Appendix 7

Forest Products Research and Development: Status and Prospects

Burning wood directly as fuel was arguably the first forest product. Using whole logs to build houses for shelter was another early use of wood. Today, we cut logs into thin slices or chip them into flakes and fibers to make plywood and other panels. Beyond the mechanical breakdown of wood into bits and pieces, we can chemically break down chips to separate rosin, fatty acids, lignin, and hemicellulose from wood fiber and use the fiber to make pulp. Wood pulp is converted to textile and paper products such as tissue paper, printer paper, newsprint, containers and boxes, card stock, explosives, and high-performance materials.

Research and development have made possible many products using both low-grade wood and high-value timber (Figure 1), benefiting users, creating jobs, spurring economic growth, and reducing pressure on forests.

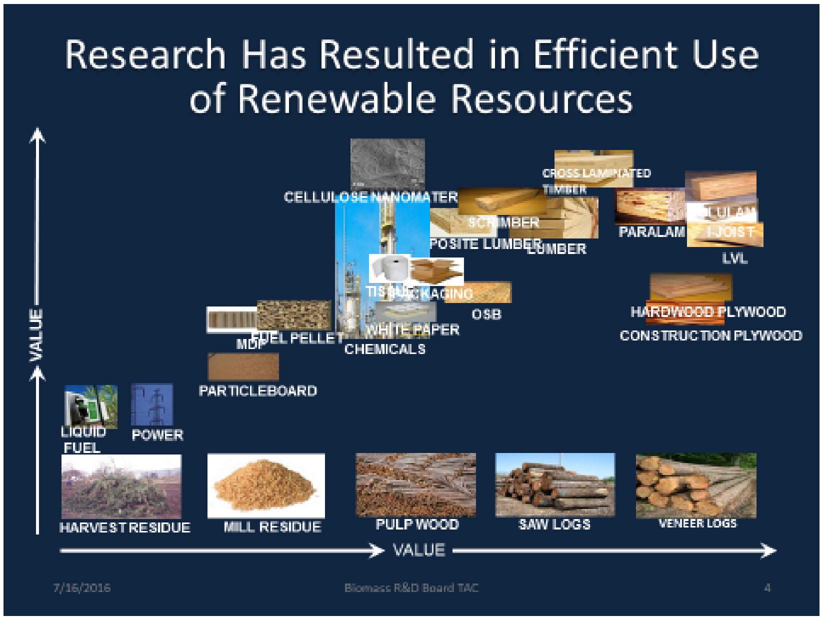

Figure 1. Forest product and wood values

This paper reviews the current state of forest products research and prospects for the future.

Forest products industry research today

Most forest products are produced with mature technologies and sold in large quantities as undifferentiated commodity goods—lumber, panels, Kraft paper. Since no unique value enhancement distinguishes one company's plywood from another's, a producer has little control over the selling price. To improve profits, then, commodity manufacturers focus on improving production efficiency and cutting costs rather than conducting research and development to create new products or enhance values. Even when some value-added characteristic is developed, the added value is quickly commoditized after ASTM testing protocols and certification standards are established. So with a few exceptions, forest products companies have downsized or eliminated their product R&D divisions. Producers have maintained technical staffs in mills to resolve product problems and rely on process engineers to improve efficiency and cut costs. Unable to hedge unstable economic and market changes, mills close when they exhaust their efforts to improve efficiency. Landowners then lose high-volume customers and the income they need to continue managing their forests, and local communities lose high-paying manufacturing jobs and tax revenue. The effects ripple throughout rural economies, affecting stores, auto dealers, and commercial service providers. The loss of tax revenue can undermine public services, such as funding for schools and hospitals.

A few new products and technologies have boosted the conventional forest products industry in the past 20 years. Examples include laminated flooring and, more recently, mass timber, an engineered wood product consisting of multiple pieces of lumber glued, nailed, or doweled together for high strength and stability. These products were developed and commercialized in Europe before appearing in the U.S. market. LignoBoost, LignoForce and sequential liquid lignin recovery and purification, technologies that separate and purify lignin from black liquor, similarly have potential. These new products and technologies are already at high technology readiness levels (TRL).

