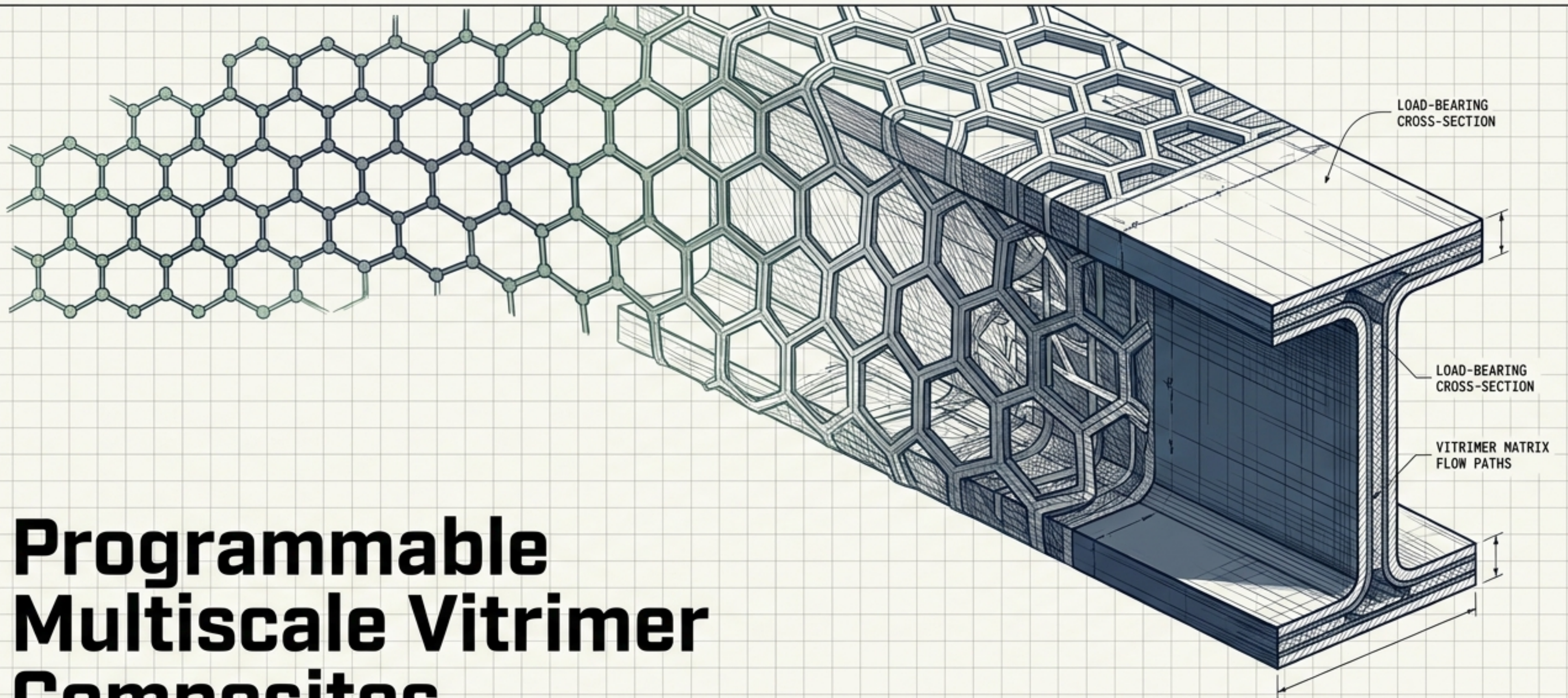


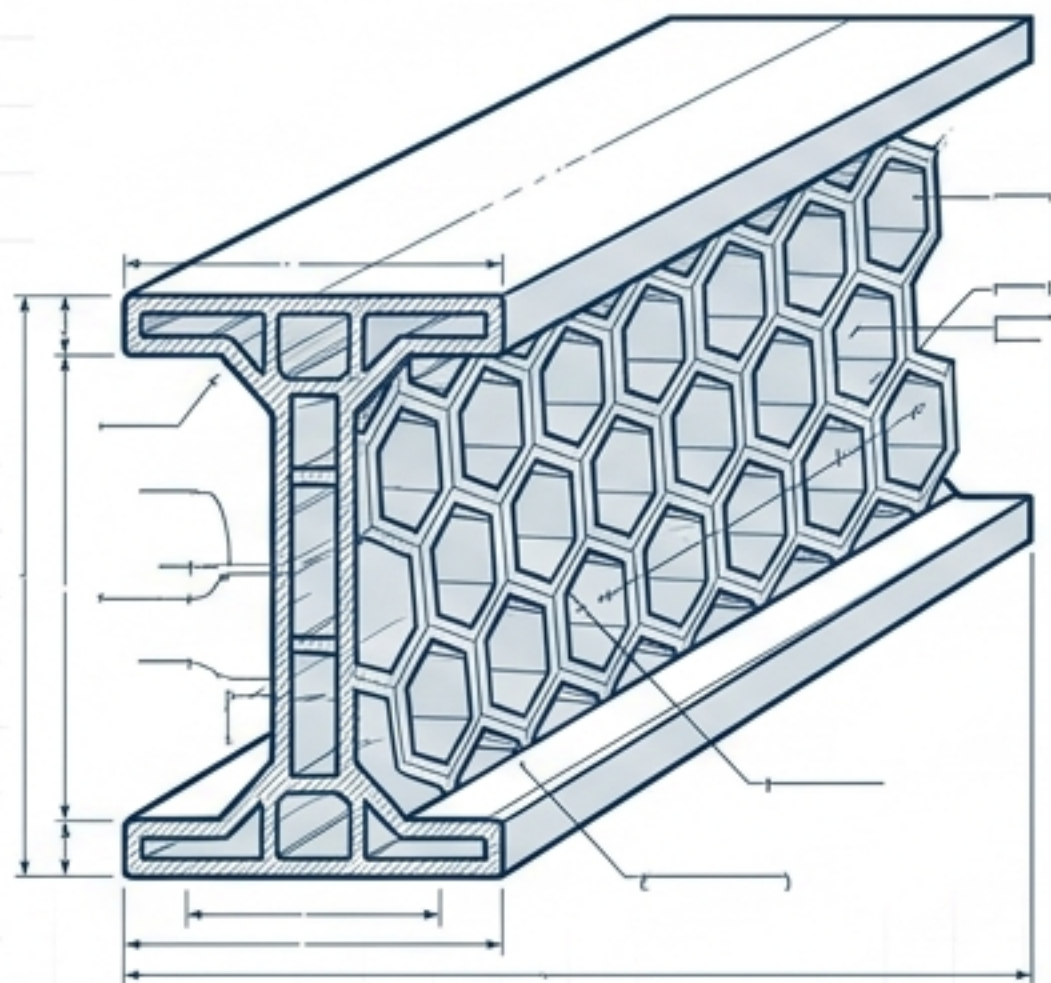


Programmable Multiscale Vitrimer Composites

Engineering a >99% Hemp-Derived Materials Platform to Outperform Petroleum Plastics, Metals, and Traditional Thermosets

SYS_VERSION: 1.0 (Based on Landry Industries Technical Report)
CORE_MATRIX: Epoxidized / Maleinized Triglycerides
NETWORK_TYPE: Dynamic β -Hydroxy Ester Exchange
CATALYST: $\text{Zn}(\text{acac})_2$ [1.5 wt%]

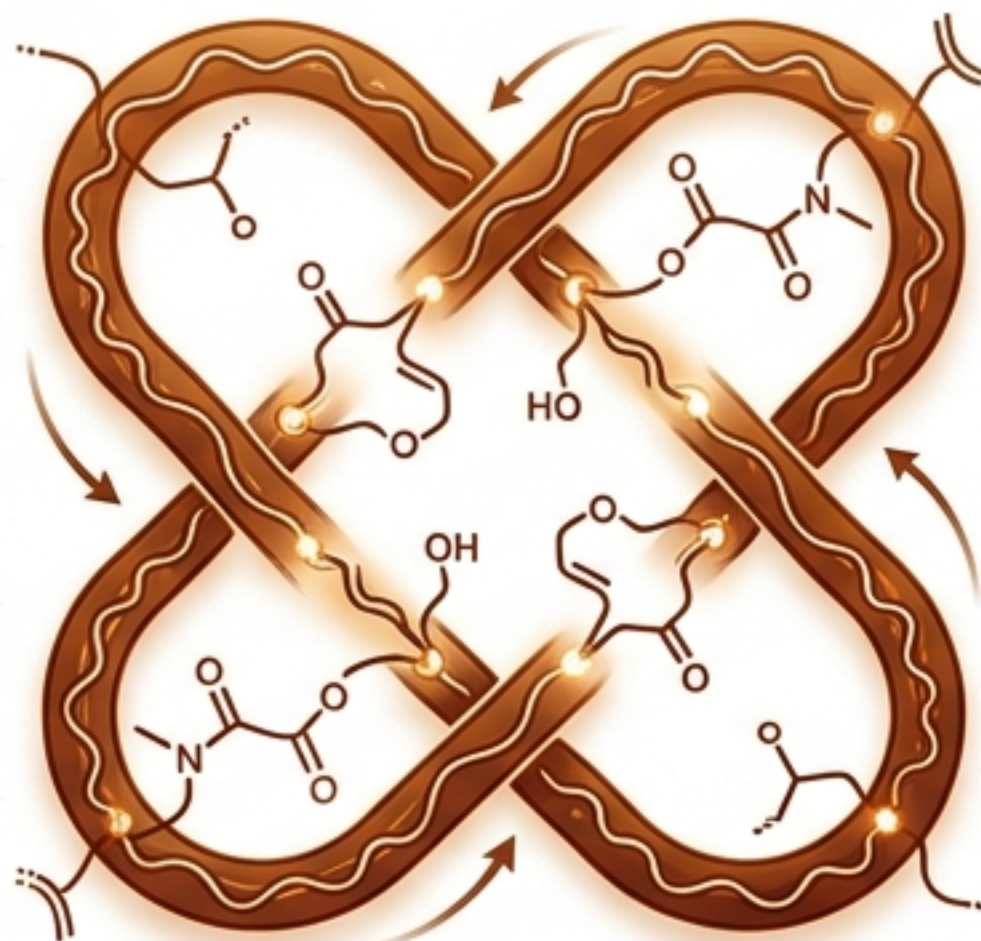
A Monoculture Feedstock Engineered to Beat Titanium, Kevlar, and Steel



