OVERVIEW

INNOVATION AND IMPACT

TECHNOLOGICAL BREAKTHROUGH

Introduction

okom wrks labs, PBC is a Delaware Public Benefit Corporation. We operate an R&D facility inside The Plant, an incubator space in Chicago, IL. The Plant allows us to collaborate with other startups, allowing for creative problem solving while we are building our circular manufacturing paradigm. In conjunction with the R&D space at The Plant, we also have lab space at Argonne National Laboratory where we are working on several collaborative research initiatives that will facilitate our pursuit of standards and certifications. Lastly, we are also working out of the Autodesk Tech Center (ATC) in Boston, MA as a member of the Autodesk Research Residency Program. The ATC in Boston allows us us rapidly prototype the tools and machines we are developing.

okom wrks labs seeks seed funding to support the full-scale commercialization and licensing of a patented mycelium-based composite (MBC) called zerø-frm (ZF). ZF is a novel type of composite material that utilizes agricultural residues, specifically hemp hurd, as the dispersion medium, and mycelium as the matrix. What sets ZF apart from other MBC technologies is its exceptional structural and load-bearing capabilities. ZF is the first MBC that can effectively serve in a load-bearing capacity within architectural and industrial applications. In light-residential construction, ZF can be used as a 2:1 replacement for stick framing lumber.

Over the next 18-24 months of R&D,o our primary objective is to validate the structural capacity of ZF for both load-bearing and non-load-bearing residential and commercial construction. In addition to its obvious structural applications, ZF technology can benefit various structural modular building systems such as SIP panels, trusses, joists, tip-up walls, and headers, among others. Furthermore, ZF has non-structural applications, including interior partitions and decorative architectural elements.

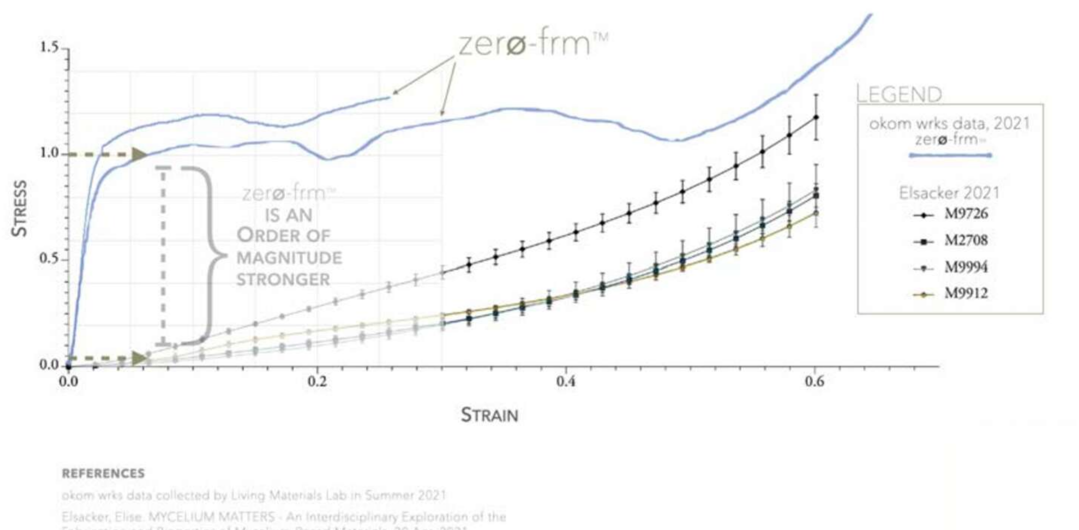


Fig 1. Chart of published compression data for mycelium based composites. Initial independent compression testing for ZF was performed at CU Boulder, Living Material Laboratory and confirmed at Queen’s University.

The Problem

COP27 concluded with a clear mandate for decision-makers in the built environment to address the significant climate impact of embodied carbon and embodied energy. Efforts to reduce the impact of carbon-intensive materials like steel and concrete have led to calls for increased use of lumber in construction to meet the needs of a growing population.

However, this increased demand for forest-derived building materials will have devastating ecological effects. Fragile forest biomes and the biodiversity they support will be immediately impacted. To meet current demand, most lumber products are obtained through clearcutting methods, and with the surge in demand for mass timber, the impact on already vulnerable forest ecosystems will be exponential. Additionally, only 10%-15% of global forest products are certified by major certifying bodies like FSC, PEFC, or SFI, meaning increased pressure on forests will hinder their ability to effectively monitor logging operations.

Due to its importance in forest biomes, it is crucial to explore alternatives to lumber in various parts of building construction.[1] This includes load-bearing and non-load-bearing wall assemblies, trusses, joists, sheathing, and columns. Considering that forestry management practices may have a larger carbon and greenhouse gas impact than previously estimated, finding regenerative alternative sources for structural building materials is essential.

Indeed, there is a lack of viable and scalable alternatives to lumber; especially in terms of regenerative, structural building materials. While there is still a long way to go in terms of certifications and standards for specifying safe structural biogenic materials, the emergence of zerø-frm (ZF) offers a potential pathway forward.