Another approach taken over the past 30 years involves treatments to protect wood from decay or insect attack or to add flame retardancy. Such innovations have added value to commodity products. Better fasteners to connect roof to wall framing and resist wind damage from hurricanes were also of substantial social benefit. Today, these values are well integrated into commodity product businesses. Creating further values for existing commodities seem like only incremental opportunities, not high-value breakthroughs.

Performance polymers or chemicals can also be derived from wood. For example, Borregaard, a Norwegian company, has an extensive line of lignin products and is venturing into cellulose nanomaterials (CNM). Solvay and FMC are in the high-purity wood fiber business, primarily for the medicinal and food industries. Ingevity (formerly MeadWestvaco Specialty Chemicals, then West Rock) has developed a unique lignin chemistry, and Rayonier Advanced Materials produces softwood fiber–based performance materials. Eastman Chemical has been a major producer of cellulose derivatives for many applications. CP Kelco markets fiber and other plant-based renewable polymers to the food, industrial additive, medical, and oil drilling markets. The R&D groups of several building materials companies (cement, drywall) have experimented with lignin. There are also three fatty-acid pine chemical companies in the United States. All these companies sell wood-derived polymer materials or chemicals whose performance characteristics are superior to those of petroleum-based materials. Although they make forest products, only a few of them have participated in traditional forest management or forest products activities.

Figure 2. Examples of products developed from cellulose nanomaterials

Governments in Canada, Japan, and many European countries are investing in cellulose nanomaterials (CNM) R&D, and a few new products are already commercially available. For example, Rheocrysta® is a CNM thickener for gel ink in ball pens sold in the United States by Uniball, which advertises “skid-free writing.” An adult diaper product produced by Nippon Paper and sold in Japan has a modified CNM deodorant layer. In Finland, UPM Biochemicals markets a CNM as an easy-to-use, one-component 3-D cell culture hydrogel, trademarked GrowDex®. Borregaard has displayed personal care lotions that contain its CNM, called EXILVA, as a rheology modifier and emulsion stabilizer.

Products made with CNM in laboratories but not yet commercially available include bike helmets (Sweden), ink additives for 3-D printing to produce human body parts (Sweden), miniature loudspeakers (Sweden), computer chips (United States), flexible display screens (Japan), foldable batteries (Korea), ultra-thin latex (Australia), water filter media (Sweden and Spain), barrier coatings for fruits (United States), and super-absorbent materials for insulation and oil spill cleanups (several countries). For the strategic thinker, all these examples of CNM applications can be inspirations for future R&D opportunities and activities involving other renewable polymers, such as lignin and hemicellulose.

Wood sciences and technologies

The forest products industry comprises numerous sectors: softwood lumber, glulam and composite lumber, plywood, oriented-strand board (OSB), particleboard, medium-density fiberboard (MDF), wood adhesives and coatings, preservatives and treatment, doors and windows, architectural wood products, furniture, and hardwood lumber. Pulp and paper products include communication paper, printing paper, newsprints, tissues, corrugated board, boxes and packaging, card stock, and specialty papers. Each of these subsectors has its own technology, but all employ the basic sciences in reducing the size of wood pieces or tearing wood apart into its components, then recombining them to make products.

The basic sciences in forest products are physics, chemistry, biology, mechanics, engineering, and wood science, but this is by no means an exhaustive list. Wood scientists study the material's anatomical structure, chemical structure and chemistry, physics and mechanical properties, and heat and mass transfer properties, plus wood-water interactions. These sciences are very important for design properties and performance of wood products, other raw materials used in the final product, and behavior of wood during the manufacturing process.

Most forest products are produced from wood that has been reduced to different sizes and shapes and from components of wood. Reduction technologies differ from product to product. Sawmills cut logs to standard dimensions with circular saws or band saws. Most veneers are cut on a rotating lathe from logs or sliced from larger pieces of wood. In OSB mills, flakers reduce debarked logs to flakes of well-defined dimensions at extremely high speed. Most particleboard mills today either use hammer mills or discs to produce "furnish" from sawdust, planer shavings, and other industrial process residues. The wood pieces are usually dried, by either air or heat (in kilns or in-line dryers), before being recombined into a final product. This drying process is extremely important for the property of the final product and subsequent secondary manufacturing steps. Wood fibers in MDF are produced by digestion and refining without delignification.