Absolute Performance

Exceeds Incumbent Specific Modulus

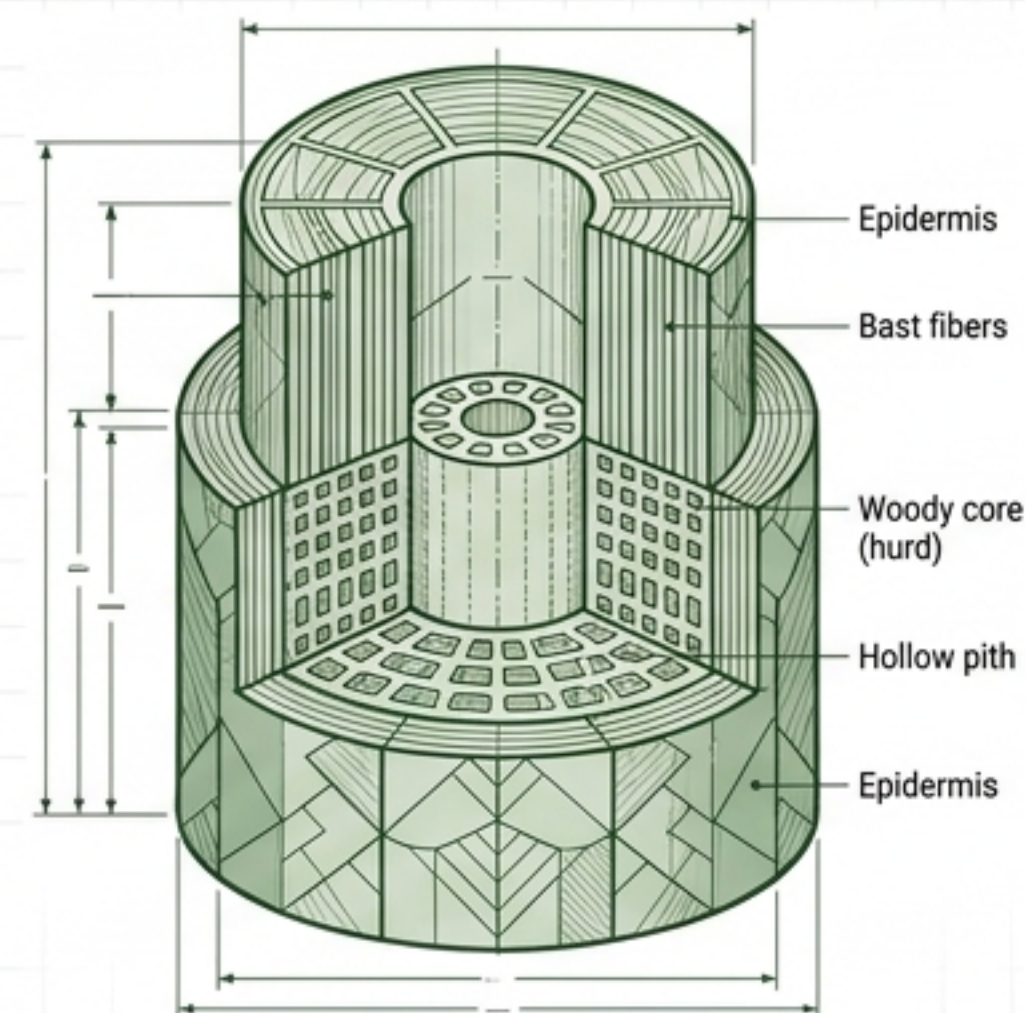
Engineered via multiscale reinforcement to deliver +193% specific strength vs. mild steel and +18% specific modulus vs. Ti-6Al-4V.



Infinite Reprocessability

Dynamic Vitrimer Network

Covalently cross-linked at ambient temperatures, flowable at 180°C. Delivers thermoset robustness with thermoplastic recycling, welding, and self-healing.

