ARUP

StopWaste

Regenerative Material Opportunities for Use in Industrialized Construction

Biogenic Building Materials Research Summaries

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Contents

1. Introduction

Arup is supporting StopWaste to carry out research on biogenic materials that lend themselves to industrialized construction, to support low carbon and circular economy solutions in the buildings sector. Biogenic materials offer sustainable construction products in terms of circularity, health, and carbon. These are renewable plants that sequester and store carbon and can biodegrade back into the earth. There is a variety of biogenic building products available in today's market; many are in early development stages and require more support to gain market acceptance and scale, particularly within advanced fabrication and delivery models.

This report consolidates desktop and interview research and provides brief summaries for a wide range of materials, plus deeper technical information on four selected biogenic materials: straw, bamboo, fire-risk wood, and hemp. These materials were selected due to their manufacturing process, innovation as building products, carbon-storing capabilities, and their potential to scale in California, or within the greater west coast. New California regulations like AB2446 should incentivize even greater uptake of biobased building materials to meet 40% carbon reductions by 2035.

Figure 1 shows a mapping of the materials summarized to the sources examined in our literature review, while Figure 2 provides of snapshot of the highest potential materials against the criteria used to determine which materials offer the greatest opportunity for the Bay Area Innovation Tech Cluster.

2. Material Summaries

2.1 Straw

Straw, an abundant agricultural byproduct in California, is a versatile biogenic building material that provides exceptional thermal and acoustic insulation properties, durability, fire resistance, seismic resilience, and compatibility with different structural systems. It is derived from crops like wheat, rice, barley, and oats, where the dried stalks are repurposed after the grain harvest, supporting both the circular economy and efforts to reverse carbon footprint. Straw can be transformed into various high-performance, carbon-storing building products, including insulating bales, board, blocks, and prefabricated structural panels (SIPs).

2.2 Bamboo

Bamboo is a fast-growing, readily available, renewable grass with a woody stem (culm) that can be harvested, processed into Structural Engineered Bamboo (SEB), and used as a versatile biogenic construction material for use in flooring systems, structural elements, wall panels, fiberboard, particleboard, furniture, and much more. Bamboo can sequester 35% to 50% more carbon than timber forests. Along with its impressive ability to sequester carbon, bamboo products are high strength, flexible in use, stiff in structure. Its stiffness and strength allow for efficient material usage in building frames, further reducing embodied carbon.

2.3 Fire-risk Wood

Fire-risk wood refers to the excess wood retrieved from forest thinning which is an important forestry management practice based on the controlled removal of certain trees to reduce wildfire fuel loads, thereby mitigating the risk of wildfires. The trunks and branches of pine trees and other low value species are collected as they can be processed towards use in several applications in industrialized construction. Fire-risk wood can be transformed by means of industrial manufacturing into wood boards, glulam load bearing structures for a building's frame or façade system, and more.

2.4 Hemp

Hemp is an adaptable biogenic building material with significant potential to revolutionize the construction industry with its significant carbon-storing capacity, tensile strength, circular economy story as it utilizes an agricultural waste product, attractive economic potential, straight-forward manufacturing process, and a strong market in California and beyond. Hemp stalk can be recovered from the hemp textile manufacturing process and repurposed into construction materials such as hemp blocks, boards, batts, and the most popular form, hempcrete. Hemp-based insulation has excellent thermal properties, is lightweight, breathable, rot- and mold-resistant, and moisture-absorbing.

2.5 Other Stalks

Sunflower stalks are an agricultural byproduct in abundance on the west coast that can be used as a biogenic construction material. The tall, fibrous stems of sunflower plants after the flowers have been harvested can be processed into panels or boards suitable for wall or ceiling applications. Cotton stalks are also an agricultural byproduct in abundance on the west coast that can be transformed into a variety of building products, including fiberboards, insulation materials, and composite panels. The stalks are thicker and stiffer than straw and must be shredded then compressed for use as a construction material.

2.6 Hulls + Shells

Rice hulls, also known as rice husks, are the protective outer coverings of rice grains. Rice hulls can be used as a sustainable material for insulation, wall panels, or as an additive in composite materials. Chaff refers to the dry, scaly protective casings that surround cereal grains like oats, barley, and wheat. Chaff can be incorporated into sustainable building materials such as composite panels, insulation, or as a filler in construction blocks.