Pulping can be achieved by mechanical, thermomechanical, chemi-thermomechanical, Kraft, sulfite, soda, and organosolv pulping. A tremendous amount of pulp is made from recycled paper. Performance fibers and polymers are produced by chemical pulping processes, and hemicelluloses can be extracted from wood. Pulping is sometimes followed by bleaching before papermaking.

Production processes

Lumber and laminated products

In sawmills, timber is cut into lumber, which is air-dried or kiln-dried and then planed and/or sanded. Glulams are produced by gluing together small pieces of lumber with cold-setting glues. In construction plywood and hardwood plywood, veneers are dried and clipped to size, followed by glue application, laying up, defect removal and patching, hot pressing, trimming, and surface sanding. Plywood lines used to be very labor intensive; mechanized layup is one production efficiency that has reduced labor requirements. Laminate veneer lumbers (LVL) for structural use are made with high-strength veneer. LVL manufacturing steps are similar to plywood but more likely to be fully automated continuous lines. A hardwood LVL is produced for furniture manufacturing.

Wood composites

In OSB, flakes are separated into face and core furnishes. Both face and core furnishes are dried to different moisture contents, followed by blending with resins and wax. Resinated face and core furnishes are then transported to formers in separate conveyor lines; the former orients the flakes and lays up the three-layer mat (top face, bottom face, and core). The mat is then compressed into OSB in a hot press. After hot pressing, the OSB is cut to size, surface sanded, and hot stacked. An edge coating is applied before shipment to customers.

The manufacturing steps in particleboard are very similar to OSB but with different equipment at each step. The flakes in OSB face and core layers, laid up in perpendicular grain directions by the former, have the same dimensions. In particleboard formers, larger particles are laid up in the core layer for better bending resistance. To provide a smooth surface for laminating thin decorative layers, the face particles in particleboard are cut smaller than the core particles and are “classified”—that is, separated by either dimension or weight. The largest particles are laid up near the core layer and finest particles are at the top and bottom surfaces. After the mat is formed, the particleboard mat is pressed, hot pressed, trimmed and cut to size, sanded, and hot stacked.

In most MDF production processes, the wood fibers are processed through refiners in a slurry, usually with twice as much water as wood fiber. The fiber slurry is then transported to tube driers by hot air in a blowline. MDF resins are introduced to the wood fiber slurry in the blowline, where the turbulent flow accomplishes the blending. The resin-coated wood fiber then enters a former that creates a one-layer mat. The mat is hot pressed, trimmed and cut to size, sanded, and hot stacked.

Composite lumbers, such as paralam and strand lumbers, are manufactured in similar ways, but the exact processes are proprietary. Process secrecy is not new. After Georgia-Pacific Corporation created the first automated layup system for southern pine plywood in the 1970s, its process and equipment remained secret for some years. For the purpose of this report, the science and technology behind composite lumbers can be considered similar to those for wood composites.

Fine paper

Papermaking generally starts with pulp preparation: wood pulp is washed, refined, cleaned, and sometimes bleached, then turned to slush in a beater. Color dyes, coatings, and other additives may be mixed in. Once the pulp is prepared and diluted (often 1 percent fiber to 99 percent water), the fiber fluid enters a headbox and former, where it is sprayed onto a moving screen up to 25 feet wide wide traveling as fast as 50 feet per second (35 miles per hour). As the water drains away and is recycled—assisted by suction from beneath the screen—the wet fiber mat, or web, is squeezed between large rollers to remove water and ensure smoothness and uniform thickness. The semidry web is then run through heated dryer rollers to evaporate the remaining water. Sizing agents, such as resin, glue, or starch, can be added to the web to alter its characteristics. An additional coating of fillers, such as calcium carbonate or china clay, produces a very smooth, bright surface with superior printing qualities. Calendars are special rollers used to make the surface extra-smooth and glossy and give the paper a uniform thickness.