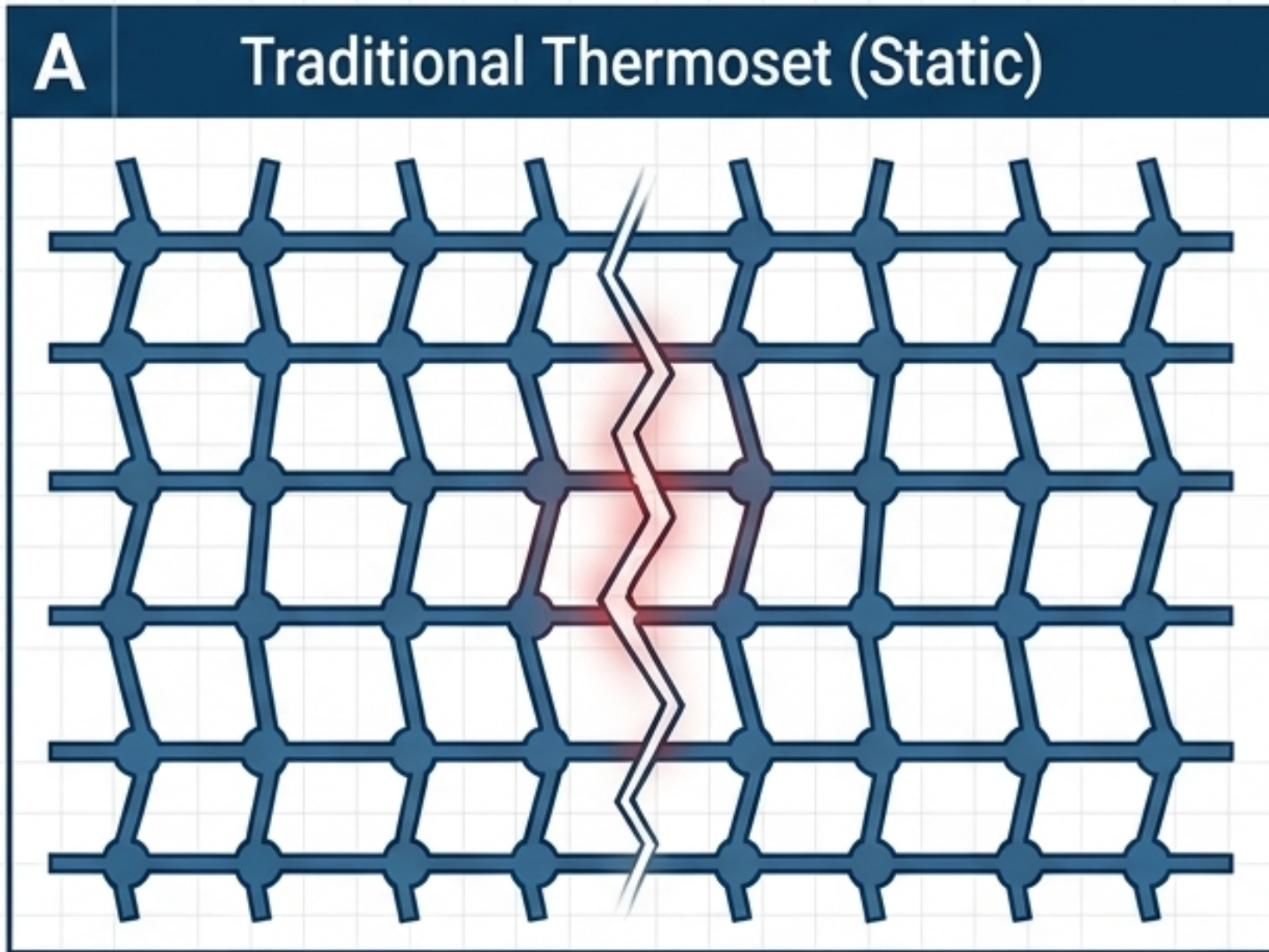


Single-Origin Architecture

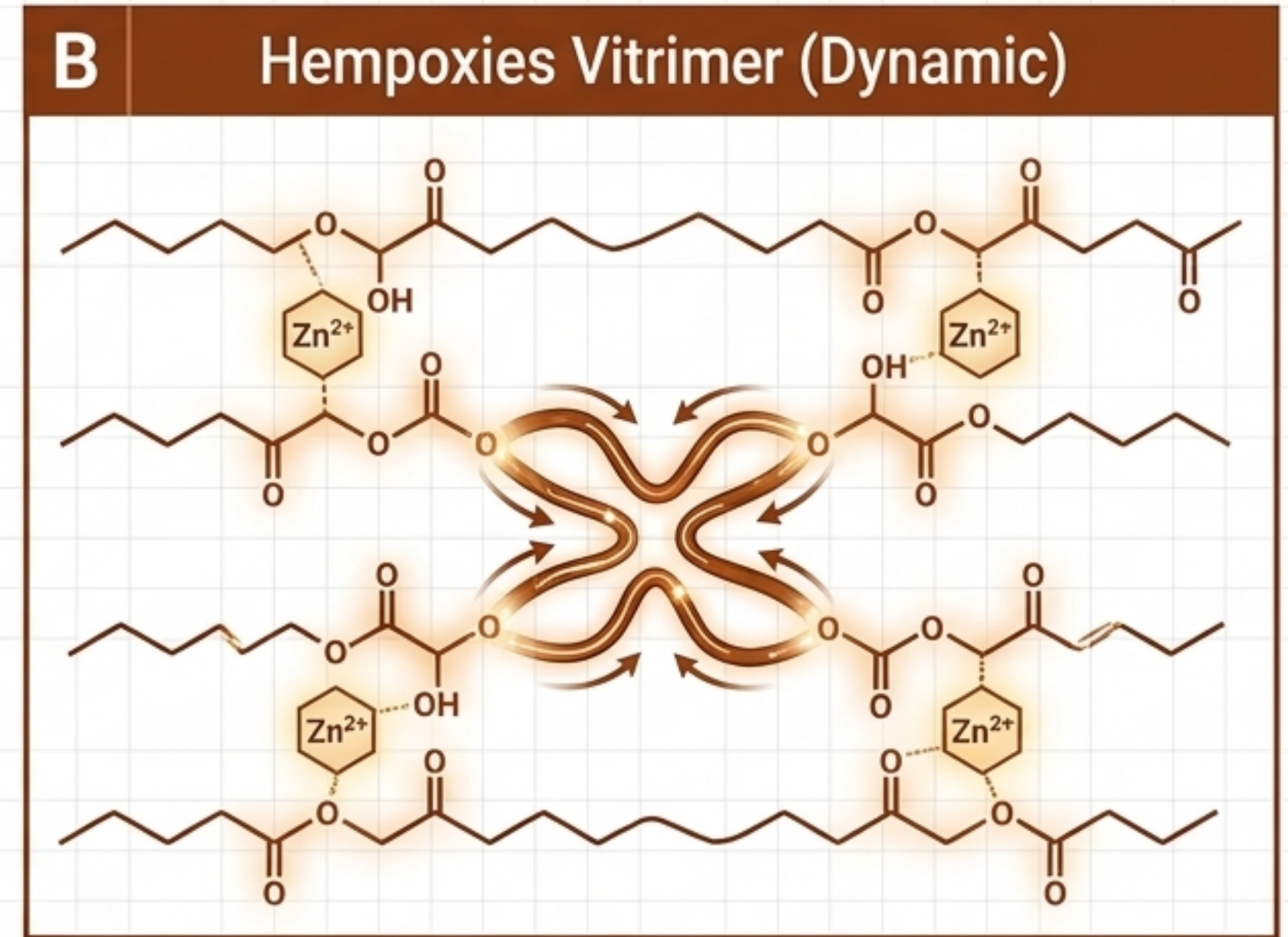
>99% Bio-Based Carbon Content

Matrix, cross-linkers, solvents, and all 5 tiers of multi-dimensional reinforcement are synthesized entirely from hemp seed, stalk, and bast.

The Kernel: Dynamic β -Hydroxy Ester Exchange

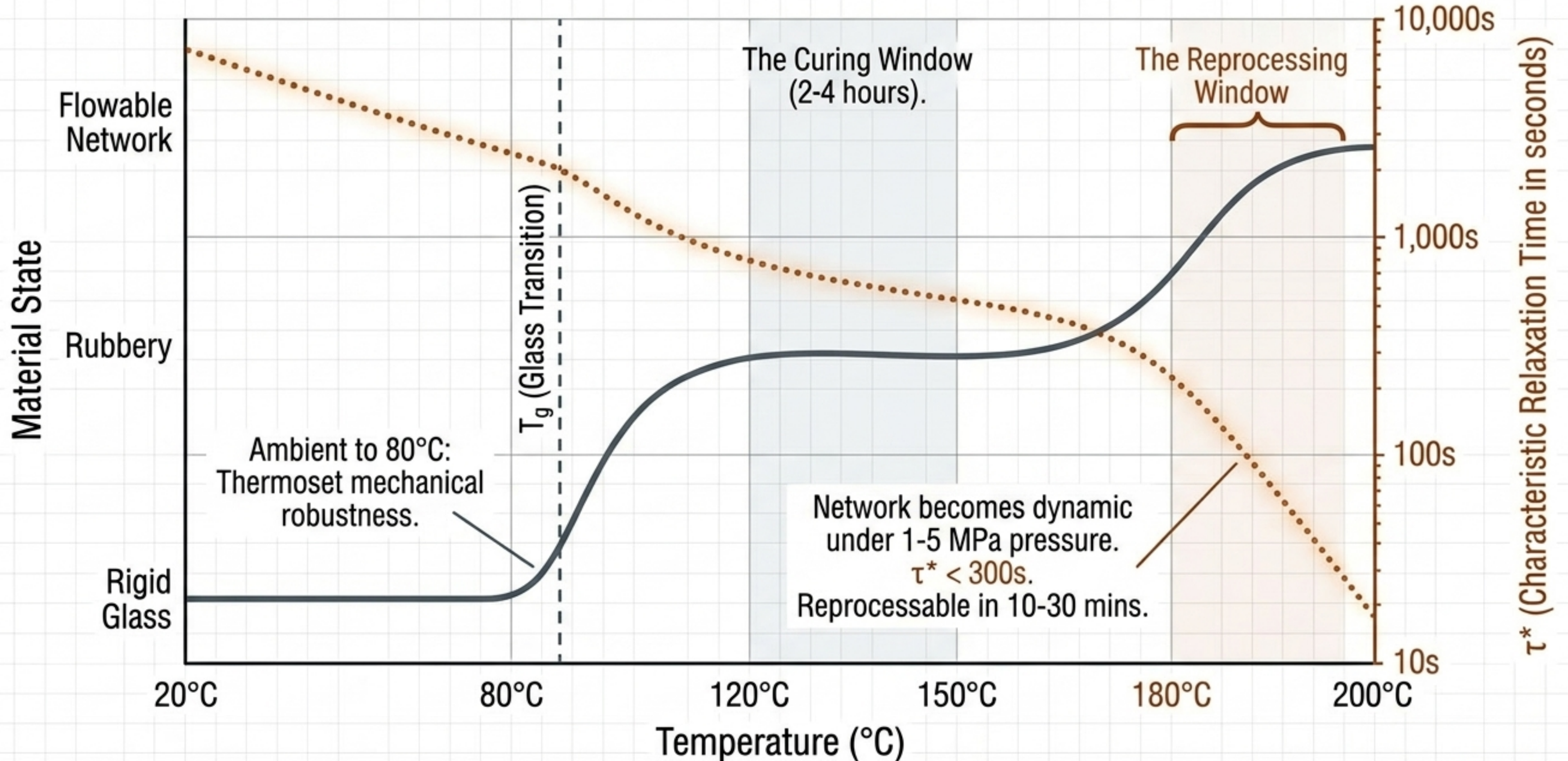


Standard epoxies permanently cross-link. Under stress, they fracture and cannot be re-melted or repaired.



EHO + MHO (1:1 mass ratio) cured with Zinc Acetylacetonate ($\text{Zn}(\text{acac})_2$). The catalyst forces transesterification. Bonds dynamically detach and reattach, enabling topological rearrangement and crack-healing without losing network integrity.

The Activation Curve: Programming the Temperature Window



The Hardware Stack: 5-Tier Hierarchical Reinforcement

Molecular (0.1–1 nm)

Furfuryl Glycidyl Ether (FGE, 8-12 phr)

Function: Reactive diluent; introduces furan rings for π - π interactions.

Nano-2D (1–100 nm)

Hemp-derived GO, rGO, and Carbon Nanosheets (<2.5 phr ceiling)

Function: Ultra-high aspect ratio barrier, electrical percolation, interfacial anchoring.

Nano-1D (1–100 nm)

Cellulose Nanocrystals (CNC, 1.0-2.0 phr)

Function: Rod-like crack pinning, modulus enhancement.