2.7 Cellulose

Cellulose is a complex carbohydrate found in the cell walls of all plants. It can account for 35-45% of the cellular make-up. Cellulose can be processed into insulation materials, such as cellulose fiber insulation, which is blown or sprayed into wall cavities for energy-efficient building insulation.

2.8 Mycelium

Mycelium, the vegetative part of a fungus, has gained significant attention as a biogenic building material due to its remarkable properties. It consists of a network of fine, branching threads called hyphae, which grow underground or within other organic matter. Mycelium can be grown using agricultural waste or byproducts, such as sawdust, straw, or husks. Mycelium possesses impressive mechanical properties due to its dense network of interlocking hyphae. Its lightweight, yet mycelium-based materials can have excellent load-bearing capabilities. Mycelium exhibits inherent fire-resistant properties and is naturally resistant to pests, such as termites and fungi, making it a durable, resilient choice for construction. Mycelium materials possess good thermal insulation and sound-absorbing qualities.

2.9 Algae

Algae are photosynthetic microorganisms that thrive in water, and offer intriguing possibilities as a biogenic building material. While still in the early stages of exploration, algae-based materials show promise in the construction industry. Algae grows rapidly and can be cultivated in a variety of different water types, including both wastewater or saltwater. The organism requires minimal resources and can be harvested multiple times a year, making algae an abundant resource that can be used in building materials as photobioreactors that can harvest, distribute, store and use solar thermal heat, and sequester carbon.

2.10 Flax

Flax, a versatile plant known for its fibrous stalks, has gained recognition as a biogenic building material due to its unique, versatile, and strong properties. Flax is a fast-growing plant that requires minimal water and pesticides during cultivation, making it a good choice for regenerative agriculture. Flax fibers possess excellent tensile strength, making them suitable for reinforcement in composite materials. When combined with a binder, such as bio-based resins or lime, flax fibers can enhance the structural integrity and durability of building components. Flax can be used in various architectural applications, such as wall coverings, flooring, decorative elements, etc. Flax is lightweight, low density, breathable, moisture-resistant, and inherently insulative, providing great thermal and acoustic efficiency.

2.11 Cork

Cork is a biogenic building material that combines excellent thermal and acoustic insulation properties, sustainability, durability, and aesthetic appeal. Its utilization in construction contributes to energy efficiency, environmental conservation, and the creation of comfortable and healthy living and working spaces. It is derived from the bark of the cork oak tree (Quercus suber). Cork has been used for centuries due to its exceptional properties and sustainability. One of the primary advantages of cork as a building material is its remarkable thermal and acoustic insulation capabilities. It possesses a low thermal conductivity, thus enhancing energy efficiency and reducing associated costs.

2.12 Clay

Clay is a natural, fine-grained soil material composed of minerals like kaolinite, iolite, and montmorillonite. Clay can be used as a sustainable building material for earthen construction techniques like adobe, rammed earth, or cob. It is also used for making clay plasters and natural paints, with many benefits.

2.13 Corn

Agricultural waste from harvesting corn can be converted into lightweight, durable, strong, low-cost products with good mechanical behavior, low embodied energy, and good thermal performance.

2.14 Sugarcane

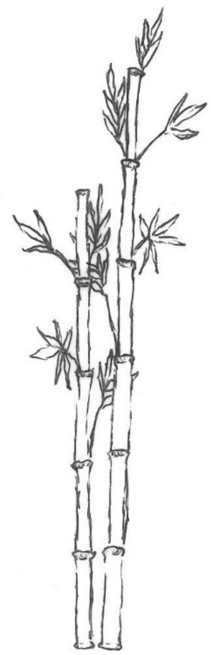
Bagasse, a bi-product of harvesting sugarcane, can be mixed with a binder and pressed to produce stiff, strong, durable boards with a blemish-free finish.