The Solution

On top of the ecological issues posed by increased logging associated with an increasing housing demand, several other problems within the built environment must be addressed over the next decades including:

- A steep decline in skilled labor within the construction trades
- The need to ensure that regenerative solutions are available to rural and low-income housing needs
- Maintaining high standards of building envelope efficiency, maximizing the operation costs over the lifetime of the building
- End-of-life issues and design for dismantling (DfD) associated with building material choices

Modular/Prefabricated Construction Techniques

To address the decline in skilled labor within the construction industry there has been a rise in the adoption of prefabricated and modular construction methods. Added benefits of prefabricated, modular technologies like structural insulated panels (SIP) ensure that precision work is done in controlled environments with far less waste than traditional stick framing. The work done on the job site is performed with more precision and in half the time. Crews with general carpentry skills can safely and accurately construct a dwelling. The co-benefit is that SIP (and other modular) technology is ideal for rural and low-income housing needs. Larger municipal structures can also be built in rural areas, providing state of the art energy efficiency and healthful interiors made with regenerative materials. When combined with MBC technology like zerø-frm, conventional SIP panels become a truly regenerative solution with favorable cradle-to-cradle implications. [2]

Improving the Embodied Carbon of the Conventional SIP Panel

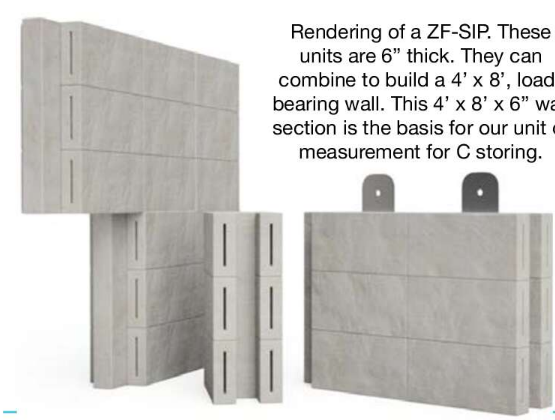
The Conventional SIP - SIP systems offer many benefits with respect to energy efficiency. The benefits to the overall energy efficiency, the so-called operational carbon phase of the building, are dramatic; however, this comes at a cost to embodied carbon, as conventional SIPs are constructed of a petro-based foam core with a sandwich of two OSB skins joined with adhesives. At their best, these SIP panels provide great operational performance, however the cost related to embodied carbon makes them undesirable. Finally, at the end of their useful life, they pose toxic disposal challenges.

Alternative SIP Designs - Recent development of SIPs that incorporate natural building systems like cob, straw bale, hempcrete, etc., are now commercially available. okom wrks labs co-founder and Chief Climate Officer, Chris Magwood, has been an instrumental figure in designing and testing straw bale SIP walls. The straw bale SIP (S-SIP) has been shown to have the same core benefits of the conventional SIP, but with the added benefit of being constructed from materials that provide a much more handsome embodied carbon profile. Straw bale construction is among the most carbon friendly methods of construction (especially when derived from regenerative organic sources). [3]

A typical S-SIP has a lumber frame made from 2x4 or 2x6 sticks. The insulation of an S-SIP comes from straw (usually compressed). Sheathing is typically provided by OSB, plyboard, magnesium board, or any other standard sheet goods suitable for the application. Other types of non-foam SIP insulation includes hemp wool, rock wool, or even cob; although systems that include earthen materials are often prohibitively heavy and result in costly logistics.

Making the S-SIP A Truly Regenerative Solution - S-SIPs have an incredible potential to improve on an already impressive building technology (i.e.-conventional SIPs). In order to further improve the embodied carbon of the S-SIP, the framing and sheathing are two components that can be replaced with materials with even better embodied carbon profiles. For reasons that will be discussed in detail later in this proposal, there are many causes for concern for the future of our forest ecosystems. Forests provide carbon sequestration, microclimate regulation, biomes for biodiversity, but only when they remain intact. The only effective means of mitigating the effects of forest disruption from timber harvest is to reduce harvesting. Replacing the lumber frame of an S-SIP with zerø-frm can facilitate a significant reduction in the embodied carbon of a building incorporating the technology.

The Most Regenerative Solution - We believe that ZF-SIPs are the best viable option for storing large amounts of carbon per panel. By using hemp, a very efficient CO_2 sequestering plant, as a bulk substratum (dispersion phase), we can build monolithic wall panels made entirely from ZF (hemp hurd + mycelium). Each 4’ x 8’ x 6” monolithic, mono-material panels



Rendering of a ZF-SIP. These units are 6” thick. They can combine to build a 4’ x 8’, load-bearing wall. This 4’ x 8’ x 6” wall section is the basis for our unit of measurement for C storing.

> *“Through structural calculations based on initial compression and modulus of elasticity testing, the material was found to be sufficient to perform wall stud-like action with similar wall stud-like shapes to resist gravity loading in moderate residential construction conditions. Though increased compression loading due to wind or earthquake forces would exceed the capacity documented in the existing strength tests and require custom design solutions.*
>
> ***- VERDANT STRUCTURAL ENGINEERS***

(the unit) will store approximately 16.3Kg of C in the built environment. Storing C in the built environment allows for an easier recording and future accounting of the location and durability of the C storage (at a particular address). This provides high quality accounting records of C storage that municipalities, states, and federal gov't agencies…as well as private citizens and corporations can rely on when reporting their C footprint. Long-term storage of C in the built environment is a durable record for generations.

Wider Material Applications - ZF's unique structural qualities combined with the durability provided by agricultural residues like hemp hurd and robust mycelial growth create opportunities for ZF to be used in a wide array of structural and non-structural capacities. This can further displace the need for other lumber and engineered lumber products in items such as: trusses, joists, headers, sills, columns, and beams. The use of ZF in non-structural, interior partitions and decorative architectural elements can also displace the need for lumber and gypsum board in the interior. Perhaps the biggest way that ZF can impact the embodied carbon of a building is to incorporate ZF into concrete applications, eliminating steel rebar and reducing volume of concrete by an estimated 40%-60%.