Micro-0D (1–100 μ m)

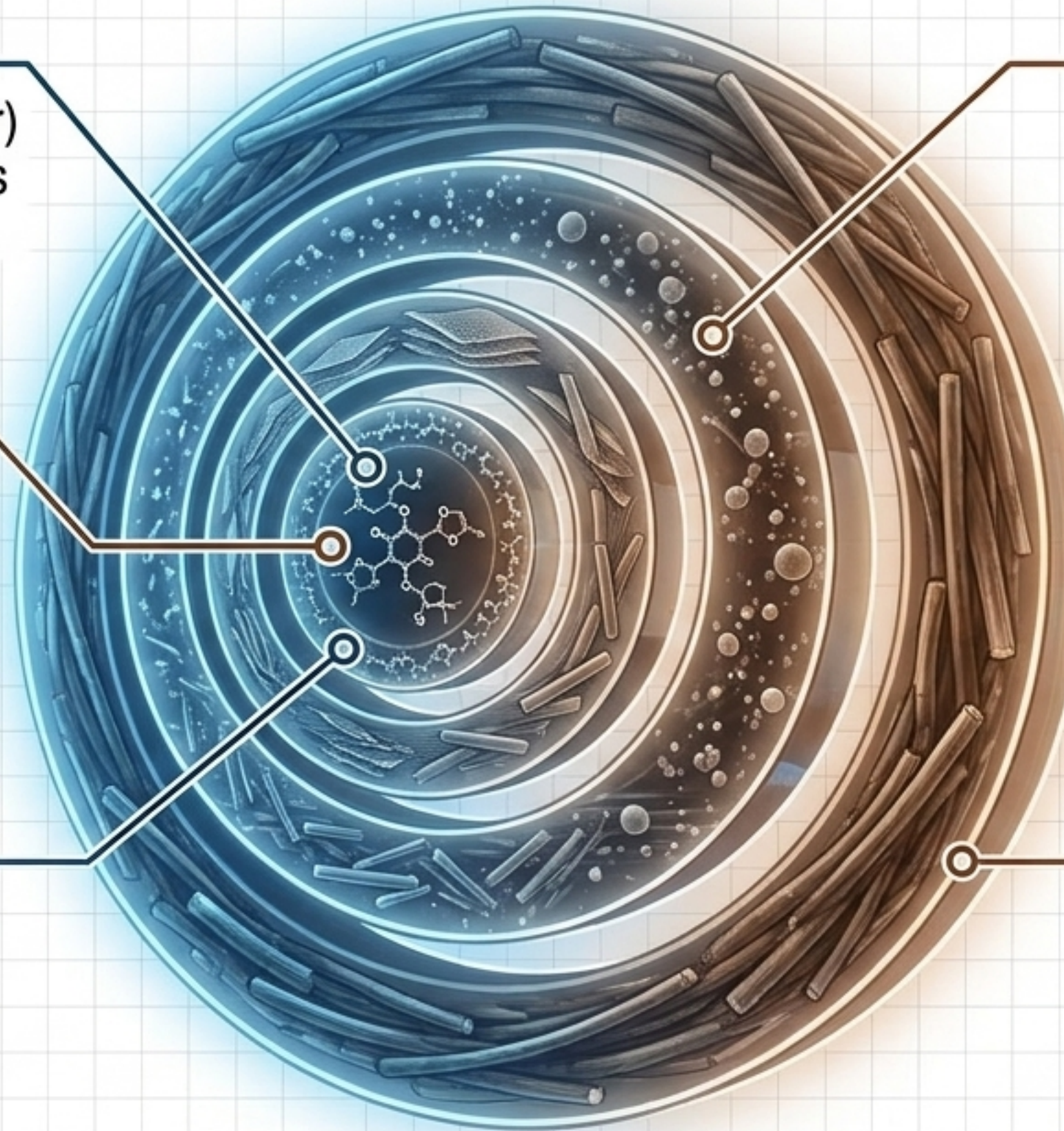
Hemp Biochar (3.0-5.0 phr)

Function: Interstitial volume filling, compressive modulus, reduces resin-rich pockets.

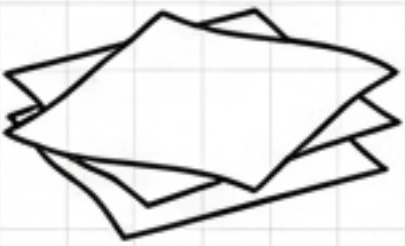
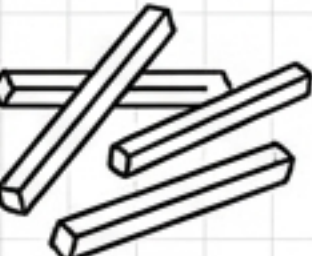
Macro-1D (mm–cm)

Short Hemp Carbon Fiber (3-6 mm, 15-20 phr)

Function: Primary macroscopic load-bearing reinforcement.