2.15 Pineapple

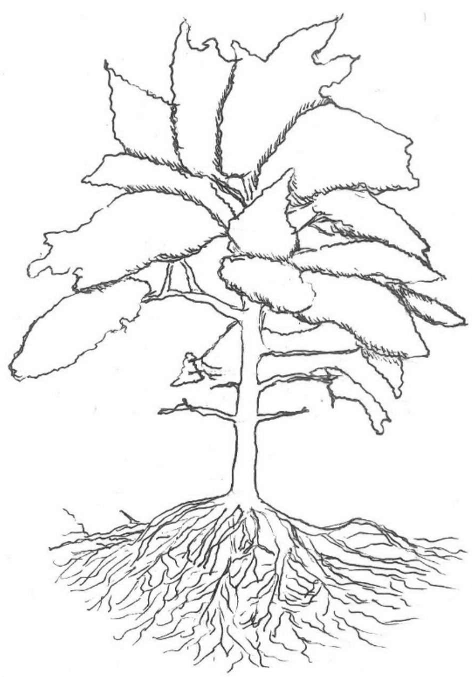
Fibers extracted from pineapple waste after harvesting can create textiles for use in construction that are soft, pliable, and strong.

3. Detailed Descriptions for Highest Potential Materials

Straw



Bamboo



Fire-risk Wood

Hemp

3.1 Straw

Carbon storing capacity

1.16 kg CO_2e/kg

Material Description

Straw, an abundant agricultural byproduct in California, is a versatile and sustainable building material that provides excellent thermal and acoustic insulation properties. It is derived from crops like wheat, rice, barley, and oats, where the dried stalks are repurposed after the grain harvest, supporting both the circular economy and efforts to reverse carbon footprint. Straw can be transformed into various high-performance, carbon-storing building products, including insulating bales, board, blocks, and prefabricated structural panels (SIPs), through a manufacturing process involving shredding, blending, and compressing.

Straw bale wall assemblies are particularly noteworthy for their exceptional thermal performance, durability, fire resistance, seismic resilience, and compatibility with different structural systems. Additionally, straw can be used in both custom and prefabricated construction projects, as well as a strengthening agent in other low-carbon (or carbon-storing) building products.

Straw is adopted by the International Residential Code (IRC) and the California Residential Code (CRC), which significantly supports market adoption. Most California counties are becoming increasingly more familiar with straw in construction, and thus it is becoming easier to obtain permits. There are local architects and contractors who specialize in straw-buildings, and a network of innovators who are developing straw-based building products with optimal performance and function. The availability of straw bale as a raw material is widespread and is historically used primarily for residential applications. On the other hand, the availability of innovative straw-based products is nascent. As the market grows, code continues to be adopted, climate is an increasing concern, and more pilot projects are developed, straw will expand further into commercial applications.

List of companies in California

StakBlock LLC

List of companies elsewhere

Technology readiness

9 Application of tech in its final form

Straw block

Product Description

Stak Block by StakBlock LLC in California is an example of a commercialized interlocking straw block made from dried rice straw mixed with formaldehyde-free glue. The blocks are fabricated from very high temperature compression molds, then assembled and clamped with threaded rebar. Straw blocks are used to form structural and/or insulating wall systems.

The transformation of straw into a block is an energy and labour efficient alternative to the energy-consuming structural materials such as concrete and steel. Straw blocks are a substitute to foam, fiberglass, and batt insulation which are most often petroleum-based products that can contain toxic ingredients.

Straw blocks offer a scalable and environmentally friendly solution to repurpose rice production byproduct. They provide greater insulation performance compared to standard wood stud and bat insulation construction due to reduction of thermal bridging.

List of companies in California

CalPlant1 (liquidation or being purchased by October 2023)

List of companies elsewhere

Durra Panel, Australia
Ekopanely, Czech Republic
Strawtec, Rwanda
CooBio Circular Materials, UK
Straw Resource Limited
aKacia, Frances
Vestta Eco, Poland

Technology readiness

9 Application of tech in its final form

Straw board

Product Description

Compressed straw boards are fabricated from the compression of straw under high pressure and temperature with recycled paper or cardboard sheets which can be adhesively fixed, free of formaldehyde glue or other VOCs.

Straw boards are a high-quality, healthy interior, commercial and residential building material typically used as wall/ceiling boards and for mill work applications. The cost is comparable to wood-based MDF. They represent a sustainable solution in residential and commercial construction, and even in the manufacturing of furniture. Straw boards provide a fire-resistant sound and thermal insulation that has a workability and machinability similar to that of wood; they can be sawn, drilled, routed, nailed, screwed, and glued. The boards are typically heavier than traditional wood MDF solutions but match the strength of wood and can be more water-resistant. At the end of life of a building, straw boards can either biodegrade or be remanufactured into new board.