MARKET, ECONOMIC ANALYSIS, AND COMPETITIVE LANDSCAPE

Market Volatility in the Timber Sector

Market volatility in the timber sector, exacerbated by the pandemic and drawn into sharp focus by current climate understanding, shows that we need to preserve timber stock for efficient use.[4] The conundrum that humanity faces is that we are simultaneously asking to reduce our impacts on forests while also increasing consumption and use.[5] The impact of increasing our reliance on timber for the built environment bears the risk of locking in short-sighted goals at the expense of biodiversity and land-use change.[6] There is an unacceptably high risk of irreparable damage to biodiversity across large swathes of remaining forests if we indefinitely expand our harvesting of timber. Eventually, humanity will need to find alternative sources of building materials as the forests that have been degraded by clearcut will begin to indefinitely become a net source of carbon emissions.[7] Plantation forests replacing natural forests become carbon sources for 13 years[8] following clearcut, which is the dominant form of timber harvest. Clearcut harvest is allowable in all current FSC, PEFC, and SFI guidelines (varying from 40 acres to 120 acres). The critical nature of the climate crisis means that we cannot ignore warning signs that we may be overestimating carbon drawdown potential and therefore the carbon neutrality of timber harvested with current methods.[9]

Slow to Adopt, But Quick to Adapt

For very good reasons directly related to everyone's health and safety, builders and architects are slow to adopt new technology. Builders are also resilient and resourceful. Facing a shrinking supply of skilled labor, builders turn to modular techniques to maximize the workers they have available. SIP wall assemblies show up to the job site fully assembled. This fully assembled system that does not drastically change a crew's workflow will meet very little opposition.

Significant LULUCF Advantages of zerø-frm Are Also Significant Market Advantages

As we approach 2030 and while 2050 is not very far off on the horizon, decision-makers need to have available options that can verifiably draw down significant amounts of carbon. Drawing down carbon, all while simultaneously: improving biodiversity, improving soil health, improving social justice, improving rural health, and respecting the rights of Indigenous Peoples. These are a few of the 17 different U.N. Sustainable Development Goals, or SDGs. LULUCF and SDG issues are interconnected. ZF boasts significant increases in land use efficiency. Comparing an acre of existing farmland growing industrial hemp (the main component in ZF).

A helpful comparison is to show a comparison of the raw material (14.7 MBF, ~6.3bf/sq.ft.)[10] required to build the frame for a single 2,333 sq ft home (median home size according to most current U.S. housing data).[11], [12], [13], [14], [15]

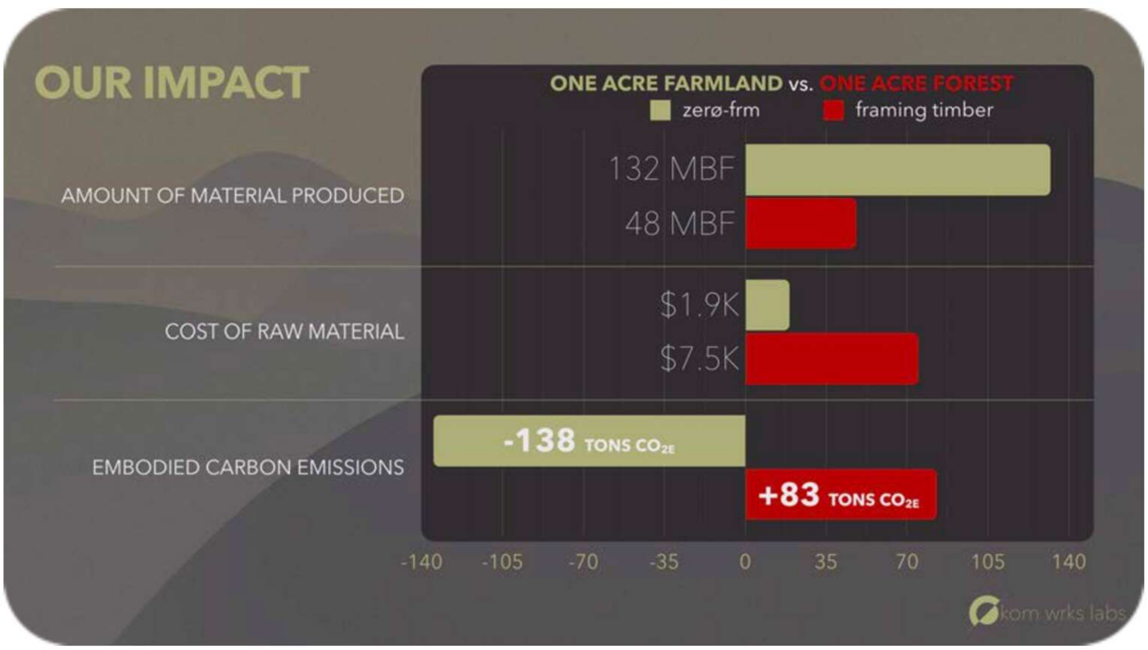


Fig. 2 - Land use comparison between one acre of farmland growing industrial hemp and one acre of even-aged forest (30 years). The timescale for the calculations is 30 years.

