Wood Chips 2.0: Collaboration Yields Biodegradable Computer Chips Made from Wood

By Rebecca Wallace, Public Affairs Specialist

If a centuries-old material can undergo an extreme makeover, this is it: wood, a staple in keeping humans warm and sheltered for ages, could soon be found in your smartphone.

Research at the Forest Products Laboratory (FPL) is taking a thrilling turn with the advent of nanocellulose, and Zhiyong Cai, a research materials engineer at FPL, and his partners at the University of Wisconsin–Madison are situated at the forefront of possibility, developing a semiconductor chip made almost entirely of wood.

The research team, led by UW–Madison electrical and computer engineering professor Zhenqiang “Jack” Ma, described the new device in a recently published paper in the journal *Nature Communications*. The paper demonstrates the feasibility of replacing the substrate, or support layer, of a computer chip with cellulose nanofibril (CNF), a flexible, biodegradable material made from wood.

“The majority of material in a chip is support. We only use less than a couple of micrometers for everything else,” Ma says. “Now the (new) chips are so safe you can put them in the forest and fungus will degrade it. They become as safe as fertilizer.”

Cai, who has been developing sustainable nanomaterials since 2009, explains that the most common product from broken-down wood is paper, and the dimension of those fibers is in the micron stage. “But what if we could break it down further to the nano scale? At that scale you can make this material very strong and transparent CNF paper,” says Cai.

Working with Shaoqin “Sarah” Gong, a UW–Madison professor of biomedical engineering, Cai’s group addressed two key barriers to using wood-derived materials in an electronics setting: surface smoothness and thermal expansion.

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Wood You Believe

By Madelon Wise, Technical Publications Editor

FPL made national news in 2008 and 2011 when Research General Engineer Dave Kretschmann and his team became known for their work with Major League Baseball and the perplexing problem of breaking baseball bats. But did you know that FPL’s foray into sports goes back much farther than our work with baseball?

These photos, taken from the FPL Library’s history room, show various experiments on laminated bowling pins. These pins originated from a conscientious desire to preserve our forests.

A 1920 USDA Technical Publication, “Fabrication and Design of Glued Laminated Wood Structural Members,” tells of the earnest Assistant Director of the Forest Products Laboratory at that time who “asserted that it would be possible to save ten billion feet of timber annually, if the American people would put in general practice what is already known relative to the closer utilization and preservation of wood.”

In an attempt to preserve what virgin forest remained, experiments began in 1912 to create bowling pins of laminated construction. Athletic goods, according to this publication, “require but a small number of woods for their manufacture. Special qualities are necessary, however, to meet the requirements of these products.”

These photos show special strength tests that resulted in standards that are still adhered to, according to the United States Bowling Congress and its USBC Equipment Specifications and Certifications Manual: “Gluing procedures should conform to those described in the Forest Products Laboratory (U.S. Department of Agriculture) manual entitled ‘Fabrication and Design of Glued Laminated Wood Structural Members.’”

So when you’re knocking back a few sodas or beers and knocking down those pins at the bowling alley, just remember that FPL and utilization of our forest resources helped make your pleasure possible.
Upcoming Events

19th International Nondestructive Testing and Evaluation of Wood Symposium
September 22–25, 2015, Rio de Janeiro, Brazil

The 19th International Nondestructive Testing and Evaluation of Wood Symposium is a forum for those involved in nondestructive testing and evaluation of wood, wood-based materials and products. It will bring together the international nondestructive testing and evaluation research community, users of various nondestructive testing technologies, equipment development and manufacturing professionals, representatives from various government agencies and other groups to share research findings and new nondestructive testing products and technologies.

For more conference information, visit http://abendieventos.org.br/wood_symposium/.

North American Wood Window and Door Symposium
September 23–25, 2015, Forest Products Laboratory, Madison, Wisconsin, USA

A premier symposium focused on the effective use and optimal performance of wood and wood-based materials in window and door manufacturing. The purpose of this conference is to ensure that wood remains a viable option for windows and doors and to educate attendees of the benefits of wooden fenestration, as well provide instruction that will ensure optimal performance of these products. The target audience will consist of manufacturers, architects, contractors, designers, researchers, and policy makers who influence selection of materials for residential and commercial construction.

For more conference information, visit http://www.forestprod.org/wooddoorsymposium/.

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Weathering the Storm: Protecting Homes from Moisture

By Madelon Wise, Technical Publications Editor, and C.R. Boardman, General Engineer

Moisture is the archenemy of wood-framed houses, and wind-driven rain is the primary external culprit. Despite understanding various ways moisture can enter houses through exterior walls, researchers still have not achieved the elusive perfect wall system.