CalPlant 1 was a Northern California-based company focused on the manufacturing of rice straw-based MDF. Although it recently declared bankruptcy, the company is in the midst of negotiating a change-of-ownership and aims to be selling product again soon.

List of companies in California

Verdant-CASBA

List of companies elsewhere

Ecococon, Slovakia, Lithuania
Croft. USA
New Frameworks, USA
Okambuva, Spain
Modcell, UK
Modulina, Lithuania
Eco-Bud, Ukraine
Stramit
Solomit, Australia

Technology readiness

6 Prototype/representative model

Straw panel infill

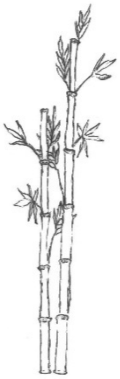
Product Description

Straw panels, known as prefabricated structural insulated panels (SIP), are made with densely packed straw infill, are used as structural and wall insulation material, and offer superior carbon and climate benefits to comparable products. Straw SIPS boast high thermal and acoustic insulation capabilities, easy application, and carbon-storing capacity. They are known to have a higher R-value (R35-40) compared to typically built walls (R13-16).

Straw SIPs are easy to install, often paired with a timber structural frame and lime rendering and can be combined with clay to enhance insulation properties and improve binding strength and stability. Prefabrication allows acute control over the moisture content, which is sealed by wood, plaster or concrete to protect the panel from any weather or humidity exposure.

Straw SIPs are currently used for residential construction primarily, but there are manufacturers who aim to create a standardized code-compliant product optimal for commercial applications. Greater support is needed to get these prefabricated SIPs on the commercial market. SIPS can be a cost-competitive solution to typical wood products. Straw bale can cost around 18$/sf, while typical walls of residential homes can cost between 16-25$/sf. Typically, the straw is low-cost, but it’s important to note that labour is still cost-intensive.

3.2 Bamboo



Carbon storing capacity

1.36 kg CO_2e/kg

Material Description

Bamboo is a fast-growing, readily available, renewable grass with a woody stem (culm) that can be harvested, processed into Structural Engineered Bamboo (SEB), and used as a versatile construction material for use in flooring systems, structural elements, wall panels, fiberboard, particleboard, furniture, and much more.

The bamboo plant is able to thrive in California, restore degraded landscapes with its extensive root system, and sequester more carbon than a traditional timber forest, making it a great candidate in decarbonization efforts. Bamboo can sequester 35% to 50% more carbon than timber forests. Smart management of bamboo forests allows for a quick, continuous harvesting cycle, without the need to replant. While over 1,600 bamboo species exist globally, only a few, such as Moso, Asper, and Guadua, possess the necessary qualities for construction. These are called clumping-bamboo, which are not considered invasive.

Along with its impressive ability to sequester carbon, bamboo products are high strength, flexible in use, stiff in structure. Its stiffness and strength allow for efficient material usage in building frames, further reducing embodied carbon.

Bamboo requires treatment during the manufacturing process to increase its durability and resilience against insects, fungi, moisture, and UV radiation, which greatly impacts its end-of-life options. The most responsible means to treat bamboo is either through exposure to high heat or salt water. Or, boron-treated bamboo can be safely composted, used as biofuel, or even serve as fertilizers, but care must be taken to avoid harmful impacts on rivers through overuse or improper disposal.

List of companies in California

None

List of companies elsewhere

Lamboo

Technology readiness

9 Application of tech in its final form

Profiles and cross-ply panels

Product Description

Bamboo cross-ply panels offer structural, environmental, and aesthetic advantages. The panels are manufactured by layering bamboo strips in alternating directions, providing enhanced strength and stability while reducing the risk of warping or shrinking. The product is aesthetically pleasing.