Newsprint

Newsprint is generally made from mechanically produced pulps with high lignin content. Traditionally, newsprint was made from fibers extracted from various softwood species (most commonly spruce, fir, or pine). However, an increasing percentage of the world's newsprint is made with recycled fibers. Paper machines have been specifically designed to produce newsprint, following a process similar to that outlined above.

Tissues

Tissue paper is produced on a paper machine that has a single large steam-heated drying cylinder fitted with a hot air hood. The drying cylinder is sprayed with an adhesive, and crêping (crinkling) is done by a "doctor" blade on the drying cylinder that scrapes the dry paper from the cylinder surface. Other steps in tissue papermaking can include embossing and through-air drying to improve water absorbency. Tissues are made with recycled pulp mixed with other types of pulp for specific targeted properties.

Corrugated containers

Corrugated containers are made from two types of paper—corrugating medium for the core and linerboard for the top and bottom. Corrugating medium, the fluted core of cardboard, is made from hardwood pulp. Linerboard, the facing, is usually made from softwood pulp. The first step in making corrugated board is the single facer, where flat paper passes through a set of corrugator rolls to give it the wavy flutes. A glue is applied to the flute tips and a pressure roll combines the fluted medium and linerboard together to form a single-faced web. The single-faced web is transported to a bridge that carries the web to a second glue unit, which applies glue to the remaining flute tips of the single-faced web and adds the second linerboard surface. Some corrugated board has a two-layer linerboard for added strength, or even two layers of corrugating medium, creating a five-layer sandwich alternating linerboard and corrugating medium. The glued board is heat dried and then sent through cutters, scorers, slitters, folders, gluers, or staplers and finally printers to make boxes or containers to the end user's specifications. Box making may occur at the plant that manufactures the cardboard, but sometimes corrugated cardboard is cut into large sheets and sent to a different plant for customized box production.

Fibers and polymers

Fibers and lignin are produced by pulping. Different pulping processes produce different types and grades of fiber and different types of lignin. Fiber can be further broken down to cellulose. Pulp mills usually burn their lignin as fuel for in-house use (generating steam or electricity for the manufacturing processes and/or sending electricity to the local public utility's network). Lignin can also be further processed into different chemical products. Hemicellulose products are usually extracted from wood, and the nature of these products depends on the wood species pulped and the chemical processes used.

Binders, chemicals, and additives

Improving binders, chemicals, and additives is part of forest products R&D. These essential ingredients hold wood together, protect wood, chemically separate components from wood, or otherwise improve the properties of forest products. The major types of binders, chemicals, and additives have not changed much since their introduction to the market; however, formulations for these products have advanced to reflect changes in regulations and customers' needs. Formulation R&D is best achieved by directly working with customers in their mills. It is high TRL research.

Future potential

The future of forest products will be a bioeconomy, a world in which high-rise buildings, furniture, clothes, electronics, biomedical products, transportation vehicles, smart packaging, electronic paper—and just about everything else in our society—will include wood or wood-derived polymers or chemicals. And wood, the source of these biomaterials, is renewable. This provides an enormous opportunity for forest products R&D, not least because the infrastructure and supply chains to harvest, transport, and manufacture wood products or renewable polymers from wood already exist. Unlike the solid wood products markets, where products are undifferentiated commodities and more R&D can create only limited and temporary value-added gain for early adopters, the emerging bioeconomy presents more opportunities for R&D to create long-lasting, high-value, profitable new products.

A decade or two hence, there needs to be an active research and development component in the processing and manufacturing parts of the U.S. forest sector and, more broadly, the development and implementation of national environmental policies. There are already many examples from other countries.

- In Japan, CNM is part of the nation's greenhouse gas emissions reduction strategy and national revitalization strategy. As a result, five Japanese ministries have developed a coordinated plan to research, develop, and produce CNM-containing products.
- A emerging consortium of cellulose researchers in the United States and European Union countries is exploring collaboration on carbohydrate research. Carbohydrates are the logical next step in using performance polymers or chemicals from wood because of their unique performance characteristics.
- In Canada, FPInnovations receives funding for forest products research from Canadian government innovation grants.
- Germany has a Fraunhofer Institute for wood science (WKI Institute), and other Fraunhofer Institutes house programs in renewable polymer research.
- VTT in Finland has a significant research program in forest products.
- The Industrial Technology Research Institute (ITRI) in Taiwan is interested in renewable polymers (both cellulose and lignin) because customers requested the work.