Competitive Landscape

Conventionally, structural insulated panels (SIP panels) are composed of a large block of foam sandwiched between two sheets of oriented strand board (OSB). While this building system is able to reduce job site labor costs and creates a much tighter building envelope than standard stick framing (therefore reducing the operational carbon demand), the embodied carbon of the components of a conventional SIP panel are incongruent with the push to reduce the overall embodied carbon in the built environment. Our ZF-SIP solution provides a method of improving the building envelope while also providing a carbon negative building material component. The details of the impact on emissions will be detailed in the following section. However there is also another aspect where ZF-SIP is desirable. Our initial COGS estimate of around $306 per panel makes a final retail price of $383. This is around $7/sq. ft. and is nearly identical in price to conventional SIPs. As the marketplace puts pressure on manufacturers to supply alternatives to high embodied carbon options, we are bringing to market a biogenic building material that can be a 1:1 replacement for the incumbent SIP technology at the same price point. While ZF-SIPs are carbon storing, conventional SIPs are carbon emitting (see CHART 1). While conventional SIPs are retailing around $5-$10/sq. ft., other biogenic options that can store carbon like ZF-SIPs, like straw bale SIPS (S-SIPs) or SIPs that use dense packed cellulose are around $20-$35/sq. ft. With a projected retail price of $7/sq. ft., ZF-SIPs will truly disrupt a very fast growing marketplace.

EMISSIONS IMPACT

We have a better understanding of the impact that timber harvests have on forest ecosystems. [16] Even under strict certification regimes like FSC, PEFC, and SFI, the vast majority of timber harvest is the result of clearcutting. Until such a time that the demand for timber decreases, the management of forests for the production of building materials will rely on clearcutting to ensure that capex does not price lumber out of the market altogether. In the wake of the recent pricing volatility in the timber sector, there is a far better and immediate understanding of the systemic effects of reliance on timber to meet the demands for the built environment. [17]

Going From Bad To Worse

The current conditions in the timber sector appear to be somewhat persistent. The specific supply-chain malady changes frequently. But the key takeaway from most analysts is that the drivers of the volatility are partially due to pandemic, but their roots lie deeper in the effects of a changing climate bringing more floods, fires, and other natural disruptions. This creates a whipsaw effect that can only find balance through demand mitigation.

Finding The Silver Lining

It is difficult to think of a scenario where the increased demand for lumber won’t also exacerbate the timber sector’s inherently dangerous climate impacts. It is clear that the most prudent way for our forests to continue to meet demand is to reduce the amount of timber we harvest. Viable alternatives to lumber would have to meet a few key criteria:

1. The raw material sourcing must be circular, combining regenerative practices throughout the supply chain while still providing economic benefit with social justice at the core
2. A robust and thorough analysis of the upstream carbon issues associated with the method of harvest or extraction should be done to ensure that miscounted carbon cannot hamper global efforts to reduce GHG in pursuit 2030 and 2050 goals
3. Disruption to the forestry industry should be considered when ramping toward full-scale commercialization of an alternative building material. Efforts to mitigate the social impacts of disruption should be considered and implemented in consultation with all stakeholders in line with UN SDG Goals

With few viable alternatives to lumber are available in the marketplace, demand for timber will increase with potential for disastrous consequences due to the ill effects of even-aged timber plantations and clearcutting methods. The few alternatives that exist will typically include capital intensive tooling and the use of adhesives. There is a significant need to invest resources and effort into finding lumber alternatives that can reduce the demand on forests while ensuring economic security for disrupted communities that once relied on higher demand for support. These co-benefits will compound with the job-site benefits detailed above (tighter envelope, fast build times, less construction waste).

Reducing demand on forests can help to preserve our remaining old growth forests while also providing a means to reduce reliance on clearcutting to meet demand. Regenerating our forests is the most important way that the timber industry can contribute to climate mitigation. Above ground sequestration in building materials is a very short-sighted gain. The forgone sequestration and the damage to biodiversity may be too great a risk.

The emissions impact of a material like ZF is multiplied by the elimination of the forgone sequestration associated with clearcut timber harvests. Preserving the forest's ability to draw down carbon is a vital aspect of global efforts to meet 2030 and 2050 climate goals. Before we consider expanding the use of forest products, we should get a clearer understanding of the impacts of forgone sequestration. [18]

Emissions Accounting Imperative

There are more data needed to fully understand the negative impacts of timber harvest practices, however, enough data are known to give us pause in looking to our forests to supply our building material needs. With a proper accounting of the carbon emissions of a timber harvest, it becomes clear that harvesting timber results in previously unaccounted for carbon emissions. The amount of above ground carbon stored in the materials derived from timber is far outpaced by the carbon emissions that result from that harvest.

On the whole, the manufacture of building materials accounts for 11% of annual global GHG emissions. Due to ever increasing operational efficiencies, if we do nothing to eliminate the