Lamboo® is a company that specializes in creating sustainable bamboo products for a wide variety of outdoor, indoor, and structural applications, with significantly lower carbon footprint compared to traditional ones like steel and concrete. Their product lines include exterior-grade solutions, such as wall cladding, handrails, outdoor furniture, fascia, soffit, and OEM applications. Their interior products include ceiling systems, acoustic panels, solid panels, veneers, and stair treads and handrails. Their structural line includes glulam beams, posts, purlins, window frames, door systems, curtain wall systems, storefront systems.

Lamboo is especially unique for their impressive exterior and structural lines. The bamboo used in Lamboo's products is imported from overseas and manufactured into a wide range of building materials in their Illinois factory. Their products are defect-free (ex no knots), durable, carbon-storing, and easy to work and design with.

Hallow Core Walls

Product Description

This wall system, referred to as Prime Wall, combines bamboo and eucalyptus to create a product that is carbon negative from cradle to grave, can fit within a variety of architectural designs, and offers exceptional energy efficiency by reducing thermal bridging by up to 90%. The system incorporates individual layers of ply, two species of eucalyptus, including a hybrid between Eucalyptus and Bay Laurel found in California, and bamboo.

The Prime Wall system is produced by BamCore, comprised of two parallel walls filled with a blown-in insulation of-choice, and delivered in palletized, sequentially numbered units. Every element, from doors and windows to outlets and access panels, is precisely cut at the factory, eliminating the need for onsite cutting, minimizing waste, and optimizing efficiency. Each panel is equipped with a Mechanical Engineering Plumbing (MEP) map and nail pattern, ensuring the installation process is the most streamlined possible.

BamCore is a bi-coastal company that specializes in producing sustainable bamboo building products with net-negative immediate embodied carbon. Their innovative bamboo products are fully code compliant in every state of the Union. The company was founded in Sonoma, California, but due to the expensive manufacturing costs in the region, they made the strategic decision to move 100% their production to a new facility an hour outside of Orlando, Florida. This move resulted in cost savings and easier access to labor. They primarily import bamboo from Vietnam and Ecuador; sometimes Mexico, Colombia, and Brazil as well. Bamboo farms in the US are not established currently, and it is best to source from an established grower, as bamboo plants take 5-7 years after planting to produce their first yield. Though once established, bamboo is fast producing and great for land regeneration.

Their Eucalyptus is sourced from Brazil to add into the Prime Wall systems. Eucalyptus is a softwood that allows for five harvest rotations from the same trunk over a 5-7 year lifecycle.

The company works on projects across the country such as California, Maui, Washington D.C., and Utah. They have been actively working on improving insulation and driving positive change, like being an active participant in developing Title 24, California's Building Energy Efficiency Standards. As they continue to grow, they plan to expand further into Florida and Colorado, and continue to acquire projects in California. BamCore is committed to bringing sustainable materials to the construction industry and contributing to the decarbonization of the built environment. They are also actively finalizing a new Carbon Life Cycle Assessment (CLCA) and an Environmental Product Declaration (EPD) report for their products, emphasizing their dedication to transparency and environmental responsibility.

List of companies in California

None

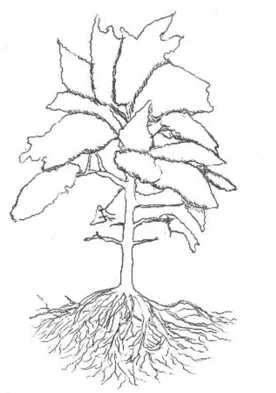
List of companies elsewhere

BamCore

Technology readiness

9 Application of tech in its final form

3.3 Fire-risk Wood



Carbon storing capacity

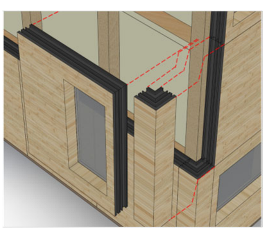
1.11 kg CO_2e/kg

Material Description

Fire-risk wood refers to the excess wood retrieved from forest thinning which is an important forestry management practice based on the controlled removal of certain trees to reduce wildfire fuel loads, thereby mitigating the risk of wildfires. The trunks and branches of pine trees and other low value species are collected as they can be processed towards use in several applications in industrialized construction.

