BIOMIMICRY CASE STUDY

PUREBOND® TECHNOLOGY: WOOD GLUE WITHOUT FORMALDEHYDE

BIOMIMICRY INSTITUTE

Purebond® Technology

Biomimicry Case Study: Biology To Design

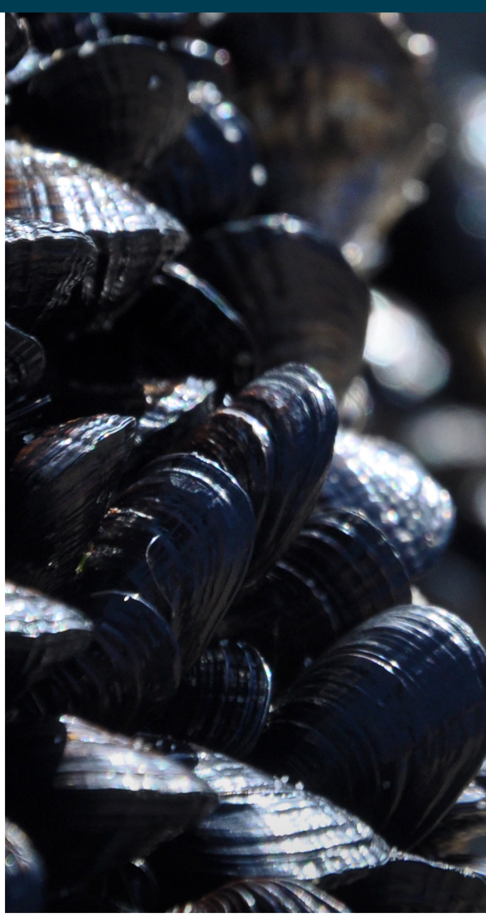
On the wave-battered shores of the Oregon coast lives a hardy creature, the blue mussel. This mollusk uses small adhesive threads to attach to rocky surfaces in tidal zones, resisting the erosive forces of water and waves. The mussel's tenacious grip has inspired new wood glue technology called PureBond® that is nontoxic and sustainable, leading the way for innovation in the wood products industry.

PRODUCT	PureBond® Formaldehyde-free Hardwood Plywood Technology
INNOVATORS	
> RESEARCHER	Dr. Kaichang Li
> COMPANY	Columbia Forest Products
WEBSITE	http://www.columbiaforestproducts.com/PureBond.aspx
SUSTAINABILITY WIN	Nontoxic, soy-based adhesive that is formaldehyde-free
EMULATING FORM, PROCESS, OR SYSTEM?	Process
LIFE'S PRINCIPLE MET	Use life-friendly chemistry

The Inspiration

Blue mussels, *Mytilus edulis*, are filter-feeding mollusks found in the intertidal zone on the North Atlantic coasts of North America and Europe, on North America's Pacific Northwest coast, and in other pockets of temperate and polar waters around the world. They feed on bacteria, plankton, and detritus filtered from ocean water. A colonial species, they cling in large groups to rocks and each other using strong adhesive threads, called byssal threads.[1] Despite living on wave-swept coastlines, mussels are able to hold on tightly using an underwater 'glue.' This ability has caught the attention of scientists and entrepreneurs.

> *"There are agents in Nature able to make the particles of bodies stick together with very strong attraction and it is the business of experimental philosophy to find them out."*
>
> – Sir Isaac Newton



The adhesive pads of byssal threads contain at least half a dozen different proteins, also called marine adhesive proteins (MAPs).[2,3,4] Using these adhesive compounds, mussels can adhere to nearly any substrate. The attachment is versatile and tough, despite continual exposure to salt water and shearing forces.[4,5] Traditionally, man-made glues perform poorly on surfaces that are wet, rough, or dirty, and the blue mussel's ability to overcome these common obstacles helped it gain attention from the wood products industry.[6]

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The Innovator

DR. KAICHANG LI

Dr. Kaichang Li is an associate professor in the Department of Wood Science & Engineering at Oregon State University in Corvallis, Oregon. His early college education was in applied chemistry and organic synthesis, and he later earned a Ph.D. in wood chemistry. Dr. Li previously had an interest in nontoxic composites, having done his post-doctoral work researching methods for making wood pulp using fungi.[7]

Low tide on the Oregon coast reveals the extensive marine life thriving on rocky outcroppings and brings hungry mussel-harvesters flocking to the shores with their galoshes and buckets. One weekend in 2000, Dr. Li was among those scouring for large mussels to enjoy at dinner. Glancing down at some of the mussels still being soaked by the receding tide, he was suddenly struck by how tenaciously the mussels clung to the rocks, despite taking a constant beating from the ocean. This curiosity followed Dr. Li back to the laboratory and helped lead him into innovative research.[8,9,10]

"I was amazed at the time to see these small mussels attach themselves so strongly to rocks... I didn't know of any other adhesive that could work this well in water and withstand so much force."