CARBON DRAWDOWN SCENARIOS FOR ZF-SIP - TABLE 1

Structure Size (sq. ft.)		1,600	2,100	4,500	9,200	37,000	490,000	
# of UNITS/STRUCTURE		40	46	70	192	480	700	
EACH PANEL CONTAINS 0.02T C x # UNITS = T of C / Structure		0.8	0.9	1.4	3.8	9.6	14.0	
EACH PANEL CONTAINS 0.07T CO_2 x # UNITS = T of CO_2 / Structure		2.9	3.4	5.1	14.1	35.2	51.4	TOTAL
Scenario 4	# of STRUCTURES/YR	2,000,000	2,000,000	2,000,000	1,000,000	500,000	250,000	7,750,000
	T of C Stored/YR	1,600,000	1,840,000	2,800,000	3,840,000	4,800,000	3,500,000	18,380,000
	T of CO_2 Seq./YR	5,920,000	6,808,000	10,360,000	14,208,000	17,760,000	12,950,000	68,006,000
Scenario 3	# of STRUCTURES/YR	1,000,000	1,000,000	1,000,000	500,000	250,000	150,000	3,900,000
	T of C Stored/YR	800,000	920,000	1,400,000	1,920,000	2,400,000	2,100,000	9,540,000
	T of CO_2 Seq./YR	2,960,000	3,404,000	5,180,000	7,104,000	8,880,000	7,770,000	35,298,000
Scenario 2	# of STRUCTURES/YR	500,000	500,000	500,000	250,000	150,000	50,000	1,950,000
	T of C Stored/YR	400,000	460,000	700,000	960,000	1,440,000	700,000	4,660,000
	T of CO_2 Seq./YR	1,480,000	1,702,000	2,590,000	3,552,000	5,328,000	2,590,000	17,242,000
Scenario 1	# of STRUCTURES/YR	250,000	250,000	250,000	150,000	50,000	25,000	975,000
	T of C Stored/YR	200,000	230,000	350,000	576,000	480,000	350,000	2,186,000
	T of CO_2 Seq./YR	740,000	851,000	1,295,000	2,131,200	1,776,000	1,295,000	8,088,200

A unit is (1) 4' x 8' x 6" thick panel. For 9,200 sq. ft. structures, there are 16' tall walls. For 37,000 and above, there are 20' tall walls.

embodied carbon of a building, 90% of a building's total emissions will be due to it's embodied carbon.[19]

Reducing the embodied carbon of building materials is part of global efforts to decarbonize the built environment.[20] As the population increases, the demand for new construction will double as we approach 2050. Structural components of the built environment are crucial contributors to a building's embodied carbon. A typical residential construction sees 10% of its embodied carbon spent in its framing.[21] *This does not include the newer understanding about timber harvest emissions. It does highlight the impact that eliminating timber from a building's framing with an alternative that is carbon negative.*

According to RMI, "Buildings account for at least 39 percent of energy-related global carbon emissions on an annual basis. At least one-quarter of these emissions result from embodied carbon, or the greenhouse gas (GHG) emissions associated with manufacturing, transportation, installation, maintenance, and disposal of building materials." [22] These calculations do not typically include the GHG emissions associated with harvesting timber for building materials. According to Architecture 2030, "To accommodate the largest wave of urban growth in human history, we expect to add 2.4 trillion ft^2 (230 billion m^2) of new floor area to the global building stock." [23] If only 3.8% of that square footage was framed with zerø-frm technology (estimated ~0.008 tons CO_2 per sq.ft), we hypothesize that ~511 million tons of CO_2 would be drawn down by 2050. When combined with the forgone sequestration added back into the global forest carbon sink, the carbon draw down implications are significant. [24]

COMPARATIVE ANALYSIS OF FOREST VS. AGRICULTURAL DERIVED BUILDING MATERIALS

In order to provide a direct comparison, we analyzed the emissions impact of sourcing wood framing vs. our ZF-SIP system. We analyzed the impact of timber harvest on the carbon emissions and found that the total impact of emissions is well understood to be a carbon source[25,26,27]

PROBLEM

Forest Scenario

In the previous *Market Analysis* section we show a land-use estimate that approximately one acre of pine saw timber is required to frame an average home (2,333 sq.ft) [28]

- That acre of forest becomes a ***net emitter of 26 tons of CO_2 for 13 years after the harvest*** (338 tons CO_2 emitted over 13 years) [29]
- That acre of forest can begin to draw down 4.76 tons CO_2 after that for 17 years (79.9 tons of CO_2 drawn down over 17 years) [30]
- This results in a ***net emissions of 83 tons of CO_2*** from an acre of forest harvested for framing timber ***for (1) 2,200 sq. ft. structure.***

This scenarios makes the following assumptions:

- Even-aged plantation timber grown for 30 years
- Following prescribed standards (FSC, PEFC, SFI) for clearcut harvesting