The value of fire-risk wood lies in its versatility to undergo different processing and treatment techniques for the development of construction products that have high fire resistance, durability, and low environmental impact. For instance, the wood can be cut, laminated with an adhesive, and pressed into a load bearing structure for a building's frame or façade system. The wood can also be processed to arrive at the fiber level when the material is then combined with a binder, and temperature and pressure treated to achieve high density, thermal, and acoustic performance for application in wall lining as wood boards. Similarly, for the purpose of insulation, wood fibres can be processed as well as acquired from residual wood and non-sawable thinnings from the manufacturing of mass timber. In these cases, while the wood itself does not demonstrate toxic properties, the chemical binders and additives used may emit harmful substances. Therefore, it is important to check products for compliance with health standards and building regulations, as well as responsible sourcing certifications.

Ultimately, fire-risk wood poses a significant opportunity to leverage the wood left over from forest thinning to produce various construction products. These products also offer a circular resource model by recycling, reusing, or using as biomass fuel.



List of companies in California

Fabric Workshop

List of companies elsewhere

Thermory, Estonia (Mfg)
Stonewood Architectural Panels, Wisconsin
Rulon International, Florida
Parplex Prodema, Spain

Technology readiness

2 Technology concept and/or application formulated (California), 5 (Elsewhere)

Wood façade system

Product Description

The material selected for application in wood façade systems vary based on the desired characteristics of the final construction. Factors such as suitability for local climate conditions, aesthetic appearance, and budget are key considerations. In the case of using reclaimed wood from forest thinning, there is less room for selectivity, however, the sourcing is more environmentally friendly.

Wood façade systems may take the shape of traditional vertical or horizontal sliding boards, prefabricated wood panels, and roof shingles. While there is a large demand for wood-based architectural systems, there lacks research and supply chain visibility on sourcing the wood from forest thinning practices. The companies involved in wood facade systems procure their material from raw material sources and sell their products within their local markets as well as export to regions where there is demand for these systems. The designs can also be customizable to meet the architectural needs of a given projects, however, this leads to a higher cost of the overall system.

Glulam

Product Description

Glued laminated timber, commonly referred to as Glulam, is a mass timber product composed of individual lumber wood components laminated together in a manner where the grains run parallel with the length of the member. Its use dates back far into history and represents a structurally durable and moisture-resistant product that can be curved, tapered, and straightened to the desired formfactor. Applications range from columns and beams in buildings to bridge and canopy construction.

The wood from Douglar fir trees roughly represent 75% of the lumber that makes up Glulam. This is not as common of a species in California's forests, therefore a glulam manufacturer located in California would likely rely on a supply outside the state. This is reflected in the glulam used in California which is produced in Oregon, Washington, British Columbia, and Quebec. However, there are several notable species of spruce, pine, and fir trees that are commonly harvested in California and marked as allowable for use in glulam. Existing glulam and cross-laminated timber (CLT) manufacturers in the US were able to scale their production capacity to respond to increased demand for engineered wood products. With the increased need for forest thinning in California's forests, the supply of wood that may be put towards glulam production offers the opportunity to source material locally.

California is the largest mass timber market in the United States, capturing 1 out of every 7 new mass timber buildings and uses 30 million+ board feet of glulam annually. However, there are currently zero mass timber or glulam manufacturers in California today. Fabric Workshop's product line will consist of two layup options including an industry standard, Douglas Fir layup. Fabric is also designing a proprietary layup made from overgrown, lower value species that are fueling California's catastrophic megafires and that need to be thinned. The TRL of Fabric's Douglas Fir beams and columns is TRL #9 while its proprietary spruce-pine-fir (SPF) beam and column is TRL #3 as R&D and supply chain analysis is currently being conducted.

While energy costs related to forestry, milling, and transportation are higher in California compared to nearby competitor states, the manufacturing energy costs in Northern California are lower than competitor markets. Raw material costs are at parity with competitive states. However, due to the lack of secondary wood product manufacturers in California today our overall material costs will trend higher as there are fewer opportunities for Fabric to re-sell wood that isn't to grade and waste (saw dust, chips, etc.) to third parties. Fabric anticipates 106,000 m3 maximum production output equating to 99,604,508 kg of CO_2 storing capacity. In total, Fabric expects to create 58+ full time positions in a rural, Northern California county with management personnel in urban centres close to client offices and projects. Market research conducted by Fabric shows a strong client preference for local, California-sourced materials and there exists state incentives that promote local mass timber sourced from wildfire projects. Overall, the localizing of the supply chain streamlines the production process, offers economic development to the region, and reduces the environmental footprint as well as costs.

