# BIOBASED BUILDING WITH SOY

Supporting a more sustainable lived environment

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# Introduction

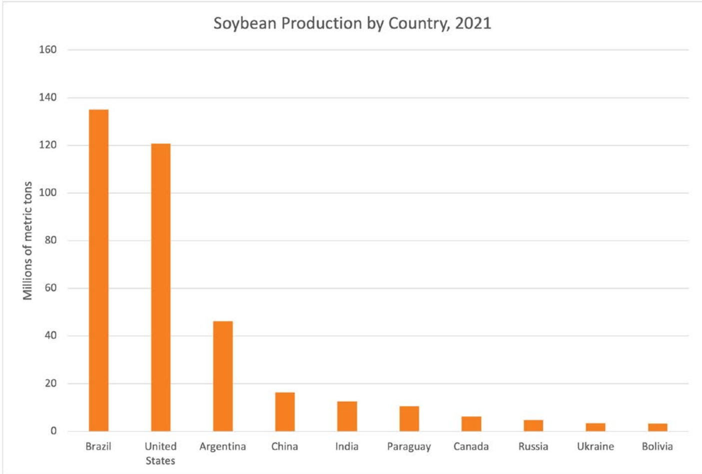
We all want to live and work in spaces that are safe, stylish, and sustainable. It's estimated that Americans spend about 90% of their time inside, so it's only natural that the built environment is a major part of quality of life.[1] In addition, our homes, offices, and public spaces are a large investment of money and physical resources. Making sustainable choices about our building materials can have a positive impact.

But it can feel like everything in our lives is made with petrochemicals. Coatings, adhesives, plastics, and paints derived from fossil fuels are nonrenewable and nonbiodegradable. Their production can also contribute to environmental degradation. Including emissions from producing construction materials and operating buildings, buildings represent almost 37% of global carbon emissions in 2021, according to a report from the International Environment Agency of the United Nations.[2]

Sustainability in buildings is about not just the global but the personal. While we may think of our homes as safe, our indoor environments are often surprisingly polluted. In fact, the concentrations of certain pollutants are 2–5 times higher indoors than outdoors, according to the US Environmental Protection Agency.[1] Everyday materials such as plywood and paints may release odorless volatile organic carbons (VOCs) that are linked to impaired focus, lung damage, and increased cancer risk.[3]

Luckily, a growing number of biobased building materials are becoming commercially available, and soy is one of the ingredients at the heart of these innovations. Researchers from across academia and industry have found that soy-based chemistry can create cost-effective and high-quality sustainable products.

What is so special about soy? Unlike most other crops, soy is rich in oil and protein, which makes it a source of key ingredients for a wide range of products. The chemicals found in soy can also be modified in a variety of ways, so chemists have many opportunities to develop products that offer both superior performance and sustainability. Soybeans can also be produced sustainably and abundantly. The US is also one of the largest soybean producers in the world.[4]




Soybean production (in metric tons) of the 10 top soy producing countries in 2021. Source: Food and Agriculture Organization of the United Nations.[4]

While it may sound fanciful and futuristic to talk of building homes with soy, it's already a reality. Dozens of building materials and coatings, including insulation, paint, carpet, roofing, and asphalt, use soy-based technology.

This e-book explores three uses of soy-based technology in building materials: plywood adhesive, concrete sealant, and artificial turf. These applications showcase the fascinating chemistry that goes into these ubiquitous materials, as well as the many ways soy can be used to solve thorny research problems.

Explore these case studies to learn more about advantages of bringing sustainability to our lived environments.

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# CHAPTER 1:
# Stronger concrete for a better environment

***Credit:*** *Red Fox Studio/Shutterstock*

**Pop quiz:** What is the most used building material in the world by weight? You're wrong if you guess wood, brick, or steel. It's concrete. In fact, more concrete is used than all those other building materials combined.[1]

But concrete doesn't last forever. It erodes over time, meaning that patios, bridges, and dams become less safe as their structural integrity is compromised. Some concrete buildings put up during the Roman Empire still stand, but most of the concrete used in today's transportation projects lasts only a couple of decades. "I'd say the service life you're shooting for with concrete is in the range of 25–30 years," says Paul Imbrock, the product manager for the concrete treatment PoreShield™ at Crafco.