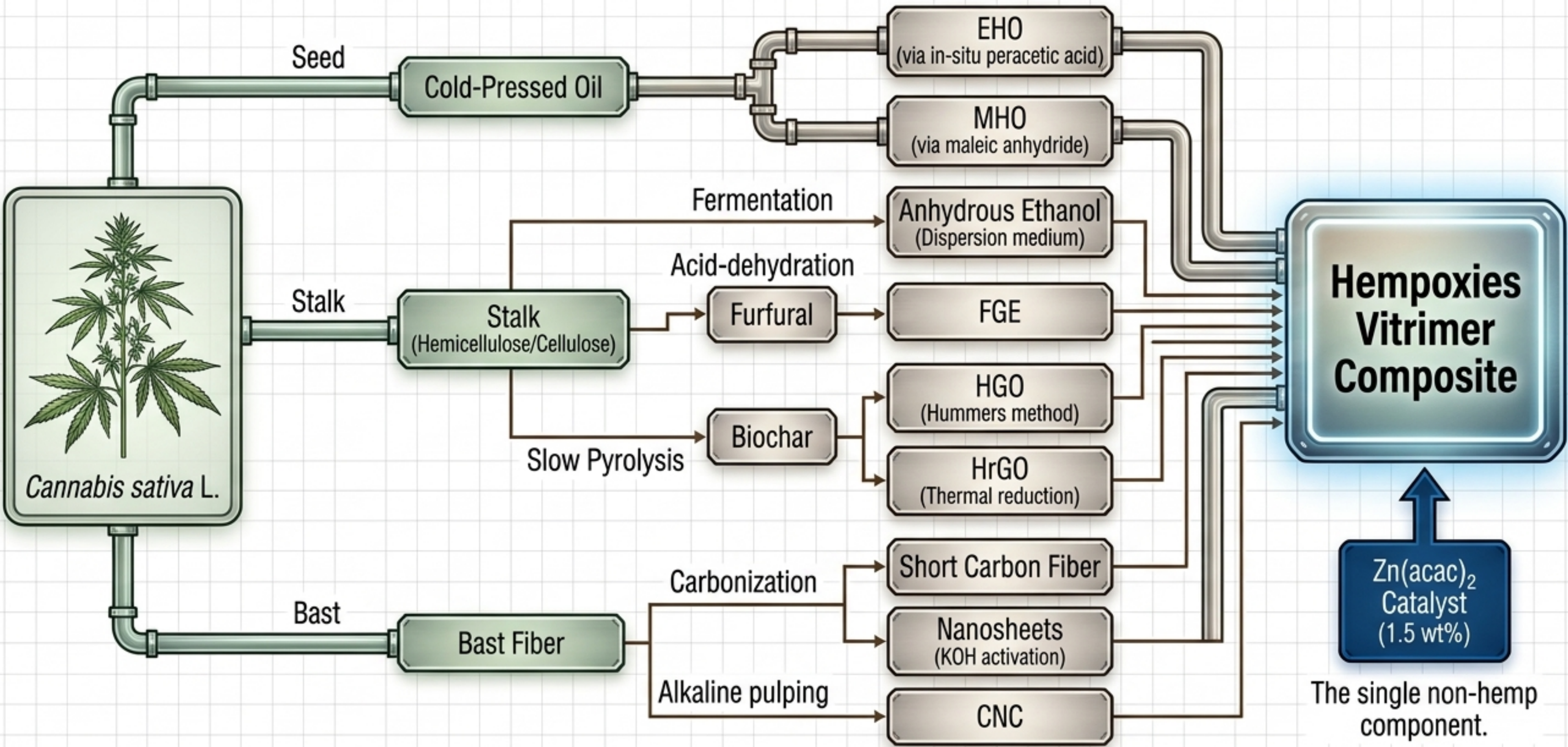


The Interfacial Matrix: Functional Niches at the Nano-Tier

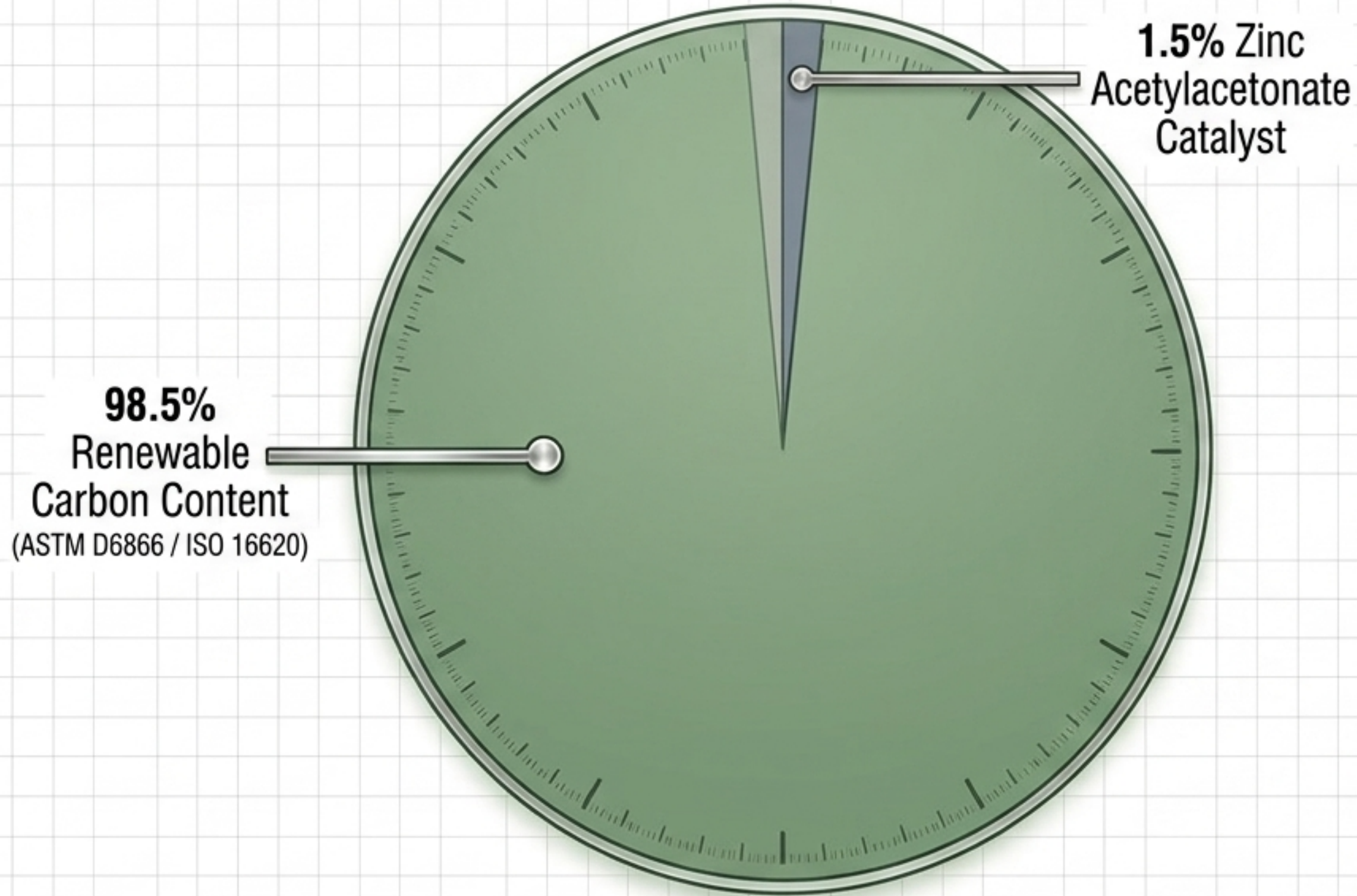
	Hemp-Derived GO (HGO) 	Hemp-Derived rGO (HrGO) 	Carbon Nanosheets 	Cellulose Nanocrystals (CNC) 
Dimension	2D	2D	2D	1D
Target Loading	0.3-0.5 phr	0.2-0.3 phr	0.5-1.0 phr	1.0-2.0 phr
Functional Niche	Covalent Integration	Conductivity & Backbone	Barrier & Stiffness	Crack Deflection
Mechanism	High C/O ratio (2.0-2.5) reacts with epoxides for strong interfacial bonding.	Restored sp ² carbon lattice provides electrical/thermal percolation pathways.	KOH chemical activation yields sheets that reduce O ₂ permeability by >70%.	Acid-hydrolyzed high-crystallinity rods deliver 15-25% tensile modulus increases.

CRITICAL THRESHOLD: Total nano-filler loading must not exceed ~2.5 phr. Exceeding this causes exponential viscosity spikes and Zn(acac)₂ catalyst adsorption, starving the vitrimer network.

Monoculture Supply Chain Map



The Single-Origin Paradox



Extreme material complexity does not require ecologically devastating global supply chains. It requires superior chemical architecture applied to a single, hyper-efficient biomass source.

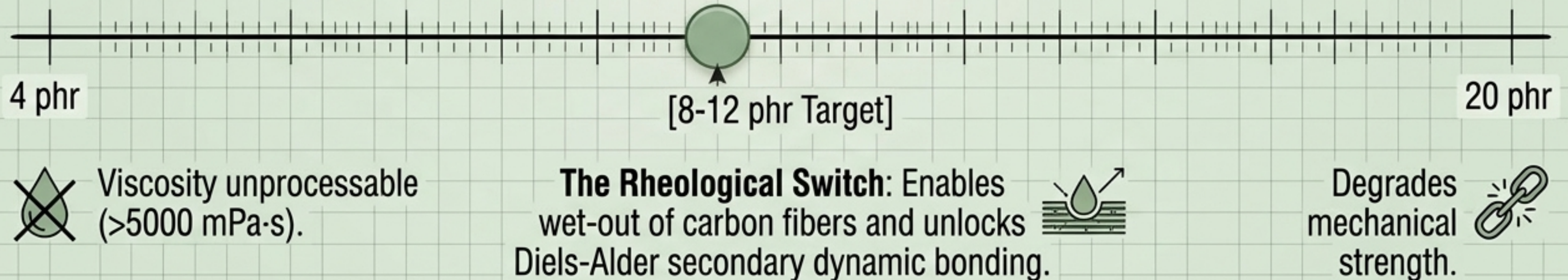
Every cross-link, every reactive diluent, every nanoscale barrier, and every macro-fiber in this composite is derived from one plant. . . . are derived from from one plant. The total non-hemp fraction is just ~1.5%.

Parametric Control Board: The Matrix & Rheology

EHO:MH0 Stoichiometry (Anhydride-to-Epoxy Ratio)