– Dr. Kaichang Li

Moving From Biology to Design: Motivation

As a researcher in the wood science industry, Dr. Li knew the pitfalls of existing wood adhesives. In recent decades the most commonly used glues for wood composites have been urea-formaldehyde (UF) and phenol-formaldehyde (PF) resins.[11] When these formaldehyde-based adhesives are used in the production of plywood and particle board, formaldehyde is released in a process called off-gassing.[11] Emissive formaldehyde vapor can cause irritation of the eyes, skin, nose and throat, raising health and toxicity concerns for consumers and wood product manufacturing workers alike.[6,11,12] There is evidence linking formaldehyde and certain cancers, and the World Health Organization recently recognized formaldehyde as a potential human carcinogen.[6,12,13] Researchers estimate that of all the formaldehyde made each year, over half of it is used in wood adhesives.[2]

Of the more than 1.78 million metric tons of adhesive resin solids consumed by the wood products industry in North America in 1998, over 90% were formaldehyde-based.[14]

Formaldehyde-based resins are also created using fossil fuels. Though there is no immediate shortage of petroleum resources, they are naturally limited. To stay productive in the long-term, the wood products industry must look to alternative and sustainable options for the future.[11] The U.S. and Canadian forest products industries spent over 7.4 billion dollars on wood adhesives in 1999.[13] As one of the largest manufacturing sectors in the U.S., the wood composites industry highly values new alternatives.[11]

Moving From Biology to Design: Process


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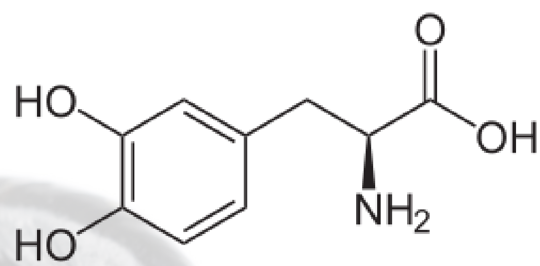
PRELIMINARY RESEARCH

Dr. Li was not the first to notice the remarkable abilities of mussels and other marine organisms to cling to irregular, wet surfaces. Other researchers had investigated the compounds responsible for such adhesive feats, so Dr. Li looked to their research papers for information. Marine adhesive proteins (MAP) found in the byssal threads of blue mussels contain several unique amino acids, the building blocks of proteins. One of these amino acids, 3,4-dihydroxyphenylalanine (DOPA), is believed to play a key role in the powerful adhesive properties of byssal threads.[1,2,3,4,15] One of the distinguishing features of DOPA is the catechol functional group—two adjacent hydroxyl groups (-OH) sticking out from a benzene ring like ears on a mouse.[1,4,11] These catechols form strong bonds with catechols on adjacent molecules and with metal atoms present in the surface of most natural solid substrates. When bonded together, they overcome a solid surface's otherwise strong preference for water molecules, a preference that causes most man-made adhesives to fail on wet surfaces. With their remarkable 'glue', mussels are able to adhere to an astounding variety of surfaces, including Teflon, steel, and glass.[2] Though other researchers had considered using or mimicking DOPA for various adhesive applications, Dr. Li was the first to consider its potential in the wood science industry.[15] Testing his theory in the lab, he successfully demonstrated the potential of mussel proteins as wood adhesive elements.[16]



L-DOPA (L-3,4-dihydroxyphenylalanine)

Soy Provides Solutions

Dr. Li had shown that marine adhesive protein had the right properties to be used as an effective formaldehyde-free wood adhesive. Marine adhesive protein, however, is expensive and not readily available, so it is not a competitive alternative for commercial use as an adhesive.

Dr. Li's knowledge in wood science led him to consider soy protein as part of the equation. He knew soy protein had been used as a wood adhesive in the past and had been replaced over time by the stronger and more durable formaldehyde-based resins.