SOLUTION

Agricultural Scenario

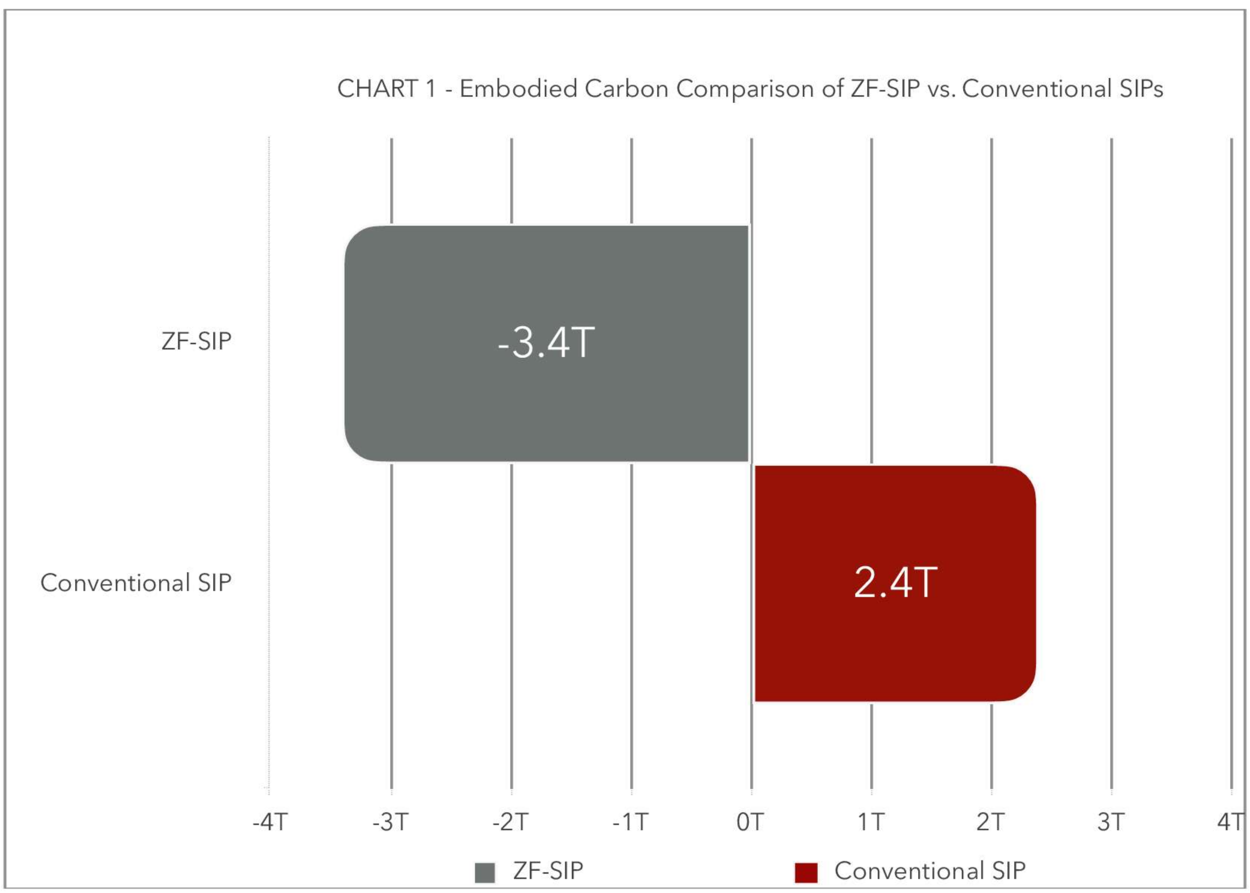
An average yield for an acre of farmland growing industrial hemp is 3 tons of hurd. This 3 tons per acre produces (40) 4' x 8' x 6" ZF-SIPs. [31]. A ZF-SIP unit is one 4' x 8' x 6" thick SIP. The following table illustrates how many tons of C are stored in structures of different sizes using ZF-SIPs for structure.

One acre of farmland growing industrial hemp can grow enough material to build a structure that is roughly 2,100 sq. ft. One structure that is 2,100 sq. ft. made using ZF-SIPs for the exterior walls would store 0.92 T of C and draws down 3.4T CO_2…just for the load-bearing exterior walls.

The Drawdown Potential of ZF

Compared to an acre of forest, not only is an acre of farmland growing industrial hemp able to grow enough framing material to build 4-6 more houses (than an acre of forest), that same acre of farmland growing hemp will also draw down 138 tons of CO_2. When combined with the preservation of the carbon sequestration of an intact acre of forest left standing due to the decrease in demand, an additional ~62 tons of CO_2 is realized.[32]

Further, a standard 4' x 8' x 6" thick EPS and OSB (incumbent tech) has embodied carbon ***emissions of 2.4T of CO_{2e}*** per 2,100 sq. ft. structure. Conversely, a similar structure made with ZF-SIPS would ***draw down 3.4T of CO_{2e}***. In spite of conventional SIPs having exceptional operational savings, their embodied emissions render the savings null when considering the embodied carbon of the conventional panels. A ZF-SIP loses nothing in operational carbon savings over the incumbent, yet starts with a carbon deficit before the occupants even move into the building. Further incorporation of ZF technology into other areas of the built environment can multiply the impact potential. Interior partitions are a perfect example of a product line that can drastically increase the drawdown and carbon storing potential of ZF technology.



A) Detail of mycowelded parts. No adhesives required for bonding separate parts. B-D) different views of the finished, desiccated structure made from 7 different mycowelded parts of ZF

KEY METRICS ASSESSMENT - TABLE 2

Key Metric	zerø-frm Today	zerø-frm 24-months	zerø-frm Long term
Compressive strength of ZF-SIP	150 psi (1 MPa)	218 psi (1.5 MPa)	300 psi (2 MPa)
Bending strength	These data will be collected in the early days of the next 18-24 months of R&D		
Shear strength of mycelial bonds			
Thermal conductivity	R = 2.4 per 1”	R = 2.7 per 1”	R = 3 per 1”
LCA Analysis (A1-A3)	A part of the effort for this incubator will be to analyze the lifecycle impacts of both lumber and zerø-frm. Updated LCI of lumber is appropriate in light of recent published data.		

Key Metric 1: *Compressive strength of ZF-SIP* - Structural analysis by Verdant Structural Engineers confirms that our material’s currently known structural mechanical profile is sufficient to designate its use as a structural building material in a 2:1 replacement for framing lumber. When considering that using a material like ZF in a composite assembly like ZF-SIP, the composite action of the cross-laminated parts (held together with mycowelds) will far exceed safety standards. The work of this phase is to quantify the compressive strength of a full-scale ZF-SIP unit.

Key Metric 2: *Bending tests* - The missing data for a final analysis of the structural mechanics of zerø-frm are bending strength. While the results of the forthcoming bending tests are not expected to decrease confidence in the ability of zerø-frm to serve in structural capacities, the details gleaned form these test results will determine the OOP load handling ability for zerø-frm. Better performance in these tests would enable the use of zerø-frm in structures with multiple stories. Our work during the next 18-24 months of R&D will be to explore unique geometries to achieve high strength building material systems with lightweight construction.