Concrete must be replaced as it decays, and that comes with a cost. "One county in Iowa told me they had over 200 bridges they're responsible for maintaining," Imbrock says. "Replacing one of those bridges cost them about four times their annual maintenance budget."

## Concrete chemistry

What causes concrete to deteriorate, and how can we stop that process? To answer this, we need to explore the chemistry of concrete. The material is made by combining three ingredients:

**Aggregates:** Solids such as small rocks and sand, which improve the durability of concrete but are not involved in chemical reactions

**Cement:** A fine powder containing calcium oxide (CaO), silicates, and other inorganic salts

**Water:** Helps convert cement ingredients into a strong building material

The CaO in cement reacts with water to create calcium hydroxide, which sets off a series of reactions that ultimately form calcium silicates. These reactions occur while the cement cures and create a mineral network that acts as a glue to hold the concrete together. This network turns concrete from a gray powder into a durable, fireproof, and water-resistant material.

Concrete has vulnerabilities, however. Countless pores remain throughout the material even after it has cured. This allows water to seep in. Salts dissolved in the water—such as the magnesium chloride and calcium chloride used in deicing salt—react with the calcium silicates, breaking down the networks that give the concrete its structure. While the effects will be undetectable initially, the concrete will eventually weaken and break down.[2]

A process called frost wedging also contributes to concrete's degradation. If the temperature drops below 0 °C, water in the pores will expand, which causes pressure on the surrounding concrete. Cracks will eventually form over many freeze-thaw cycles. This effect creates a feedback loop with salt-induced erosion: freezing leads to cracking, which increases the surface area for chemical erosion and in turn leads to weaker concrete that cracks more easily.

*Once concrete starts to erode, the breakdown will often accelerate.*
***Credit:** Mykhailo Pavlenko/Shutterstock*

## Harder, better, faster, stronger

This problem isn't new: scientists and engineers have been trying to fight concrete erosion for many years. "Concrete treatments have been around a really long time, going back to the early 1900s," Imbrock says.

Many treatments work as sealants, creating a layer on top of the concrete to stop water penetration. But these treatments wear off after a couple of years as constant traffic breaks down the barrier. In addition to poor performance, such treatments carry environmental risks. Many of them contain high levels of volatile organic carbons (VOCs), which can contribute to smog and harm people applying the treatment.

The Indiana Department of Transportation decided it needed something better. It was spending too much money fixing pavement, and the available treatments were insufficient. The department partnered with a team of researchers at Purdue University to find a solution.

## The power of PoreShield

The team at Purdue developed a concrete treatment made of soy methyl ester polystyrene. It would eventually be known as PoreShield. This durability enhancer is a liquid polymer that can be mixed with wet concrete or sprayed on dry concrete. It enters the pores of the concrete to block water. This stops both the penetration of ions from dissolved salts and the stress caused by the freeze-thaw cycle.[3]

The key to the long-term performance of PoreShield is soy. "When you process soy oil into methyl ester, it can run and spread very thin but remains viscous and hydrophobic," Imbrock explains. This allows the product to saturate any new pores formed as the concrete ages. Ultimately, PoreShield can increase concrete's service life by 5 to 9 times, as determined by the Wisconsin Department of Transportation.[4]

But what about the environmental impact? PoreShield™ contains only 43.3 g/L of VOCs—much lower than many competitive products.[5] It also reduces concrete's environmental effects by extending its life.

Here's why: One of the ingredients in concrete is cement, which is roughly 60% calcium oxide (CaO) by weight. CaO is generated by heating calcium carbonate ($CaCO_3$) to temperatures above 1,400°C, releasing carbon dioxide as a by-product.