Soybeans are 40% protein and are an abundant and annually renewable resource.[13] Dr. Li realized soy protein and marine adhesive proteins had complementary features, making them ideal partners.[6,11] Soy protein modified to look like mussel proteins could gain the strength and durability necessary to compete with UF- and PF-resins, while the availability of soy could make it cost-effective. Dr. Li tested this idea by chemically modifying soy protein, decorating it with DOPA-like catechols. When he found it to be comparable to formaldehyde-based resins in strength and durability, he started searching for industrial partners to develop a commercial product.[11]

Photo (left to right): © Bill Strong, © Columbia Forest Products

MARINE ADHESIVE PROTEIN	SOY PROTEIN
• Expensive	• Inexpensive
• Not readily available	• Abundant and annually renewable
• Strong	• Low adhesive strength
• Water-resistant	• Low water-resistance
• Highly resistant to biological degradation	• Easily degraded

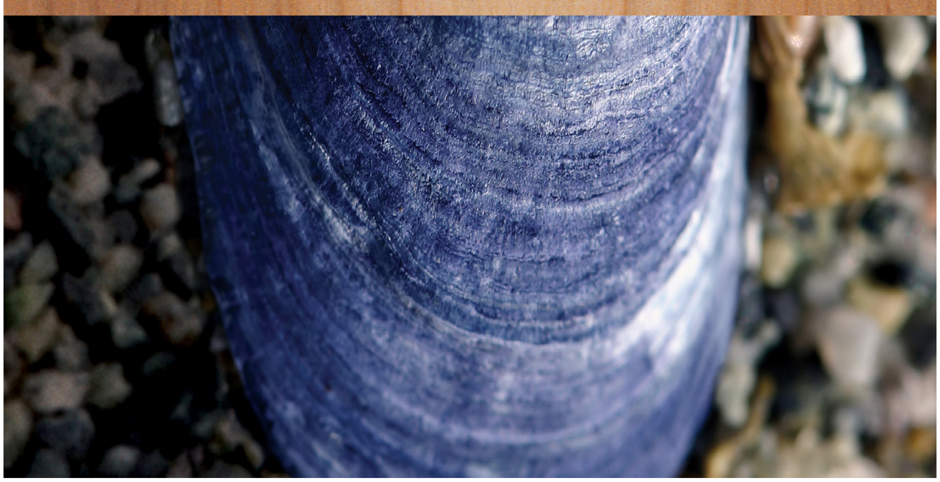
Moving From Design to Market

INDUSTRY INVOLVEMENT

Having shown in the lab the potential of a modified soy protein adhesive, Dr. Li needed to see if any companies were interested in his ideas.[11,16] While attending a Forest Products Society meeting in 2003, he met Steve Pung, Vice President of Technology and Innovation at Columbia Forest Products (CFP). CFP had been looking for alternatives to formaldehyde-based resins and agreed to fund research and design efforts to create a commercial product. Dr. Li knew his employer, Oregon State University (OSU), had a good relationship with Hercules, Inc., a resin supplier for the paper industry, so CFP approached them about jointly developing a product. They agreed, and joint proprietary funding from CFP and Hercules began in early 2004.[8]

Dr. Li received multiple patents during the development process, which were patented through OSU and licensed to Hercules. CFP gained exclusive sub-licensing rights from Hercules on the developed adhesive and its proprietary curing agent, Kymene.[9] CFP designed a manufacturing process for hardwood plywood panels using the new adhesive technology developed by Dr. Li and called it PureBond.[8]

Columbia Forest Products was founded in 1957 and is the largest manufacturer of hardwood plywood and hardwood veneer products in North America. They support responsible and sustainable forestry practices and offer several Forest Stewardship Council (FSC)-certified wood products.[8]



THE PUREBOND TIMELINE:

2000
Dr. Kaichang Li is inspired by mussels on the Oregon coast

2003
Steve Pung of Columbia Forest Products meets Dr. Li; CFP agrees to fund R&D efforts

2005
PureBond announced to the public and production begins

2006
CFP converts all 7 of its plywood plants to PureBond technology

2007
Dr. Li, CFP, and Hercules, Inc. receive Presidential Green Chemistry Challenge Award

2008
CFP announces production of 25 millionth hardwood plywood panel using PureBond technology

2010
Over 40 million PureBond panels have been manufactured and sold

Product Development

DESIGN

With funding in place, Dr. Li experimented further with chemically modifying soy protein to more closely resemble mussel proteins. This included decorating soy protein with various catechol-like structures and other functional groups to mimic the role of DOPA in the mussel's adhesive proteins.[10,17] However, a chemical modification process wouldn't be realistic for manufacturing large quantities of plywood products, so he developed a curing agent, Kymene, that could modify soy protein when panels are heated during production.[10] Kymene blocks certain amino acids in soy protein that aren't present in mussel proteins; the modified protein more closely resembles the adhesive proteins mussels use.[10] In the manufacturing process, soy protein is infused into wood fibers. The Kymene resin is then added, and upon heating it cross-links with the soy protein to form a strong bond.[6,10,17] After Li and his team honed the adhesive chemistry, mill trials and scaled up experiments were done to perfect the PureBond technology.[10]

Soy Protein-Kymene® Adhesive used in the PureBond® Process		Formaldehyde-based wood adhesives	Traditional soy-based wood adhesives
✓ Low cost		Low cost	High cost
✓ Soy-based (renewable resource)		Petroleum-based (non-renewable resource)	Soy-based (renewable resource)
✓ High Strength		High strength	Low strength
✓ Water-Resistant		Water-Resistant	Low water-resistance
✓ Nontoxic		Toxicity Concerns	Nontoxic

PureBond plywood after ANSI HP-1-2004 cyclic boil test. PureBond's superior moisture resistance approaches Type 1 for waterproof performance.