Key Metric 3: *Shear strength of mycelial bonds* - Knowing the capabilities of the mycelium to create bonds capable of safely withstanding the stresses experienced in a building (e.g.-wind, seismic, etc) will assist in determining the ability to grow the structural components together in super-structures that do not require metal fasteners or any type of adhesives.

Key Metric 4: *Thermal conductivity of ZF*[33] - Though the thermal conductivity of mycelium composites have been described in the literature, scant data and different material qualities necessitate the assessment of zerø-frm's own thermal conductivity qualities. Early ZF data indicate an R/in. of 2.4. We anticipate that our current R&D efforts will be able to improve ZF's R/in. to 2.7 - 3.

Key Metric 5: *LCA Analysis (A1-A3)* - In light of recent scholarship an updated analysis of lumber's (A1-A3) impact will be useful. Validation of the early analysis conducted by okom wrks will be a key product of the next 18-24 months of R&D. We believe that we can show an increasing level of carbon storing as we find more ways to incorporate our formulation into more aspects of the built environment (structural and non-structural).

INTELLECTUAL PROPERTY STATUS

Our newly patented process for creating load-bearing MBCs gives okom wrks a clear advantage among potential competitors in the subset of fungal based materials referred to as mycocomposites.[34] The USPTO has granted us full allowance of all 19 claims that make up our patent.

Novel, Non-obvious Design

Our novel approach serves to place zerø-frm in a class by itself among the MBC landscape. Since the science and applications for MBCs are nascent, there is no precedent to set zerø-frm against. zerø-frm is the first MBC to produce structural qualities.

> "zerø-frm has very different material properties than other mycelium based composites. From its surface hardness to its overall rigidity, strength, and durability; these unique material properties open up brand new opportunities for mycelium-based materials to serve in actual load-bearing applications."
> — Wil V. Srubar III, Ph.D., Associate Professor | University of Colorado Boulder

> "In the landscape of mycelium composites, there is nothing quite like zerø-frm! The potential impact of this kind of truly sustainable building material can't be overstated."
> — Dr. Andrew Dent, EVP of Research | Material ConneXion

IP/Patent Ownership

Joshua English is the sole inventor of zerø-frm. The patent is assigned to okom wrks labs upon issuance. No other institution or person can claim ownership of the IP or patent.

PROPOSED PROJECT PLAN AND APPROACH

Much of the plan is asynchronous inasmuch as some of the science (i.e.-mycology) will run concurrently with the development of the engineering solutions. Below are the proposed milestones and initiatives necessary to attain a clear path toward commercialization.

Phase 1: Initial Research and Development (Q3 2024)

- **Identify Relevant Provisions**: Review existing codes and standards related to your technology.
- **Assess Compliance Issues**: Identify potential problems or opportunities within these documents.
- **Initial Testing**: Conduct in-house lab tests to ensure the product meets basic safety and performance requirements.

Phase 2: In-Depth Testing and Certification (Q1 2025-Q1 2026)

- **Third-Party Testing**: Engage accredited labs to conduct standardized tests (e.g., fire, structural, thermal).
- **Documentation and Reporting**: Prepare detailed reports of test results for certification purposes.
- **Product Modifications**: Make necessary changes based on test feedback.

Phase 3: Regulatory Approval (Q3 2026)

- **Evaluation Reports**: Secure reports from evaluation services like ICC-ES (International Code Council Evaluation Service).
- **Code Revisions and Approvals**: Develop new standards or revise existing ones to ensure compliance.
- **Conformity Assessment**: Conduct required assessments to document compliance with revised codes.

Phase 4: Market Deployment (Q4 2026)

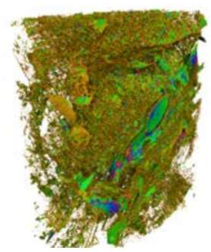
- **Educational Programs**: Create training programs for builders, code officials, and other stakeholders.
- **Marketing and Outreach**: Disseminate informational materials to promote the new technology.
- **Field Monitoring**: Conduct field research to monitor acceptance and gather feedback for future improvements.

4. Monitor and Iterate (Ongoing)

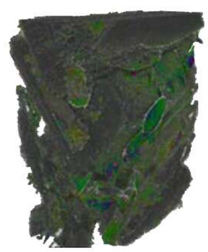
- **Continuous Improvement**: Based on field feedback, refine and enhance the technology.
- **Re-certification**: Regularly re-evaluate and re-certify the product to maintain compliance with evolving standards and codes.

5. Develop non-destructive imaging analysis (Q1 2024 - Q4 2026)

- In Q2 2022 we began developing an AI driven system for imaging MBC parts with magnetic resonance, ultrasound, and or x-rays and providing deep analysis of the microscopic and macroscopic qualities of the parts. This will facilitate the understanding of the effects of fungal ecology and species/substrate selection on the final part. These initial scans were a wealth of information for the team. Below are some samples of the output from a sample run performed by Tescan. Tescan has pioneered the use of micro-CT scanning at commercial scale. Part of our research funding will go toward in-house micro-CT capabilities.



MYCELIUM (Color coded to cell wall thickness)



HEMP HURD (Showing ease of segmentation)

Using micro-CT, we can now both qualify and quantify the actual hyphal growth. Knowing the hyphal width distribution will help build models for QC. Assuring that adequate amounts of the trimitic hyphal morphologies are present. We will expand the use of this vital insight during the next 18-24 months of R&D.