To advance toward that goal, a Forest Products Laboratory (FPL) facility, affectionately called the CARWASh (Chamber for Analytical Research on Wall Assemblies exposed to Simulated weather), was created to investigate the water management performance of exterior wall assemblies. The chamber creates controlled outdoor and indoor conditions to study the effects of wind-driven rain.

C.R. Boardman, a general engineer in the Building and Fire Sciences work unit at FPL, explains that this laboratory can help validate computer models that factor in various boundary conditions (such as temperature and humidity), driving forces (such as wind and rain), and the fundamental physics of heat and moisture transfer to predict how moisture moves in buildings. “The facility provides a controlled environment where we can experiment with full-size wall assemblies and wind-driven rain and thus evaluate wall design and window detail for moisture management,” Boardman says.

In the past, researchers and manufacturers with similar interests have tested wall assemblies by spraying water directly at test assemblies for 15 minutes to see if water would get through. The difference with the CARWASh, says Boardman, is that the water spray rack is pointed down, so that the kinetic energy of the water that hits the wall all comes from the wind, which blows rain into the wall. The CARWASh was designed to provide realistic wind-driven rain under typical conditions.

To give an idea of how the CARWASh is used, let’s review a 2013 study in which the CARWASh delivered wind-driven rain at two wind conditions and a range of rain intensities to a simple wall. In their experiments, Boardman and Sam Glass, a physical scientist at FPL, first needed to quantify exactly how much water was delivered to the wall depending on location, rain intensity, and wind speed. They presented a map of wind-driven rain delivered to the wall, measured with wind-driven rain gauges, which described the local distribution of that rain under two different wind speeds and a variety of different rain intensities in the CARWASh.
Armed with this basic data they were able to start studying how much wind-driven rain got past the cladding. In this preliminary test, researchers created a very simple defect by putting a wedge in the lapboard siding. Boardman and Glass quantified how much water got past the cladding by placing absorbent pads in the drainage cavity between the cladding and the sheathing to capture any moisture that got past the siding. After rain events, the researchers measured the weight change in the absorbent pad. The percentage of moisture getting past the cladding was correlated with wind pressure across the cladding for various wind speeds and rain intensities.

This particular defect did not allow any water to get past the cladding without the wind driving the rain into the defect. Other studies of wind-driven rain have focused on other kinds of defects that allow water entry simply based on gravity flow. Rain water running down the siding typically creates a cascade that washes over any defects and often allows water entry without direct wind pressure.

Boardman and Glass plan to create a typology of defects and characterize both gravity alone and wind effects on a variety of defect types. The CARWASh will be the perfect instrument for advancing our knowledge of wind effects on these defects and thus provide a better characterization of wind-driven rain driving forces needed for improved computer modeling that can inform more robust wall design.

With this unique facility, the possibilities are endless because as Boardman says, “I can dial up any weather I want. I have complete control of the environment.”

Capabilities of the CARWASh

- Both indoor and outdoor sides of chamber are temperature- and humidity-controlled.
- Indoor controls can vary relative humidity from 30 to 70% and temperature from 60 to 80 °F (15 to 27 °C).
- Outdoor controls, including wind, rain, and sun, can vary dew point from 25 to 80 °F (–4 to 27 °C) and temperature from 30 to 110 °F (–1 to 43 °C).
- Infrared lamps that simulate the drying effects of the sun are capable of heating from 0 to 100 W/ft² (0 to 1,100 W/m²).
- Measurement systems can probe the wall for temperature, relative humidity, and wood moisture content.
- Sensors can probe pressure differentials across wall assembly elements to 1 Pa resolution.
- Wind speeds range from 2 to 25 mph (3.2 to 40 km/h), and wind gusts can be simulated.
- Rain intensities range from 0.25 to 6 inches per hour (0.6 to 15 cm/h).
- Computer control of rain, wind, and sun allows programming of weather patterns that can last months.
- Two types of wall orientation are possible, with wind hitting either a corner or a flat section.
Natural Nanocrystals Shown to Strengthen Concrete

Purdue University News Release

Cellulose nanocrystals derived from industrial byproducts have been shown to increase the strength of concrete, representing a potential renewable additive to improve the ubiquitous construction material.

The cellulose nanocrystals (CNCs), produced in a pilot facility here at the Forest Products Laboratory (FPL), could be refined from byproducts generated in the paper, bioenergy, agriculture, and pulp industries. They are extracted from structures called cellulose microfibrils, which help to give plants and trees their high strength, light weight, and resilience. Now, researchers at Purdue University have demonstrated that cellulose nanocrystals can increase the tensile strength of concrete by 30%.