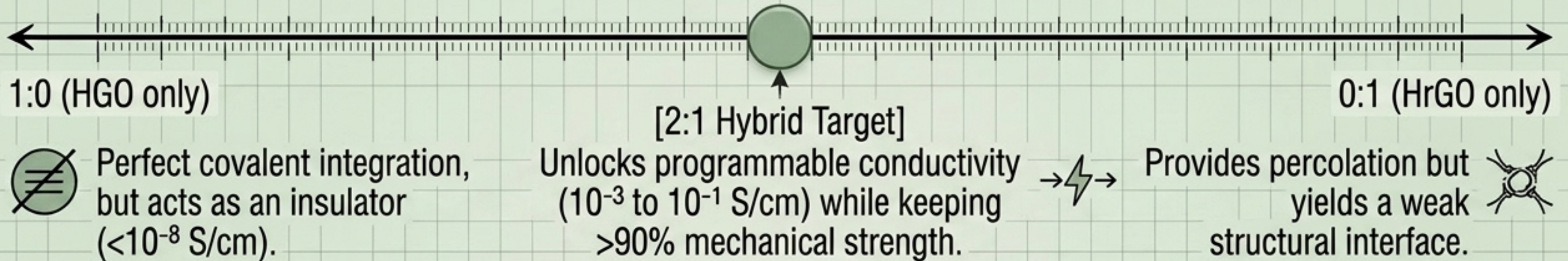


FGE (Reactive Diluent) phr

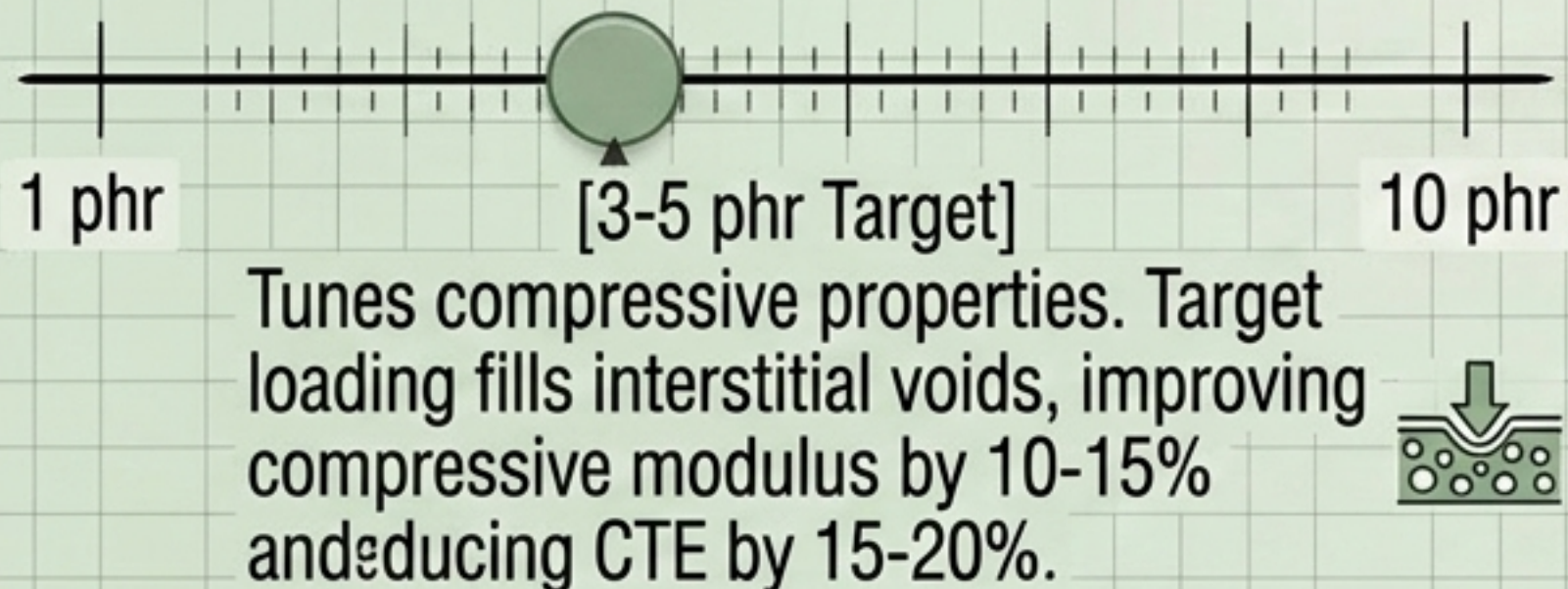


Parametric Control Board: Electrical & Mechanical Tuning

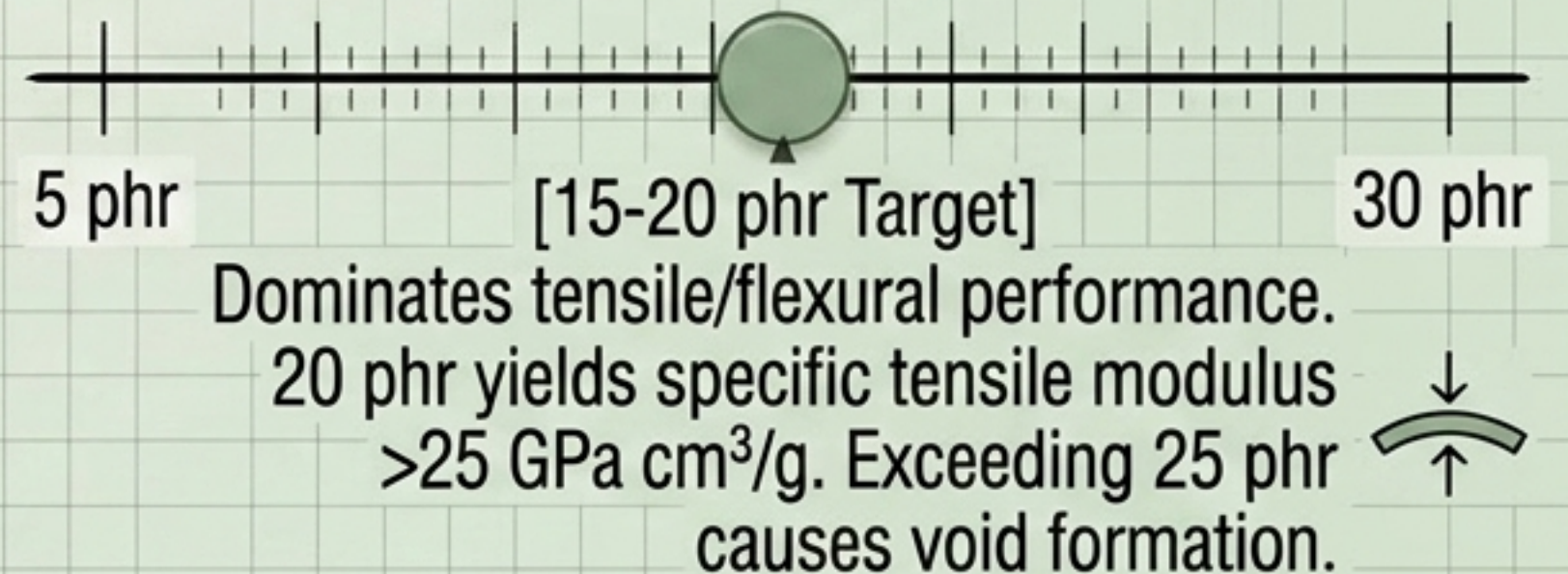
HGO:HrGO Ratio (The Percolation Switch)



Biochar phr (Micro-Tier)

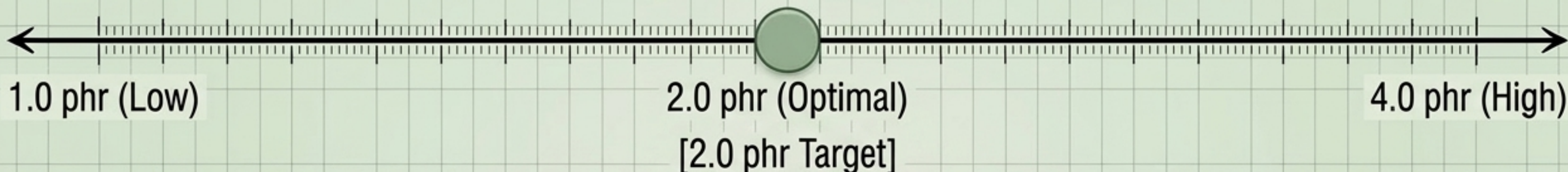


Short Carbon Fiber phr (Macro-Tier)



Parametric Control Board: Network Dynamics & Reprocessing

Zn(acac)₂ Catalyst Loading



1.0 - 1.5 phr

- Slow cure.
- $\tau^* > 1000\text{s}$ at 180°C .
- Material acts like a traditional thermoset with limited reprocessability.



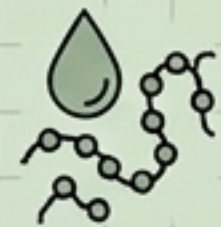
2.0 - 2.5 phr General Purpose

- Complete cure in 4h.
- $\tau^* = 100\text{-}300\text{s}$ at 180°C .
- Delivers a 40°C “dynamic window” (T_g to flow temp). Reprocesses in 10-30 mins.



3.0 - 4.0 phr Rapid Thermoforming

- $\tau^* < 60\text{s}$ at 180°C .
- Reprocesses in under 10 mins.
- Compresses the dynamic window to 20°C . Tradeoff: Excess Zn^{2+} risks ester hydrolysis in humid environments.

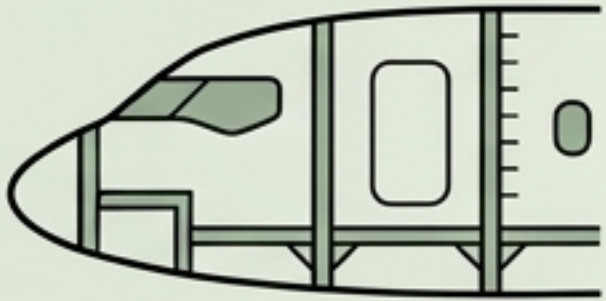


HUD NOTE — The Catalyst Tax: Formulations with >2.0 phr total nanofiller require a $+0.5$ to $+1.0$ phr catalyst boost to offset surface adsorption by HGO/HrGO.

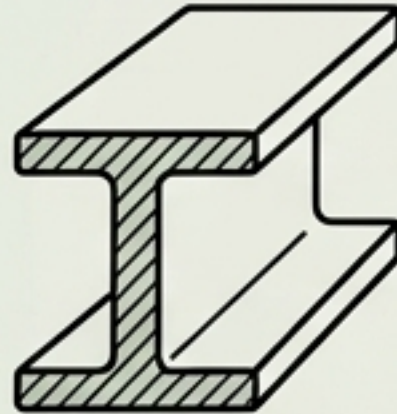
The Benchmarks: Targeting Incumbent Materials

Because the Hemproxies platform is parametrically tunable, it is not a single material. By independently tuning the seven compositional variables, we engineered eight specific variant formulations designed to defeat the specific performance metrics of industry-standard incumbents.