About 600 kg of $CO_2$ is generated for every metric ton of cement. Overall, concrete manufacture is responsible for an estimated 8% of global carbon emissions.[6] Extending the life span of concrete reduces the need for replacement and thus lowers overall environmental impact.

## Building a legacy

Imbrock was part of the research team at Purdue that performed the initial research for what became PoreShield. After completing graduate school, he founded a company dedicated to further developing and commercializing the product. In the summer of 2023, PoreShield was sold to Crafco, a concrete product manufacturer. Imbrock hopes this investment will help bring PoreShield to a broader market and allow more people to benefit from its environmental and economic benefits.

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# CHAPTER 2:
## PLYWOOD AND PURE AIR: HOW SOY ADHESIVES SUPPORT INDOOR AIR QUALITY

**Credit:** *Ground Picture/Shutterstock*

Some of the wood products in your home or workplace—furniture, cabinetry, shelving—could be releasing gases that are bad for your health.

Composite wood products like plywood are cost-effective alternatives to conventional material. Plywood is made from sheets of wood traditionally held together with urea formaldehyde or other formaldehyde-based adhesives. Though strong and inexpensive, these adhesives can emit formaldehyde. The emissions are highest when the materials are new but can continue at lower levels for months.[1]

Dozens of studies have been done on formaldehyde's health effects, and the results are cause for concern. According to the World Health Organization, prolonged exposure can lead to eye irritation, respiratory issues, and an increased risk of cancer. Even low levels of exposure can cause respiratory problems or have neurological and allergic effects.[2]

“I've been in places where they have urea-formaldehyde in the press, and your eyes are watering,” says Josh Tyler, adhesives manager at Columbia Forest Products, which makes hardwood plywood. “It's not fun. It can irritate your skin—gives you rashes and makes you itchy.”


PureBond® plywood uses a soy-based adhesive to create a formaldehyde-free product. Courtesy of the United Soybean Board

## A solution that sticks

While formaldehyde's health impacts have been known for some time, it was challenging to find an alternative that created an adhesive strong enough to meet the needs of consumers. This puzzle was solved by Kaichang Li, an associate professor in the wood science and engineering department at Oregon State University who was inspired by mussels that stick to rocks using proteins.[3]

It wasn't practical to use bivalves for making plywood, so Li had to find a different source of protein. Li noticed that soy flour, which is packed with proteins and starchy sugars, was the best fit for a biobased plywood adhesive. "Both the proteins and carbohydrates have lots of functional groups that can react with cross-linking chemicals, like our resin and other cross-linkers," Tyler says. "These functional groups can self-associate, creating networks of cohesive bonds among themselves and adhesive bonds with the surfaces they interact with."

Li partnered with Columbia Forest Products to develop PureBond® plywood, which is made with a soy-based adhesive and now available in dozens of finishes. Since the product's release in 2006, over 150 million panels have been sold. It can be found in most Home Depot stores throughout North America.

## Soy LEEDs the way

Why has PureBond plywood been such a success? There are many reasons, but one driver of demand for formaldehyde-free plywood is LEED (Leadership in Energy and Environmental Design) certification.

Developed by the US Green Building Council (USGBC), the certification is a globally recognized standard for sustainable buildings.

A building achieves certification by acquiring LEED points. Points are awarded for actions that promote sustainability, such as using energy-efficient technologies and ecofriendly materials, incorporating renewable energy sources, and optimizing water usage. The more points a building accumulates, the higher its LEED certification level.

Buildings with LEED certification are more sustainable, and occupants enjoy healthier indoor environments, such as air quality. According to the USGBC, the intent of selecting low-emitting building materials is "to reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants."[4]

A building can be awarded a LEED point if the composite wood used in its interior contains no added urea-formaldehyde resins. This means that choosing PureBond plywood can help product managers get closer to LEED certification.[4]

## Superior plywood with soy

PureBond is not only sustainable but offers solid performance, which was an issue with soy-based adhesives in the past. “Eighty years ago, people would hang up wallpaper with a soy and water mix,” Tyler says. “The problem was that once it got wet, it fell apart.”