List of companies in California

Fabric Workshop

List of companies elsewhere

Rosboro, Oregon, USA
DR Johnson, Oregon, USA
SmartLam, Montana and Alabama, USA
FraserWood, BC, Canada
Goodfellow Inc., QC, Canada
Buckland Timber, UK
Bischoff Schafer, Germany

Technology readiness

9 Application of technology in its final form

List of companies in California

None

List of companies elsewhere

TimberHP, Maine, USA
STEICO, UK
BetonWood, Italy
GUTEX, Germany
Bischoff Schafer, Germany
Beltermo, Russia

Technology readiness

9 Application of technology in its final form

Wood Fiber Insulation

Product Description

Wood fiber insulation may come in the form of board, batt, and loose fill insulation. In the context of California, wood chips and debris from California's softwoods such as pine and fir trees are used to produce insulation catered to the climate conditions of the state. Though certain processing steps may vary given the desired final form of the insulation, there are two typical approaches in manufacturing, both starting with a grinding process to obtain fine wood fibers. In the wet method, a pulping process is followed where the material is mixed with water and a binding agent, ending with a compression and drying step. In contrast, the dry method mixes the grounded fibers with a polyurethane-based glue, typically paraffin wax to enhance water resistance properties. While the dry method is most common for boards in United States and uses approximately 40% less energy than the wet method, the paraffin wax is produced with petrochemicals.

Overall, the wood fiber insulation market in the United States remains underdeveloped as boards are generally imported from Europe for sale in the East Coast. The cost premium and environmental impact associated with long shipping distances combined with the availability of supply in California presents an opportunity to grow the market in the West Coast. TimberHP by GO Lab is a success case example in Maine where an old paper mill was redeveloped towards the production of wood fiber board, batt, and loose fill insulation.

3.4 Hemp

Carbon storing capacity

1.68 kg CO_2e/kg

Material Description

Hemp is a versatile biogenic building material with significant potential to revolutionize the construction industry with its enticing carbon-storing capacity, tensile strength, circular economy story as it utilizes an agricultural waste product, attractive economic potential, straight forward manufacturing process, and a strong market in California and beyond. Hemp stalk can be recovered from the hemp textile manufacturing process and repurposed into construction materials such as hemp blocks, boards, batts, and the most popular form, hempcrete. Hemp-based insulation is lightweight, breathable, rot- and mold-resistant, and moisture-absorbing. Hemp has excellent thermal properties, with an insulation value of around R2-3.5 per inch, suited for internal and external walls, floors and roofs.

Hemp is a highly sustainable crop that requires minimal water, pesticides, or herbicides for cultivation, grows rapidly, fixes nitrogen, and sequesters the most amount of carbon compared to any other crop or forest. A single hectare of hemp has the capacity to sequester approximately 22 tonnes (~24 tons) of CO_2.

Compared to concrete, hemp produces less emissions from transportation due to its light weight, has a better capacity to regulate moisture, and has better insulative properties against heat and noise. Its pest and fire resistance makes it a competitive alternative to wood as well. Hemp materials also contribute to clean indoor air quality due to their non-toxic nature that promotes a low exposure to VOCs.

A barrier hemp is lack of building codes and high cost of the machinery (decorticator) necessary to process the crop. Although the industry is still in its nascent stages, increased investment, research, and market demand can accelerate its adoption and scalability to a commercial application.

List of companies in California

None

List of companies elsewhere

Mirreco, Australia
R&D at Texas A&M

Technology readiness

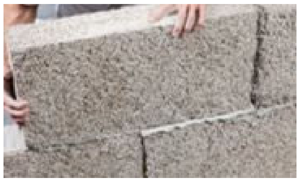
6 Prototype/representative model

3D-printed Hempcrete

Product Description

After hemp fibre is processed in a decorticator, the leftover woody core of the stalk, called hemp hurd, is combined with a binder, such as lime or clay, to form a composite material known as hempcrete. The most common application of hempcrete is in residential construction as an insulating bio-composite. Most used in wall systems, the hempcrete is either spray-applied or cast-in-place around traditional wood framing. Hempcrete can take a 5-or-more layer wall system (drywall, insulation, sheathing, weather barrier, cladding, etc.) and reduce it to a 2-or-more layer wall system (hempcrete, lime plaster or other cladding), reducing embodied carbon in a project significantly.