TESTING

To test wood composites for water-resistance, variations of cyclic boiling and drying tests are performed.[12,13] For example, for exterior-use wood composites, standard procedure is to boil a wood sample in water for 4 hours, dry it, and boil it again. If it doesn't degrade, it's considered highly water-resistant.[9]

Lab testing demonstrated that composites created with adhesive technology using modified soy protein are comparable in both water resistance and shear strength to traditional phenol- and urea-formaldehyde resins.[11,13] The cross-links created in PureBond panels are so strong that they can be boiled for hours without degrading.[6,9]

"For 50 years…the wood products industry has been arguing about what levels of formaldehyde emissions are safe for humans. But now some companies are taking a different approach – instead of explaining how much formaldehyde is wafting out of their wood products, they're saying, 'Our products are essentially formaldehyde-free.'"

– Dr. Kaichang Li

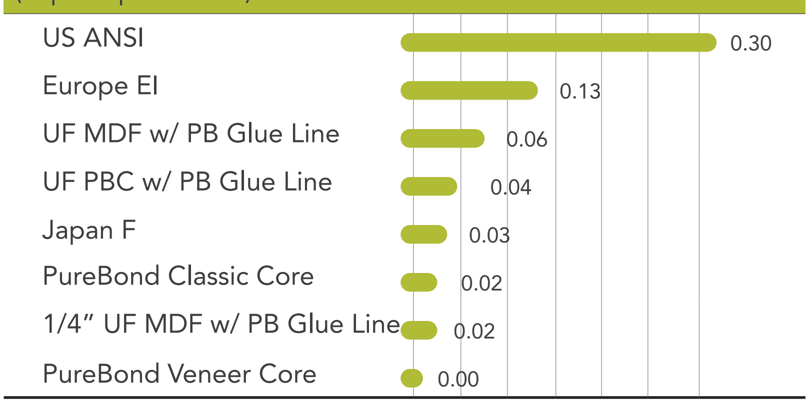
Why is this Product Better?

The PureBond process and the soy-based Kymene adhesive it uses are formaldehyde-free, sustainable, and comparable in strength to formaldehyde-based adhesive systems.[6,11,12,13] The adhesive also creates lighter glue lines that are more aesthetically appealing to consumers.[13] Other alternative wood adhesives incorporating soy are available, but only PureBond is cost competitive with formaldehyde-based resins.[11] Adhesives that use soy protein require less time and less energy to cure before use, and are safer and easier to handle.[6] In 2006, CFP converted all seven of its plywood plants to the PureBond manufacturing process, distinguishing it as the first company in the wood products industry to switch to a completely formaldehyde-free, soy-based resin.[6] In doing so, it replaced the use of an estimated 47 million pounds of conventional UF and PF resins and reduced emissions of hazardous air pollutants at each of its plants by 50-90%.[10]

In 2007 Dr. Li, Columbia Forest Products, and Hercules, Inc. won the Presidential Green Chemistry Challenge Award, a program sponsored by the Environmental Protection agency.[5]

Panels created using PureBond technology meet the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) Standards.[17]

UREA FORMALDEHYDE EMISSION LINE COMPARISON
(in parts per million)



Composite core hardwood plywood tested contained urea formaldehyde resins but were laminated with Columbia's formaldehyde-free PureBond technology.

Veneer core plywood made with PureBond formaldehyde-free technology meets CARB P2, the most stringent of all US formaldehyde emission regulations.

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Quotes

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Video available for viewing: *Sustainability Amidst Uncertainty: Columbia Forest Products' Pursuit of Sustainability in a Changing Market*

A video created by the Portland State University School of Business. Video highlights the PureBond® story, with emphasis on Columbia Forest Products and their sustainability initiatives as a company. Features interviews with Dr. Kaichang Li from Oregon State University, Elizabeth Whalen (Director of Corporate Sustainability), Steve Pung (VP of Technology), Harry Demorest (Former CEO of Columbia Forest Products) and Ed Woods (Executive VP of Sales & Marketing).

Source URL: http://youtu.be/JJ02IMpFhuA