“This is an abundant, renewable material that can be harvested from low-quality cellulose feedstocks already being produced in various industrial processes,” said Pablo Zavattieri, an associate professor in the Lyles School of Civil Engineering.

Cellulose nanocrystals might be used to create a new class of biomaterials with wide-ranging applications, such as strengthening construction materials and automotive components.

Research findings were published in February in the journal Cement and Concrete Composites. The work was conducted by Jason Weiss, Purdue’s Jack and Kay Hockema Professor of Civil Engineering and director of the Pankow Materials Laboratory; Robert J. Moon, an FPL researcher; Jeffrey Youngblood, an associate professor of materials engineering; doctoral student Yizheng Cao; and Zavattieri.

One factor limiting the strength and durability of today’s concrete is that not all the cement particles are hydrated after being mixed, leaving pores and defects that hamper strength and durability.

“So, in essence, we are not using 100% of the cement,” Zavattieri said.

However, the researchers have discovered that cellulose nanocrystals increase hydration of the concrete mixture, allowing more of it to cure and potentially altering the structure of concrete and strengthening it. As a result, less concrete needs to be used.

Cellulose nanocrystals are about 3 to 20 nanometers wide by 50 to 500 nanometers long—or about 1/1,000th the width of a grain of sand—making them too small to study with light microscopes and difficult to measure with laboratory instruments. They come from a variety of biological sources, primarily trees and plants.

The concrete was studied using several analytical and imaging techniques. Because chemical reactions in concrete hardening are exothermic, some of the tests measured the amount of heat released, indicating an increase in hydration of the concrete. The researchers also hypothesized the precise location of the nanocrystals in the cement matrix and learned how they interact with cement particles in both fresh and hardened concrete. The nanocrystals were shown to form little inlets for water to better penetrate the concrete.

The research dovetails with the goals of P3Nano, a public–private partnership supporting development and use of wood-based nanomaterial for a wide range of commercial products.

“The idea is to support and help Purdue further advance the CNC–cement technology for full-scale field trials and the potential for commercialization,” Zavattieri said.

This research was funded by the National Science Foundation.
FPL Welcomes Deputy Chief Weldon as Leaders Converge in Madison

By Rebecca Wallace, Public Affairs Specialist

The “Destination of Innovation” had a welcomed visit from Leslie Weldon, Forest Service Deputy Chief for the National Forest System.

Deputy Chief Weldon recently visited the Forest Products Laboratory (FPL) to participate in a Forest Service joint leadership team meeting comprised of representatives from FPL, the Northern Research Station, Region 9, and the Northeastern Area. The Forest Service’s Middle Leader Program was also on site and was fortunate to have Weldon meet with their group. Her perspective as a member of the Forest Service Leadership Team and her willingness to share her experiences went a long way to making the big week a tremendous success.

“By almost all standards, I believe this was one of the most successful leadership meetings I have attended,” said Michael T. Rains, Director of the Forest Products Laboratory and Northern Research Station. “The voice of ‘one Forest Service’ is beginning to get quite loud and it sure sounds good to me.”

Weldon and the Middle Leader participants were able to break away from their meetings and see FPL research first-hand. The group was lucky enough to see one of FPL’s most impressive tests...a shot from our air cannon. It’s not every day one sees a 2x4 piece of lumber flying at 100 mph toward a test wall!

A Lesson in Nanocellulose: Video Lecture Available Online

By Rebecca Wallace, Public Affairs Specialist

Robert Moon, a materials research engineer at the Forest Products Laboratory (FPL), recently presented an hour-long lecture at Georgia Tech University titled “Cellulose Nanomaterials: Plant-based Nanoparticles Growing a Sustainable Future.”

The lecture was recorded and is freely available for public viewing from the Georgia Tech library.

Moon’s presentation gives viewers a thorough overview of cellulose nanomaterials, including sources, properties, and applications. According to the video’s abstract, applications include but are not limited to “reinforcing fillers for polymers, cements, fibers, transparent films, flexible transparent displays, biomedical implants, drug delivery, barrier films, separation membranes, batteries, supercapacitors, sensors, etc.”