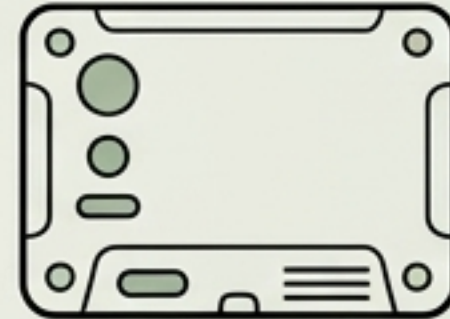
Aluminum 6061-T6



Mild Steel



ABS Plastic



C30 Concrete



Standard DGEBA Epoxy



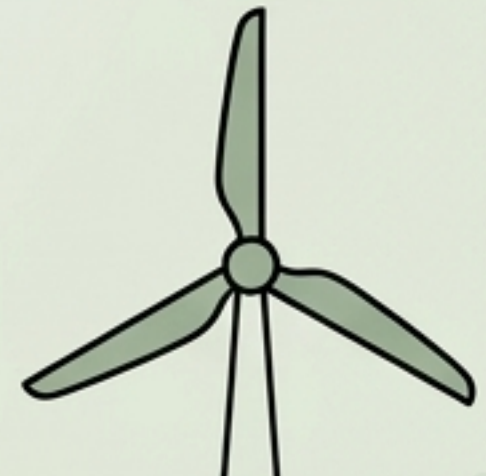
Kevlar-49



Titanium (Ti-6Al-4V)



E-Glass/Epoxy (GFRP)



Defeating Aerospace Metals: Specific Modulus

HEMP-AL vs. Aluminum 6061-T6

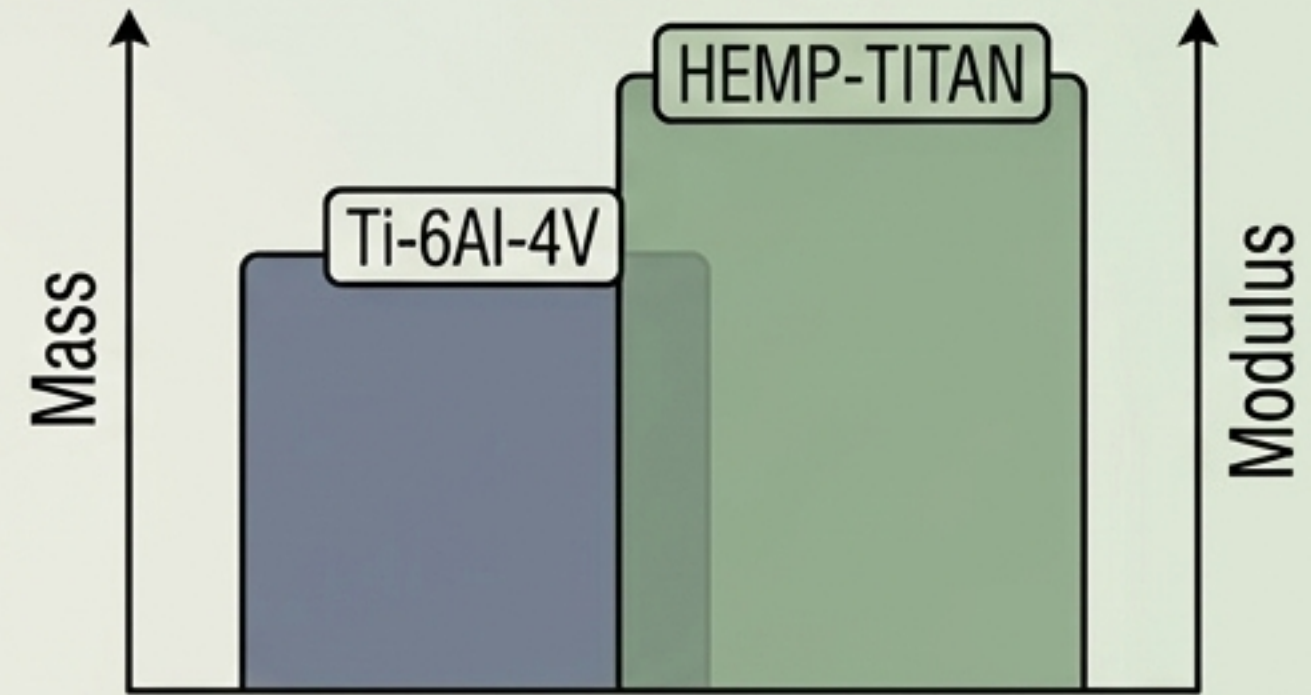


Tuning: Anhydride-rich matrix (45:55) for maximum rigidity. Max unidirectional carbon fiber (25 phr).

Result: Specific Modulus of 28.1 GPa cm³/g (+9.8% vs Al). Specific Strength +80%.

Mass Delta: -50% mass vs. Aluminum.

HEMP-TITAN vs. Ti-6Al-4V



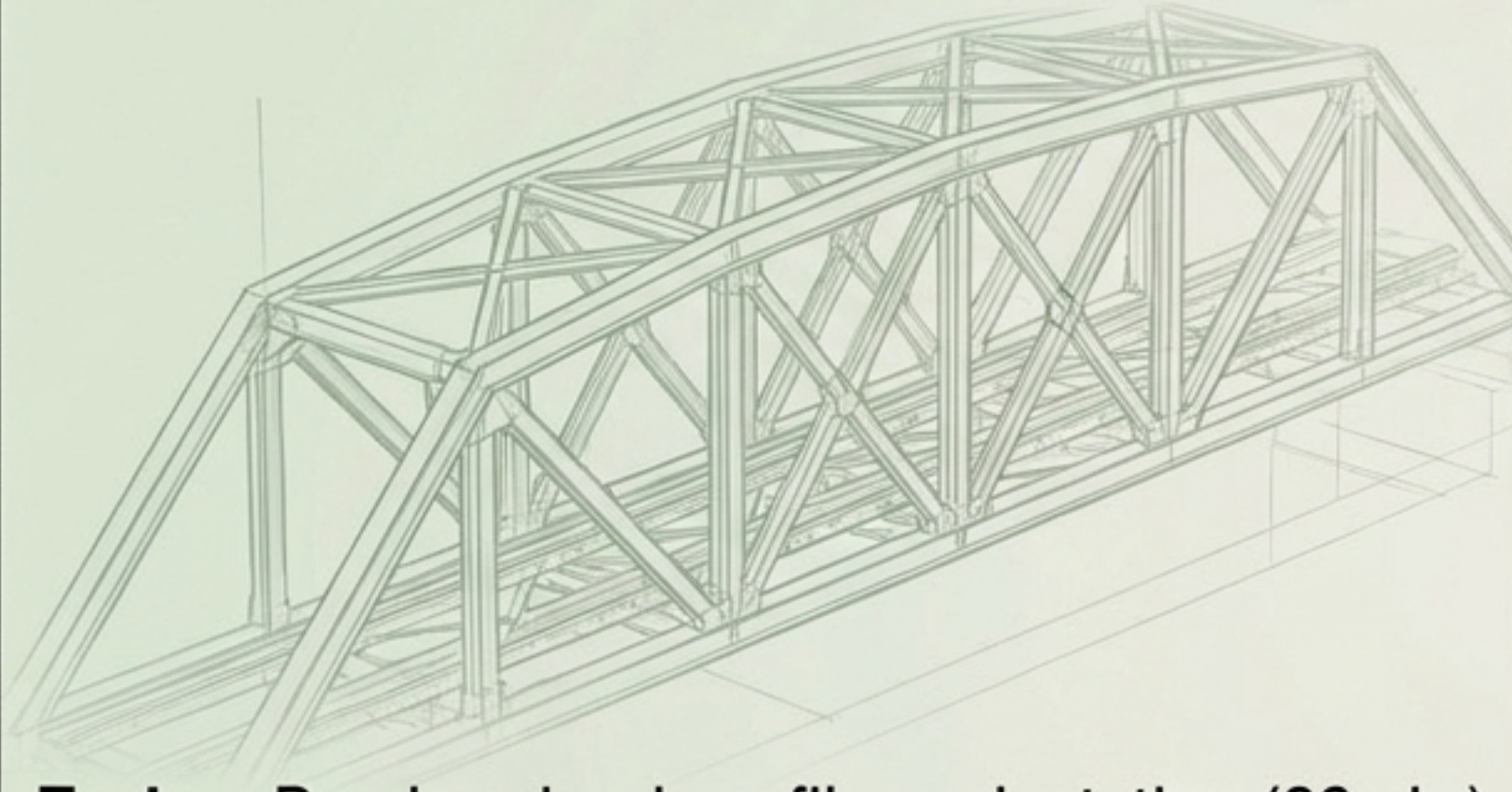
Tuning: Extreme nano-filler loading (3.6 phr) + near-max aligned carbon fiber (28 phr) to stiffen matrix for ultimate load transfer.

Result: Specific Modulus of 30.4 GPa cm³/g (+18% vs Ti).

Mass Delta: -69% mass vs. Titanium.