According to Tyler, the ingredient that allows PureBond to excel is a resin that readily polymerizes with the soy. “The resin that we use in our adhesive is very similar to the resin used in US paper currency. It's the stuff that keeps your dollar bill from falling apart when you accidentally wash your wallet.” The interaction between the resin and the soy allows this biobased plywood to resist water.

Despite their success, Tyler and his team at Columbia are focused on continuing to advance their mastery of soy-based adhesives. “We will never stop working with our adhesive. We know that we're not where we could be, that there's so much more out there, that is yet to be dug up.”


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# CHAPTER 3: Walking a greener path: Soy and artificial turf

*Courtesy of the United Soybean Board*

It's no secret that plastic is a commonly used material. By 2019, global plastic production totaled 9.5 billion metric tons.[1] Industries with the highest annual plastic production by weight include packaging, building and construction, and textiles.[1]

Soybeans are emerging as one of the key feedstocks in the push for sustainable plastics. Soy is "definitely a leader," says Richard Heggs, director of business development at Omni Tech International, a consulting firm that specializes in commercialization of biobased products and whose clients include the United Soybean Board. With planted acreages in the US rivaling those of corn, soybeans are available in abundance.[2]

Plastic materials made using soybeans—specifically soybean oil—have been on the market for nearly 20 years. The most common class of soy-based plastics include polyurethane foams made from soybean oil polyols.[3] The alkene and ester groups in the oil are versatile handles for producing diverse plastics.

“It’s really fun to play with a molecule that has that many tricks that you can do because it’s so naturally, functionally rich,” says Eric Cochran, a polymer chemist at Iowa State University. He developed an elastic polymer from soybean oil that is being used to render recycled asphalt pavement in roads longer lasting and more flexible.

US turf manufacturer SYNLawn® uses polyols derived from soybean oil to make artificial turf. Its product shows up in a variety of spaces, including a rooftop vineyard in New York City; an elementary school playground in San Antonio, Texas; and the rocket-launch viewing lawn at the Kennedy Space Center.

SYNLawn's turf has two main components: a woven polyethylene fabric with grass-like tufts, and a spray-on polyurethane coating that backs the fabric and locks in the tufts. Before 2008, both the tufts and the backing were made with plastics derived from petrochemicals. Then, inspired by a sister company’s work in making biobased carpeting components, SYNLawn switched to including bioplastics.

“We hitched our ride to the whole sustainability movement,” says SYNLawn executive vice president George Neagle. “The product in its application saves water; it saves emissions from small lawn equipment. We wanted to be sustainable in the manufacturing as well.”

SYNLawn's artificial turf at this golf course is made with bioplastics, in which petrochemical ingredients are partially replaced with biologically sourced feedstocks, including soybean oil polyols. Courtesy of the United Soybean Board

The firm's turf is now made with plastics in which petrochemical ingredients are partially replaced with biologically sourced feedstocks. Soybean oil polyols compose the polyurethane turf backing, and sugars from sugar cane are used to make the polyethylene turf fabric. Several SYNLawn products are made with about 70% bioderived materials and have earned a Certified Biobased Product label from the US Department of Agriculture.[4]

Neagle estimates that SYNLawn has installed over 14 million $m^2$ of its turf. The company offers limited lifetime warranties but is also looking to ensure that disposed turf gets recycled and reused. SYNLawn is working to develop a recycling system in Germany in which old turf will be broken down and incorporated into underlayment panels used in turf installation.

Companies such as SYNLawn demonstrate the opportunity for putting soy into biocomposite materials. By combining recycled plastic with soy polyol, the firm achieved both functionality and ecofriendliness. Innovations like this are an important part of the solution to the plastic waste crisis.

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