Pull up a chair, go to https://smartech.gatech.edu/handle/1853/53312, and prepare to be amazed by the huge possibilities this tiny particle presents.
Essential Science: Researchers Patent a New and Natural Frugal Fungicide

By Tom Owens, Public Affairs Specialist

Sitting at the Forest Products Laboratory (FPL), microbiologist Vina Yang recounts a news story that took Madison, Wisconsin, by storm. Fourteen years ago, more than 35 students and faculty mysteriously fell ill at Caesar Chavez Elementary School. Although the school had been open for only two months, it quickly and inexplicably turned from Madison’s newest educational institution into a health nightmare. Ailments ranged from sudden onset asthma, to respiratory problems, to severe allergic reactions, and it was only after the school’s inevitable closure that officials found the source of the problem—hidden behind the pristine drywall and gleaming floor tiles of the new building, inadequate ventilation had caused mold to take a firm hold at Caesar Chavez.

Today, Yang and fellow researcher Carol Clausen are working hard on developing new techniques to combat the mold plaguing the world’s wood-containing residences, businesses, and storage facilities. More than seven years of research recently culminated in a patented method of using essential oils derived from plants to inhibit mold on cellulose-containing materials such as paper, lumber, and ceiling tiles.

Yang and Clausen’s Durability and Wood Protection unit traditionally studies preservatives for wood in exterior applications, but it quickly became apparent that there was demand for a less toxic solution for indoor use as well.

“We would always take calls from consumers asking for ways to prevent mold on the inside of houses,” Clausen recalls, adding that essential oils can be as effective as chemical fungicides without the associated health concerns, which are elevated when used in a household environment. Perhaps the biggest, albeit subjective, drawback of using the oils indoors is the odor, as they tend to smell strongly of the parent plant. “One person came by the lab and just loved the smell—others came by and told me to close the door,” added Yang.

From the original arsenal of seven oils that Yang and Clausen began to study in 2007—thyme, ajowan, dill weed, Egyptian geranium, lemongrass, rosemary, and tea tree—only the thyme oil compositions received the patent earlier this year. Patent Number 8,986,757 now awaits licensees and industry partners to deliver new products to consumers.

Yang suggests that applying the oil to wood stored in warehouses or lumber yards could prolong its storage life, while Clausen foresees the treatment as an easy way for companies to provide peace of mind to consumers. “I especially foresee a lumber or construction company using our technology as a way to provide inexpensive protection to customers,” Clausen said.

The oil can be dipped, sprayed, or brushed onto wood surfaces, and in some cases, simply exposing the material to oil vapor is enough to inhibit mold growth, making it the ideal process for fumigating large spaces or large volumes of material.

Essential oils cost roughly $18.00 per pound; when they are diluted for use, the cost is about two cents per gallon, and
fractions of a penny per square foot. Essential oil technology becomes even more affordable when one considers that health problems caused by interior mold accounted for $2.8 billion in 2002 alone.

The research may have come a bit late to rescue the doomed Caesar Chavez Elementary School and prevent the legal action that resulted from the building’s poor construction, but both researchers hope that in the future, new buildings will benefit from these surface treatments.

Clausen cautions that although effective, essential oils are not a replacement for public education or good building practices such as the proper installation of ventilation systems or flashing.

“Prevention is the key, and educating the consumer is huge, especially in flood-prone areas or in regions that face seasonal problems with mold,” Clausen said. “If they could just keep the buildings dry, that would solve all their problems.”

Wood Chips 2.0

“You don’t want it to expand or shrink too much. Wood is a naturally hydroscopic material and could attract moisture from the air and expand,” Cai says. “With an epoxy coating on the surface of the CNF, we solved both the surface smoothness and the moisture barrier.”

Gong and her students also have been studying bio-based polymers for more than a decade. CNF offers many benefits over current chip substrates, she says.

“The advantage of CNF over other polymers is that it’s a bio-based material and most other polymers are petroleum-based polymers. Bio-based materials are sustainable, bio-compatible, and biodegradable,” Gong says. “Compared to other polymers, CNF actually has a relatively low thermal expansion coefficient.”

The group’s work also demonstrates a more environmentally friendly process that mirrors the performance of existing chips. The majority of today’s wireless devices use gallium arsenide-based microwave chips due to their superior high-frequency operation and power handling capabilities. However, gallium arsenide can be environmentally toxic, particularly in the massive quantities of discarded wireless electronics.

Yei Hwan Jung, a graduate student in electrical and computer engineering and a co-author of the paper, says the new process greatly reduces the use of such expensive and potentially toxic material.

The environmental benefits don’t stop there. The Forest Service sees promise in nanocellulose as a means for promoting forest restoration activities. Severely overcrowded forests are at risk for catastrophic wildfires, insect infestation, and disease. The high cost of thinning these forests to a healthy state could be greatly reduced if the material removed can be converted to a high-value material like nanocellulose, which is applicable in countless industries.

The incorporation of these materials will have a positive impact on the environment, and Ma says the flexibility of the technology can lead to widespread adoption of these electronic chips.

