commodity product and there are nuances associated with it, but what if we make a value-added bioplastic instead of fuel from the waste sugars and other under-utilized streams? With plastic and other value-added products, the profit margin could be much higher, and hence provide a more viable option. As we look into the future, there are more opportunities for the pulp, paper and forest products industry to truly embrace the biorefinery concept and continue to be a significant part of the thriving bioeconomy.

Your other primary area of research is the study of three-dimensional (3D) structural characteristics of porous materials like paper using advanced techniques such as x-ray micro computed tomography (XRCT) and nano tomography and image analysis. How did your work in this area evolve?

Another focus area of our research group has been in the area of structure-property-performance of porous materials, especially bio-based materials. The internal structure of paper and board plays a critical role in the paper manufacturing process as we remove water on the paper machine by dewatering, wet pressing, and drying processes. Paper structure also plays an important role during various end-use applications. If we better understand the 3D internal structure of paper and quantify its relationship to water removal and end-use applications, we can more efficiently and effectively "engineer" the structure for a specific end-use application, like a coffee cup, packaging, or paper towels.

Our pursuit here has been to visualize and quantify the complex 3D structure of paper using advanced techniques such as x-ray computed tomography (XRCT). Working together with Professor B.V. Ramarao from SUNY College of Environmental Science and Forestry and other colleagues from around the world, we helped develop the use of XRCT for looking at paper's internal structure. The principle and use of XRCT is much like the way a doctor uses a CT scan. Specifically, we're looking at the interfaces between the fibers and the void spaces and characterizing the pore structures in 3D. So, if you are making the same product or two products on two different paper machines, it is possible, using this technique, to characterize the products and better understand how each machine or product is performing.

Initially, in order to do XRCT, one had to resort to synchrotron radiation facilities. Nowadays, there are commercial bench top units that can be used to do XRCT at reasonable resolutions (1–4 μm) and at a reasonable cost. Such units are currently used in many companies to benchmark their products and better understand their performance.

As we described in our recent *TAPPI Journal* paper (*TJ* 16[9]: 519[2017]), we've developed a sphere growing algorithm that takes the digital 3D volumes of paper and digitally grows spheres inside the void spaces to determine the pore size distribution of paper. Since the image is in 3D, we can visualize the complex fiber networks from multiple perspectives, as well as fly through the structure. In addition to fibers and pores, it is also possible to visualize and characterize the 3D structure in the presence of inorganic fillers or pigments, as well as how the fillers are distributed in the paper. This is important in writing and printing papers.

We have extended the above work to evaluate the transport (i.e., liquid, vapor, heat, and mass) and

mechanical properties of paper and biomaterials. Also, we are developing the use of nano scale computed tomography (nCT) using transmission electron microscopy (TEM) and scanning electron microscopy (SEM) to study the 3D ultrastructure and topochemistry of biomass and how they evolve during the biomass conversion process.

What is another promising area for our industry that is studied at the University of Minnesota?

There are number of other topics pertaining to wood and other lignocellulose that are currently being researched at the University of Minnesota. As an example, nanocellulose is yet another area that can provide a high value-added product for the industry. Some of our faculty are studying nanocrystalline cellulose (NCC), which can be stronger than steel, and how you can effectively separate it from wood and other biomass and use it in composites and other applications. This is an area where the industry is paying attention, but as with the biorefinery, success will take a great deal of long term, persistent effort. At the University of Minnesota, we are driven to discover innovative approaches, technologies and solutions for a thriving, sustainable bioeconomy, ensuring industry's long-term success. **TJ**

For more information about the University of Minnesota's Department of Bioproducts and Biosystems Engineering, please visit https://bbe.umn.edu/.