Defeating Heavy Structural Incumbents: Steel & Concrete

HEMP-STEEL vs. Mild Steel

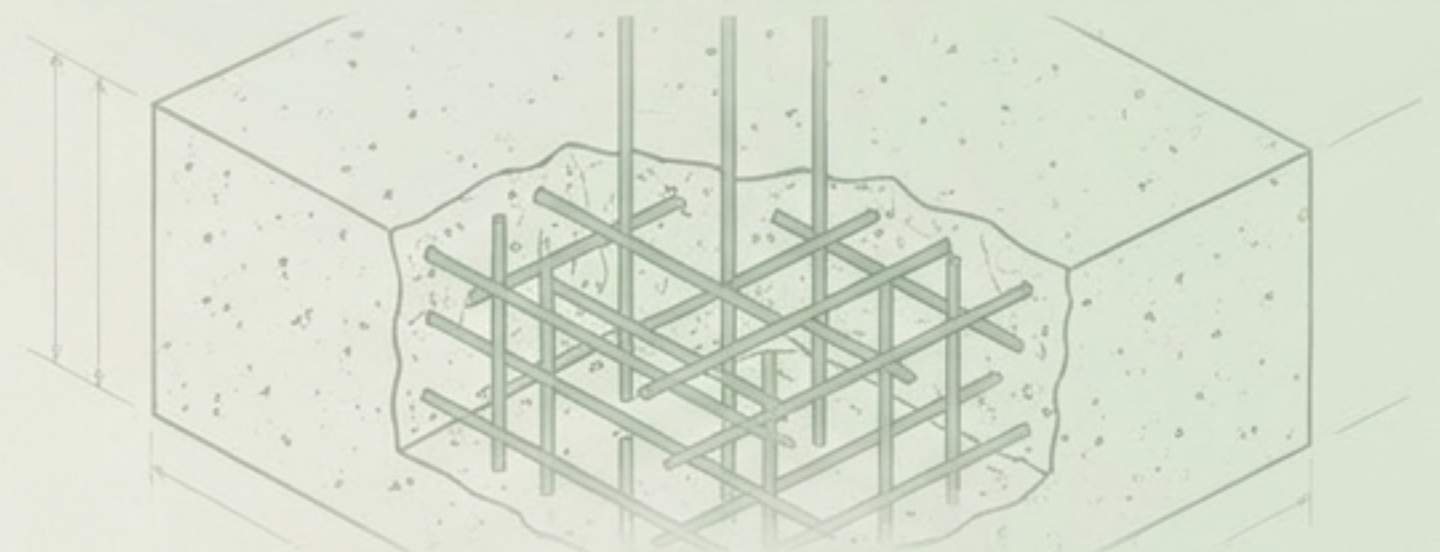


Tuning: Random-in-plane fiber orientation (22 phr) to trade unidirectional modulus for omnidirectional isotropic strength.

Result: Specific Strength of 167 MPa cm³/g (+193% vs. Mild Steel).

Mass Delta: -83% mass vs. Steel.

HEMP-CRETE vs. C30 Portland Concrete



Tuning: Extreme biochar aggregate loading (15 phr + 30 phr coarse particulate) combined with 12 phr fiber for crack arrestment.

Result: Compressive strength ~55 MPa (+83% vs concrete). Tensile strength ~35 MPa (+1067% vs concrete).

Advantage: Hydrophobic matrix eliminates freeze-thaw degradation entirely, while remaining 40% lighter than concrete and fully reprocessible.

Defeating Plastics & Composites: The Circularity Upgrade

HEMP-PLAST vs.
ABS Plastic

↑ **+89%**
Specific Strength

↑ **+139%**
Modulus

Tuning: Epoxide-rich matrix (55:45) for ductility. High biochar (8 phr) to cut costs.

Result: >12% elongation. Injection-moldable viscosity, fully bio-based.

HEP-OXY vs.
Standard DGEBA Epoxy

↑ **+100%**
Tensile Strength

↑ **+300%**
Modulus

Tuning: Stoichiometric perfect matrix (49:49) + 15 phr carbon fiber.

The Kicker: Infinitely weldable and reprocessable at 180°C (standard epoxy cannot be recycled).

HEMP-GFRP vs.
E-Glass/Epoxy

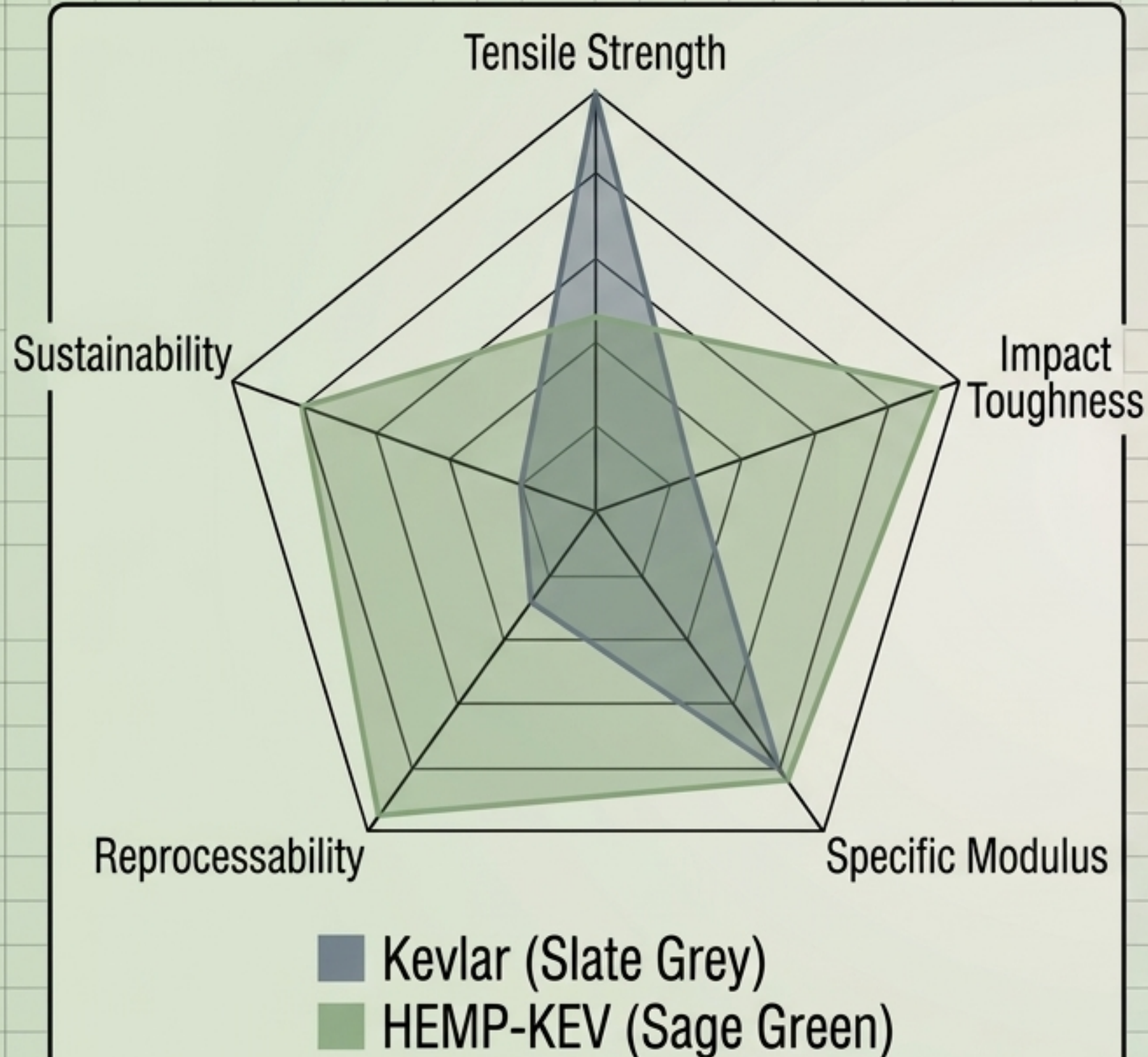
↑ **28%**
Lighter

↑ **>99%**
Bio-based

Tuning: Isotropic random fiber (20 phr).

Result: Matches specific modulus (-10%). Solves the wind-turbine blade end-of-life crisis via thermal reprocessing.

The Kevlar Pivot: Approaching Aramid Specifics



Context: Kevlar-49 is a molecularly perfect aramid fiber; chopped hemp carbon cannot match its absolute tensile strength.

The HEMP-KEV Tuning: Extreme anhydride excess (40:60) for minimal matrix volume, packed with the absolute maximum 30 phr unidirectional carbon fiber ($V_f \approx 0.35$).

The Resulting Paradigm: Delivers specific modulus comparable to glass-fiber (36.6 GPa cm^3/g).

The Victory: Kevlar is brittle in compression and non-recyclable. HEMP-KEV trades peak tensile strength for omnidirectional impact absorption and end-of-life thermal reprocessability at equivalent densities (1.42 g/cm^3).

Incumbent Defeat Matrix: The Platform Benchmarks

Variant	Target	Density (g/cm ³)	Tensile (MPa)	Modulus (GPa)	Specific Modulus	Key Advantage
HEMP-AL	Al 6061-T6	1.35	280	38	28.1	+10% sp. modulus, -50% mass
HEMP-STEEL	Mild Steel	1.32	220	28	21.2	+193% sp. strength, -83% mass
HEMP-PLAST	ABS	1.18	85	5.5	4.66	+89% sp. strength, bio-based
HEMP-CRETE	C30 Concrete	1.45	35	8.0	5.52	+1067% tensile, reprocessable
HEP-OXY	DGEBA	1.28	140	12	9.38	+100% strength, reprocessable
HEMP-TITAN	Ti-6Al-4V	1.38	310	42	30.4	+18% sp. modulus, -69% mass
HEMP-GFRP	E-Glass	1.30	200	26	20.0	Reprocessable, -28% mass

Predictions assume optimized processing (minimal void content <2%). All variants retain >99% bio-based carbon mass.

The Inevitability of Circular Performance



By ASTM D6866 standard radiocarbon analysis, this composite system is structurally finalized at >99% renewable carbon.

The Hemproxies platform proves that the transition to a circular economy does not require compromising on aerospace-grade performance.

We do not need to mine the earth to reach the stars. We just need to engineer the surface.