“Mass-producing current semiconductor chips is so cheap, and it may take time for the industry to adapt to our design,” he says. “But flexible electronics are the future, and we think we’re going to be well ahead of the curve.”

The journal article can be found at http://www.nature.com/ncomms/2015/150526/ncomms8170/full/ncomms8170.html.
Michael T. Rains, Director of the Forest Products Laboratory (FPL) and Northern Research Station (NRS), recently presented the 2015 Director’s Awards to 10 exceptional employees furthering scientific advancement at the two research facilities. Rains praised the honorees for their impacts and contributions made at their respective posts, but lamented the fact he was forced to choose only a handful of winners from a pool of such outstanding talent.

“There can be only one winner for each award—if I could do more, I would,” Rains said from the NRS station headquarters in Newtown Square, Pennsylvania.

**John Considine**

**Distinguished Science Award**

for his efforts in advancing measurement methods to understand problems affecting paper performance, spending nearly three decades working to understand and improve paper quality and properties. His contributions include developing one of the first instruments capable of testing paper and paperboard in compression, helping the United States Postal Service reduce waste in stamp printing from 40% to 15%, and investigating why machine-made paper fails at lower strength than laboratory-made sheets. Aside from his own students and the original inventors of the technique, Considine is the only scientist in the world to use the Virtual Fields Method to research paper defects.

**Keith Bourne**

**Scientific Support Award**

for his expertise in mechanical engineering and his integral role in several FPL projects over the past few years. Among other accomplishments, Bourne designed and developed measurement devices for a project funded by Shell Oil, including a new power meter and data acquisition system to measure the viscosity of biomass materials. He was also solely responsible for designing and constructing the hardware and software for the laboratory’s rainfall simulator, and is currently assisting with a project to develop an auditory termite sensing device.

**C. Adam Senalik**

**Early Career Scientist Award**

for his profound impact despite his relatively short time working at the laboratory. Senalik began his career at FPL in 2013 after working as a forensic engineer for a private firm. In the past two years at the laboratory, he has contributed to several projects, including analytical modeling of lightweight timber bridge decks, and evaluating the effectiveness of cutting-edge bridge inspection techniques. Senalik has also worked cooperatively with several other government agencies, including the Department of Defense and Federal Highway Administration.

**Kenneth Skog**

**Excellence in Science and Technology Award**

for both his international contributions establishing the role of wood product production and use in mitigating climate change, and his national contributions in identifying sustainable levels of forest-based biomass for use in energy production. Skog’s work has led to internationally accepted methods and software products to help countries calculate the greenhouse gas emissions that are mitigated by harvested wood products. He also led a team for the Department of Energy’s biomass supply report that estimated each U.S. county’s capacity to create biofuel and energy from forest-based biomass. The resultant database has been used by state governments, federal agencies, investors, and other organizations to evaluate a county’s natural resources for future economic development.
**Wood Wise—Terms from the World of Wood**

- **Tracheid:** The elongated cells that constitute the greater part of the structure of softwoods (frequently referred to as fibers). These elongated cells are also present in some hardwoods.

- **Papreg:** Any of various paper products made by impregnating sheets of specially manufactured, high-strength paper with synthetic resin. These sheets are then laminated to form a dense, moisture-resistant product.

- **Wood wool:** Long, curly, slender strands of wood used as an aggregate component for some particleboards and cement-bonded composites. Sometimes referred to as excelsior.

- **Dote:** “Dote,” “doze,” and “rot” are synonymous with “decay” and are any form of decay that may be evident as either a discoloration or a softening of the wood.

- **Oleoresin:** A solution of resin in an essential oil that occurs in or exudes from many plants, especially softwoods.


**USDA Awards Funds to Expand and Accelerate Wood Energy and Wood Product Markets**

Agriculture Secretary Tom Vilsack announced the award of over $9 million to expand and accelerate wood energy and other wood product markets. The federal funds will leverage $22 million in investments from partners, resulting in a total investment of $31 million in 23 states.

“Working with our partners, the Forest Service is promoting deployment of new technologies, designed to support new market opportunities for wood energy and innovative wood building materials,” said Vilsack. “This funding also supports forest management needs on the National Forest System and other forest lands throughout the United States.”

This year, more than 100 proposals were received for the Wood Innovations grant program, highlighting the expanding use of wood as a renewable energy source and as a building material. The awarded funds will stimulate the use of hazardous fuels from National Forest System lands and other forested lands to promote forest health while simultaneously generating rural jobs.


Even small investments in woody biomass can have substantial impacts.