RISK IDENTIFICATION

The main risks to commercialization of zerø-frm and products using it as a structural component are associated with the biological nature of the components of the MBC itself. Mycelium, while known for providing robust and reliable growth in the lab, can have a whole set of challenges that can impede commercialization. The key questions pertain to the appropriate fungal species and choice of substrate followed by the set of fungal ecology parameters. Small changes or deviations to the fungal ecology can have dramatic effects on the morphology of hyphal expression of a filamentous fungi.

While these challenges are the key issue to scalability, they are not without precedent in the world of large-scale mushroom cultivation. By utilizing the experts available to us, we will ensure that the proper, basic science is in place to mitigate the effects of using a biological organism as a matrix phase for a composite material.

As important as structural mechanics, are the supply-chain related risks involved with any biological building material. We will be engaging with researchers at Clemson University, Penn State, and Queen's University to analyze the feasibility and methods for growing industrial hemp all over North America for the purposes of creating structural building materials. By hyper-regionalizing the supply-chain, we can minimize manufacturing disruptions caused by force majeure . This hyper-regionalization approach will also help to maintain the highest levels of regeneration.

Another risk lies in the ability for the builder/construction community to accept the material. Part of our work during the next 18-24 months of R&D will be to develop non-destructive imaging tools that can analyze the micro and macroscopic characteristics of the specimens. By developing these tools for our R&D, we will have a jumpstart on methods that can be used to provide consistent standards and practices to licensees looking to incorporate zerø-frm into their products.

Finally, the structural mechanics of the material are inherently lower than other traditional building materials, especially wood. Our work will foster the exploration of novel geometries and configurations that can be utilized to maximize the strength to weight capacities of zerø-frm. VP of Engineering, Dr. John Kabanda will be vital in advising on the methodologies for this exploration.

CONTRIBUTIONS TO THE FIELD

We believe that the nascency of MBC technology, combined with the profound potential of mycelium based composites is fertile ground for publishing any and all findings. Paramount to the technology's impact on the built environment, is the potential impact on the climate. The urgency of the climate crisis requires that technologies like zerø-frm be placed in the hands of the open-source community to ensure that maximum innovation potential is reached. Our contributions to this field will include: developing first structural MVP designs, protocols for maximizing structural performance, agricultural trials for optimal feedstock, analysis of appropriate fungal species for specific regions and applications, and finally in developing codes, standards and testing regimes for the widespread adoption of this technology.

PROPOSED PARTNERSHIPS

Target Organization	Plan for Partnership Potential	Partnership Goals
Rocky Mountain Institute	Developing robust LCA analysis of zerø-frm	By using the expertise found within this organization, we can speed the time it will take to gain a thorough understanding of the climate impact of ZF
Mattamy Homes	Partnership with the largest privately owned home builder in North America will allow okom to iterate on whole house designs using ZF technology	As a new technology, acceptance in the industry will require partnership with large entities that can assist in exposing a large swath of builders to the technology.
AXA-XL	As a global employer, AXA-XL Insurance occupies over 1,000,000 sq. ft. of office space. By partnering with large employers like AXA-XL, we can show how commercial space retrofit can have a huge impact on achieving carbon goals	Having a goal to reach is a great motivator. By working with a partner to develop design solutions that may be one off, initially; we can find novel ways to improve the use of ZF at scale. We can also prove the functional utility of ZF in the built environment

PROPOSED COMMERCIALIZATION PATHWAY

Our involvement in a recent IMPEL+ cohort (2021-2022) and our current participation in the most recent Third Derivative accelerator has provided useful mentorship in building our business model canvas. Attached as a supplement, there is detail in that document regarding our larger go-to-market strategy. The strategy relies on relationship building within the ag community, Without building capacity in the heartland, there will be no viable path to commercialization. Other key stakeholders are the raw materials processors who convert the industrial hemp plant into usable, industrial materials. This vital aspect of the infrastructure necessary to manufacture ZF-SIPs at scale is already underway. We are currently co-located in a 95,000 sq. ft. facility that includes a full, state of the art hemp processing line. The operators of the hemp processing line have several thousand acres of farmland within a 50 mile radius that supply ample amounts of industrial hemp for a vibrant regional ZF-SIP supplier. With our own 10,000 sq. ft. for R&D colocated within this facility, we can realize significant economies of scale and scope. This hyper-regional approach is a key to the go to market strategy for zerø-frm and ZF-SIPs.

Because we have co-located with a large hemp processor with thousands of acres of hemp grown within 50 miles, we believe we can achieve our commercialization pathway on a 24-month timeline. As we prove our initial ZF-SIP MVP, and license that technology to manufacturers, we will be constantly looking for other novel uses of the material and/or uses of ZF in replacement of traditional materials that are high embodied carbon. Starting with ZF-SIP, we can quickly transition into a ZF-SIP flooring and roofing system. Another easy transition to an application that is very close to the original MVP form factor is creating non-load bearing interior partitions. By providing solutions for the exterior walls, the floors, and roof, as well as the interior partitions, ZF can become a ubiquitous part of the built environment.

In order to achieve our commercialization pathway, we will need to ensure the we are building appropriately scaled tools. Since our material process is largely unknown in the scientific literature, we will be creating the manufacturing process from whole cloth. Though no small task, we have been preparing for what our final process will look like at commercial scale. Thankfully, our technology utilizes very little energy and material inputs. The fungal organism and the hemp plant do a bulk of the work without human interaction. Exploring the full potential for bringing this material into widespread use in the built environment is a singular focus for us at okom wrks labs.

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