3D-printed hempcrete is made through 5-axis extrusion or 3D printing. Printing a high-density outer wall shell of hempcrete is recommended to provide adequate thermal insulation. Texas A&M was allocated $3.74M for research on 3D-printed hempcrete. With many similar initiatives, 3D-printed hempcrete is gaining momentum within the industry but is currently in a prototyping stage. Overseas, 3D printed hempcrete homes exist in Australia and Denmark.



Hemp Blocks

Product Description

Hemp blocks are made from hempcrete that is slip-moulded then hardened in an open-air setting to be used like bricks. In construction, hemp blocks can be used as drywall, insulation, boarding, and siding, while accompanying hempcrete can use used as mortar and caulk.

The flexible character of hempcrete make hemp building blocks more stable than concrete against seismic activities, offering an excellent resilience solution for regions along fault lines, such as in California. Another major benefit of hemp blocks is the reduction of construction time of up to 60% compared to other block-system alternatives.

California Hemp Block is a new hemp blocks manufacturing and supply company founded in 2021.

List of companies in California

California Hemp Block

List of companies elsewhere

Hempitecture, USA
Hemp Block USA, USA

Technology readiness

9 Application of tech in its final form

Prefabricated Hemp Panels

Product Description

Homeland Hempcrete offers pre-designed and tested hemp wall panel kits, which can be modified and customized according to specific project needs but are also offered in standardized kits for efficiency. Their kit consists of four core panels: base, corner, window, and door panels, with a thickness of 9¼ inches. For residential builds, a 12-inch-thick panel is used for better thermal performance.

The panels are tightly seated together and secured with screws, following a unique bracing pattern to ensure structural stability. They were designed to allow for both manual installation and quicker assembly with machinery like a skid-steer or tractor with chains. With a skid-steer, installation can be completed in 5-6 hours, and a 530 sf ADU model can be done in about a day.

The design of the panels involved collaboration with various build officials, and in some cases, a structural engineer may be required based on local building regulations.

Homeland Hempcrete's panel system offers consistent quality, customizable designs, a range of finishes, easy and fast installation, and the added benefit of applying finishes immediately after panel installation.

List of companies in California

None

List of companies elsewhere

Homeland Hempcrete, USA
Hempire, Poland
Nature Fibres Inc.

Technology readiness

9 Application of tech in its final form

	Primary Literature Sources	**Straw**	**Bamboo**	**Pine Fiber**	**Hemp**	Other Stalks	Hulls + Shells	Cellulose	Mycelium	Clay	Algae	Flax	Corn	Potato	Pineapple	Cork
2017	Arup Urban Bio Loop Report (2017)					Sunflower Rice	Peanut									
2021	StopWaste-CASBA-Arup Carbon Storing Building Prototype Report (2021)															
2021	Sierra Institute Mass Timber and Other Innovative Wood Products in California Report (2021)															
2021	CLF Carbon Storing Materials (2021)															
2022	HESTIA grants (2022)															
2023	CASBA Ag Biomass: Cultivating a Bioregional Building Materials Economy in California (2023)															
2023	Arup-CNCA Report (2023) *not yet available publicly*					Rice										

Figure 1: Literature Review Materials Mapping

		Criteria for choosing manufacturing partners for grant application										
Material	Manufacturer	Interested in partnership	CA grown crop used in product	CA based	CA manufacturing facility	CA office or employees	CA + west coast pre-existing projects	West coast manufacturing facility	Sustainable manufacturing process	Interested in the west coast market	Crop can viably be grown on the west coast	Use of Indus /Advanced Tech
Straw	StrakBlock											
	CalPlant 1											
	Verdant-CASBA											
Bamboo	BamCore											
	Lamboo											
Fire-risk Wood	Fabric Workshop											
Hemp	Hempire											
	Texas A/M											
	California Hemp Block											
	Homeland Hempcrete, USA											

Figure 2: Opportunity Mapping