The funding source of all the innovation institutes, such as FPInnovations, the Fraunhofers, VTT and ITRI, follows a ⅓-⅓-⅓ principle. One-third of the institute's funding comes from the national government, one-third comes from industry members in the consortium, and one-third comes from service contracts and cooperative research agreements between institute researchers and companies commissioning work on specific projects. In essence, the government and industry members create and support two-thirds of the research capacity created, and one-third of the capacity comes from specific projects with specific firms.

Conclusions and recommendations

A major reason that U.S. forest products R&D is declining is the focus on incremental work with existing products and high-volume, “me-too” commodities. Forest products R&D needs to expand its horizons and explore high-value, innovative performance materials with unique value-added characteristics. Such R&D will be sustainable because the up-front costs will be easier to recover.

Some commodity manufacturers understand they need to make changes and have begun strategically repositioning themselves by investing in, starting up, or acquiring high-valued, high-performance lines to augment their commodity lines. These business leaders realize that such a shift will help them weather downturns like the 2006–2014 recession, when the slump in housing markets shuttered more than 1,000 solid wood products mills.

Two types of investment in R&D make sense in these times.

First, invest R&D dollars in creating new uses for wood-based materials, especially renewable polymers such as fiber, cellulose, hemicellulose, lignin, and certain wood chemicals. The focus of this research must be developing products, not isolating the polymers. An example is creating high-performance plastics for touch-screen computer displays. The R&D technical needs for mature products and technology should be managed as high-TRL research or fee-for-service work. U.S. forest products R&D organizations already have in-depth technical knowledge for existing forest products but are also capable of researching renewable polymers and building research programs in this area. Our future is in new application of wood, and renewable polymers R&D is the logical next big thing in the progression of forest products R&D.

Second, invest in R&D that fills gaps in fundamental sciences. Creating new knowledge can transform product lines and industries or, better yet, launch entirely new ones. Looking beyond today’s forest products sector to other sectors, such as health care and pharmaceuticals, one can see potential customers for polymers derived from cellulose, hemicellulose, lignin, and wood chemicals.

Another recommendation is to establish at least one innovation institute whose mission is to develop solutions from wood or wood components for any application. The institute can be structured and funded as a public-private partnership through some combination of funding from government, partner members, and focused R&D projects. It needs to strategically address new product development with an eye on the entire product life cycle, from sustainable supplies of the right raw materials (tree species) through zero-emitting conversion processes, environmentally sound uses of products by customers, recycling of the products, and end-of-useful-life green disposal. The innovation institute will need a combination of fundamental and applied research, technical transfer and intellectual property management, and fee-for-service and business incubation components. It will also need a fresh culture and focus, different from that of most research today—in particular, the willingness and ability to shift nimbly to new projects or lines of inquiry as needed. Finally, firms that use wood-based materials in their manufacturing processes need to invest in the institute and commit to its long-term financial health and strategic direction. This investment and commitment must come not only from traditional forest products firms but also from firms in other economic sectors that rely on high-value, high-performance materials sourced from forests.

People have more daily contact with forest products than with many other goods and services. Because well-managed forests are renewable, supplies of forest products can be sustained well into the future and not depleted. As our population continues to grow, people and forests—including forest products manufacturing plants—increasingly will need to coexist in close proximity. Already, plants relying on supplies of recycled paper have moved closer to the source of recycled paper—cities—because it is more efficient than hauling recycled paper to rural areas. Our society will interact and demand more from our forests for renewable products, recreation, and conservation. For America to be a leader in renewable materials research, we have to rebuild public support for forest products research by improving our messages about the importance of forests and the products and services they provide. Right now, the public benefits immensely yet little understands from whence the benefits come.

Wood and renewable polymers from wood have the potential to improve thousands of products. Many European countries and Canada have already invested in the future by supporting their forest products industry. Here in the United States, a stronger, more strategically focused public-private partnership is needed both to conduct R&D and to create public awareness about the importance of forests and forest products and services to the American people.

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